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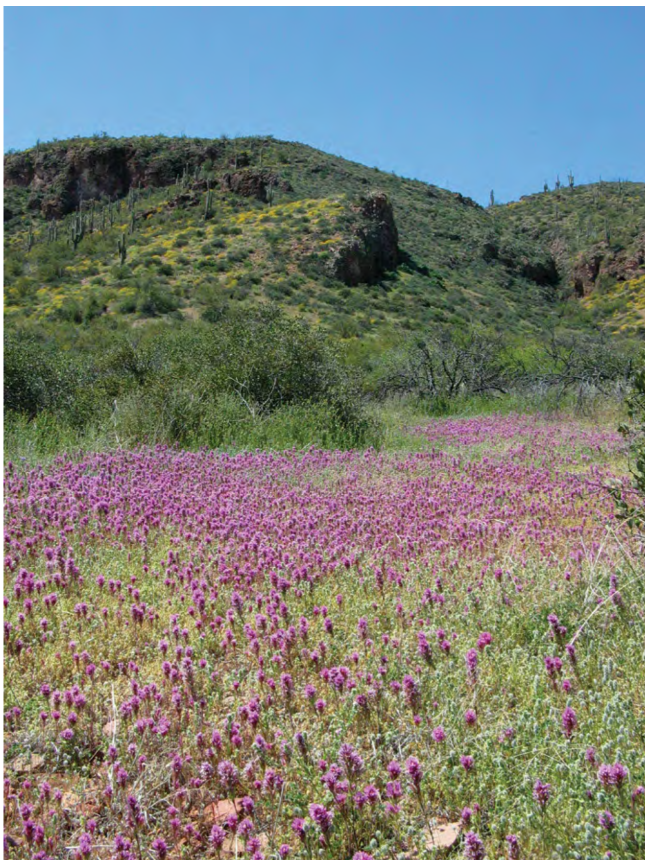
Natural Resource Stewardship and Science

Status of Terrestrial Vegetation and Soils at Tonto National Monument, 2009–2010

Natural Resource Technical Report NPS/SODN/NRTR—2013/833



ON THE COVER

Left: Wildflowers, Tonto National Monument. NPS photo.
Right: Biological soil crust, Tonto National Monument. NPS/A. Wondrak Biel.

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Contents

Figures

Tables

Acronyms and Abbreviations

ac	acres
AGFD	Arizona Game and Fish Department
ANOSIM	analysis of similarity
AVG	average
GRTS	generalized random tessellation stratified
ha	hectares
m	meters
MDC	minimum detectable change
MDS	non-metric multidimensional scaling
n	number
NF	national forest
NM	national monument
NPS	National Park Service
PDO	Pacific Decadal Oscillation
PERMANOVA	permutational multivariate analysis of variance analysis
RRQRR	Reversed Randomized Quadrant Recursive Raster
SE	standard error
SIMPER	similarity percentages
SODN	Sonoran Desert Network
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service

Species List

Acacia greggii	catclaw acacia
Achnatherum speciosum	desert needlegrass
Acourtia wrightii	brownfoot
Agrostis gigantea	redtop
Avena fatua	wild oat
Berberis fremontii	Fremont's barberry
Bouteloua curtipendula	sideoats grama
Brassica tournefortii	Sahara mustard
Bromus rigidus	ripgut brome
Bromus rubens	red brome
Canotia holacantha	crucifixion thorn
Carnegiea gigantea	saguaro cactus
Celtis laevigata var. *reticulata*	hackberry
Centaurea melitensis	Maltese star-thistle
Cercocarpus montanus	mountain mahogany
Chamaesyce arizonica	Arizona sandmat
Chamaesyce sp.	euphorbia
Cheilanthes sp.	lipfern
Cyclospermum leptophyllum	marsh parsley
Cynodon dactylon	Bermudagrass
Dasylirion wheeleri	sotol
Dodonaea viscosa	hopbush
Dudleya collomiae	Gila County liveforever
Echinocereus engelmannii	Engelmann's hedgehog cactus
Echinocereus fendleri	pinkflower hedgehog cactus
Encelia farinosa	brittlebush
Encelia frutescens	button brittlebrush
Eragrostis lehmanniana	Lehmann lovegrass
Ericameria laricifolia	turpentine bush
Eriogonum fasciculatum	Eastern Mojave buckwheat
Eriogonum wrightii	bastardsage
Erodium cicutarium	redstem storksbill
Ferocactus wislizeni	candy barrelcactus
Fouquieria splendens	ocotillo
Fraxinus anomala	singleleaf ash
Gutierrezia microcephala	threadleaf snakeweed
Gutierrezia sarothrae	broom snakeweed
Juniperus coahuilensis	redberry juniper
Lycium fremontii	wolfberry
Malva parviflora	little mallow
Mammillaria grahamii	Graham's nipple cactus
Marrubium vulgare	horehound
Melampodium leucanthum	Plains blackfoot
Nicotiana glauca	tree tobacco
Opuntia engelmannii	cactus apple
Parkinsonia microphylla	yellow paloverde
Pellaea truncata	spiny cliffbrake

Pennisetum ciliare	buffelgrass
Prosopis velutina	velvet mesquite
Quercus turbinella	Sonoran scrub oak
Rhus ovata	sugar sumac
Selaginella arizonica	Arizona spikemoss
Simmondsia chinensis	jojoba
Sonchus spp.	sowthistles
Sphaeralcea sp.	globemallow

Executive Summary

This report summarizes results of the Sonoran Desert Network's first season of terrestrial vegetation and soils monitoring in upland areas of Tonto National Monument (NM), in central Arizona. Nineteen permanent field-monitoring plots were sampled. Sixteen plots were established and sampled in 2009. Three additional high-elevation plots were established and sampled in 2010, and the 19 total plots were combined in our analyses. Our objectives were to determine the status of and detect trends, over five-year intervals, in vegetation cover, vegetation frequency, soil cover (including bare ground), biological soil crusts, and surface soil stability.

Our data indicated three general classes of terrestrial vegetation at Tonto NM: (1) jojoba (*Simmondsia chinensis*)-dominated shrublands with low paloverde (*Parkinsonia microphylla*) cover occupying the bajada, alluvial fans, and low hill slopes ("valley" stratum, <2,501'); (2) semi-desert grassland/shrub savanna systems with mixed shrubs occurring on higher slopes ("bajada" stratum, 2,501–3,700'); and (3) mountain mahogany (*Cercocarpus montanus*) and crucifixion thorn (*Canotia holacantha*) shrublands on upper-elevation slopes ("foothills" stratum, 3,701–4,500') in the southern portion of the monument. Vegetative cover was always greatest in the field height category (<0.5 m), and increased dramatically with elevation. Subcanopy (0.5–2 m) and canopy (>2 m) vegetation cover was similar across all elevation strata, consisting almost exclusively of sparse shrubs and small trees. Although Tonto NM is often perceived as having only classic Sonoran Desert vegetation, the monument encompasses transitions between Sonoran Desert scrub, semi-desert grassland, and interior chaparral. These transitions, and the monument's connection with the Mogollon Rim, lead to a surprisingly active and pervasive role of fire in terrestrial ecosystems at Tonto NM.

Five exotic plant species were detected in monitoring plots: red brome (*Bromus rubens*), wild oat (*Avena fatua*), Lehmann lovegrass (*Eragrostis lehmanniana*), marsh parsley (*Cyclospermum leptophyllum*), and redtop (*Agrostis gigantea*). Red brome was one of the most widespread plants found in the park (recorded on 14 of 19 plots). Of great management concern is the potential of incipient red brome populations to dominate monument vegetation in the future, via disturbance-mediated or indirect competition.

The biological soil crust community of Tonto NM was dominated by bryophytes (mosses and liverworts), which is unusual for the Sonoran Desert. In addition, spikemoss (*Selaginella* sp.) provided substantial ground cover and may help stabilize the soil surface in a manner similar to biological soil crusts. Bryophyte occurrence and cover was generally more associated with mid- and higher elevations, where lower temperatures and higher effective moisture favor these lifeforms. The prevalence of bryophytes suggested that the soil surface was relatively moist and well-protected from water and wind erosion.

Upland areas of the park, as a whole, appeared to be well-protected from soil erosion. Overall, surface soil aggregate stability was fairly high; only one plot (302_V001) had an average stability value of less than three. Total soil cover was also high, with little exposed bare soil (total bare soil average less than 13%). Collectively, these results indicated a high degree of inherent resistance to raindrop and surface-flow erosion. However, plant litter comprised nearly one-third of soil cover, suggesting that site susceptibility to wind and water erosion could increase if fire or drought reduce litter cover. Six plots (102_V03, 202_V08, 202_V09, 202_V13, V202_V17, 302_V04) contained rills or gullies. The rills and gullies were generally small and limited within a given site. They were likely the natural consequences of sporadic, extreme precipitation events in a semi-arid ecosystem, as well as the legacy of twentieth-century livestock grazing within the monument.

We conclude that the terrestrial vegetation and soils in uplands of Tonto NM are within the historic range of natural variability. Our data reflect an intact and functioning terrestrial ecosystem with species abundances and diversity within expected ranges. Vegetation

composition and abundance are consistent with published data from elsewhere in the Sonoran Desert ecoregion. The Sonoran Desert Network will continue to monitor terrestrial vegetation and soils at Tonto NM, and will revisit the 19 plots in 2014. Continued monitoring will permit us to detect any directional changes in the terrestrial vegetation and soils going forward.

Acknowledgements

We thank Chief of Resources Roger Dorr, Superintendent Terry Saunders, and the rest of the Tonto National Monument staff for their on-site support. We also greatly appreciate the key role that former Chief of Resources Duane Hubbard and Biological Science Technician Jenny Shrum played in establishing the upland monitoring program at the park. Beth Fallon, Laura Crumbacher, Aaron Curtis, Aedan Berge, Kate Connor, Betsy Vance, Laura Bassaraba, Jake DeGayner, and Steve Buckley conducted the field data collection. The University of Arizona's Environmental Research Laboratory processed all of the soil samples. Expert data processing and management were completed in record time by Sonoran Desert Network Data Manager Kristen Beaupré. Lindsay Fitzgerald-DeHoog updated the master plant lists.

1 Introduction

1.1 Background

Generating more than 99.9% of Earth's biomass (Whittaker 1975), plants are the primary producers of life on our planet. Vegetation therefore represents much of the biological foundation of terrestrial ecosystems, and it comprises or interacts with all primary structural and functional components of these systems. Vegetation dynamics can indicate the integrity of ecological processes, productivity trends, and ecosystem interactions that can otherwise be difficult to monitor. Land management actions often focus on manipulating vegetation to achieve park management objectives, with management strategies based on community structure or lifeform composition.

In the Sonoran Desert ecoregion (Bailey 1998), vegetation composition, distribution, and production are highly influenced by edaphic factors, such as soil texture, mineralogy depth, and landform type (McAuliffe 1999). Especially as they relate to water, these influences are magnified at local scales, as described by pioneering desert ecologist Forrest Shreve (1951): "The profound influence of soil upon desert vegetation is to be attributed to its strong control of the amount, availability and continuity of water supply. This fundamental requisite in plants is the most effective single factor in the differentiation of desert communities." As such, a fundamental understanding of soils and landforms is essential for evaluating vegetation patterns and processes (McAuliffe 1999).

The Sonoran Desert Network (SODN), as part of the National Park Service's Inventory and Monitoring (I&M) Program, has identified terrestrial vegetation and dynamic soil functional attributes as important ecosystem monitoring parameters, or "vital signs" (NPS 2005) that provide key insights into the integrity of terrestrial ecosystems at Tonto National Monument (NM; Figure 1-1). Indicators of terrestrial vegetation integrity include vegetation community structure, lifeform abundance, status and trends of established exotic plants, and early detection of previously undetected exotic plants. Indicators of soil dynamic function and erosion resistance include the cover of mineral soil and the stability of surface soil aggregates.

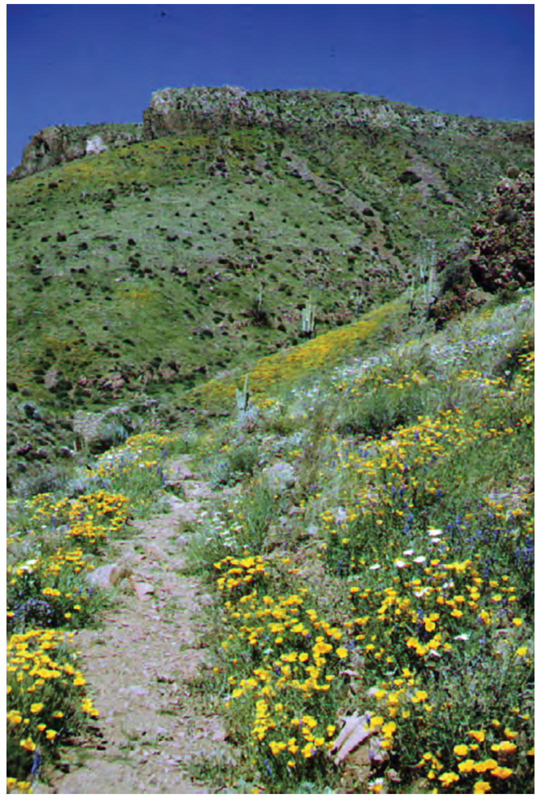

Figure 1-1. Terrestrial vegetation along Upper Cliff Dwellings Trail, Tonto National Monument.

1.2 Goals and objectives

The overall goal of the SODN terrestrial vegetation and soils monitoring program is to ascertain broad-scale changes in vegetation and dynamic soils properties in the context of changes in other ecological drivers, stressors, ecological processes, and focal resources of interest. This integrated approach explores patterns and identifies candidate explanations to support effective management and protection of park natural resources in a cumulative fashion, such that the results of each successive round of monitoring build upon the knowledge gained from previous efforts and related research and monitoring activities.

Specific, measurable objectives for SODN terrestrial vegetation and soils monitoring (Hubbard et al. 2012) at Tonto NM are to determine the status of and detect trends in (over five-year intervals):

1. Terrestrial vegetation cover for common (≥10% absolute canopy cover) perennial species (including non-native plants) and all plant lifeforms.
2. Terrestrial vegetation frequency of uncommon (<10% absolute canopy cover)

perennial species, including non-native plants.

3. Terrestrial soil cover by substrate classes (bare soil, litter, vegetation, biological soil crust, rock fragments of several size classes) that influence resistance to erosion.

4. Terrestrial soil stability of surface aggregates by stability class (1–6).

5. Basal cover and frequency of biological soil crusts by lichen growth form and morphological group.

1.3 Scope of this report

This document reports and interprets the results of the first round of terrestrial vegetation and soils monitoring at Tonto NM. Our focus is necessarily on current status, with trend evaluations to commence after the next sampling period in 2014. We do, however, contrast these current results with those from previous studies and interpret the information in the context of management objectives and ecological considerations.

1.4 Overview of terrestrial ecosystems at Tonto NM

1.4.1 Park establishment and purpose

Tonto NM protects and interprets a complex of striking cliff dwellings and other associated prehistoric sites, and the diverse natural environment that attracted and supported the Salado and other cultures prior to the 16th century. One of the first monuments to be designated under the Antiquities Act of 1906, Tonto NM comprised 660 acres (~267 ha) when initially established via presidential proclamation by Theodore Roosevelt in 1907. The U.S. Forest Service managed Tonto NM as part of the Tonto National Forest from 1907 to 1933 before the National Park Service assumed management of the monument in 1934 (Dallett 2008). An additional 460 acres (~186 ha) were added in 1937, bringing the monument to its current extent of 1,160 acres (~453 ha) (Figure 1-2).

This relatively small unit preserves the stabilized (but unrestored) remains of two cliff dwelling complexes, a recently discovered

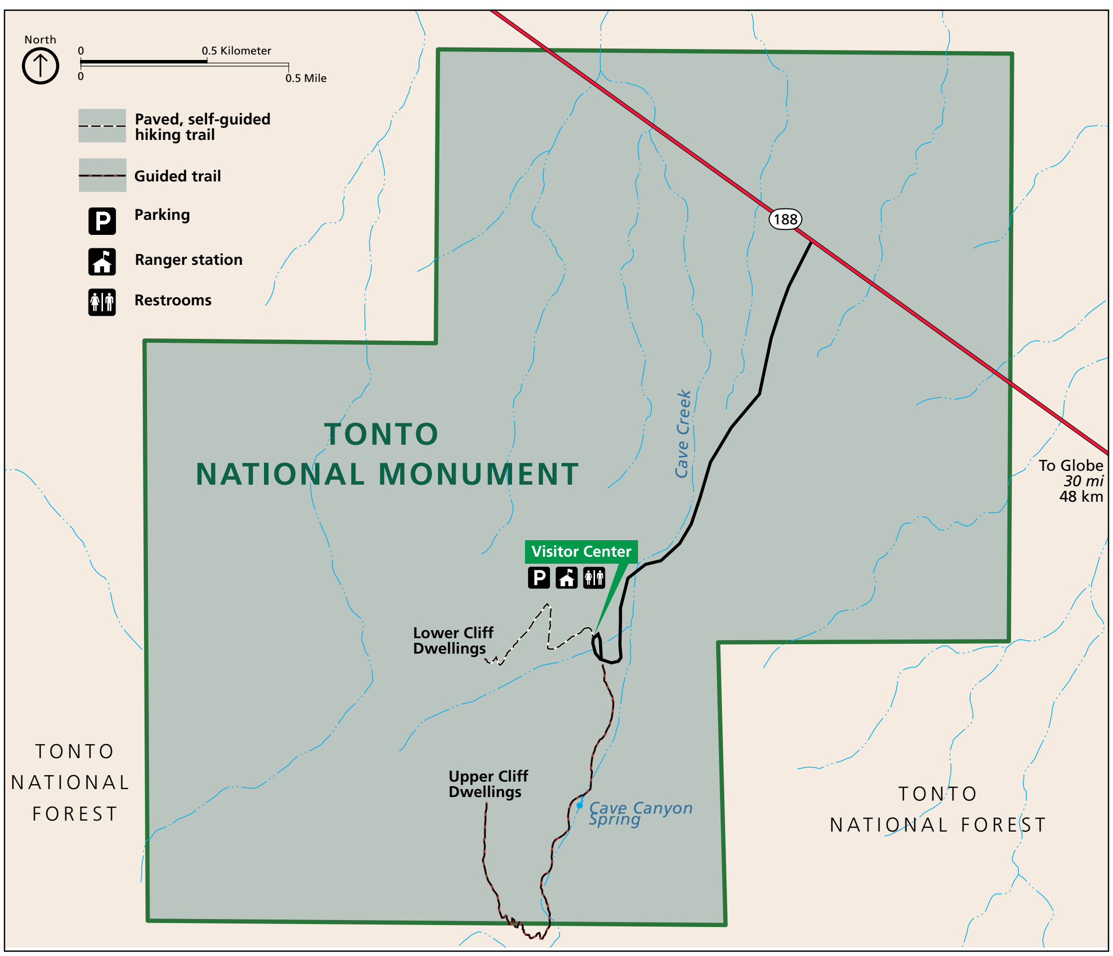

Figure 1-2. General map of Tonto National Monument.

Stone Age settlement, and numerous smaller prehistoric and protohistoric cultural sites.

As with other cultural sites in the American Southwest, the location of these important prehistoric resources is directly related to scarce and important natural resources: the perennial waters, productive alluvial soils, and diverse natural resources of the Tonto Basin.

1.4.2 Biogeographic and physiographic context

Tonto NM lies in the Tonto Basin, an inclusion of the Sonoran Desert nestled against the Mogollon Rim along the Salt River in central Arizona. The sharp escarpment of the Mogollon Rim separates the Sonoran Desert ecoregion from the Apache Highlands ecoregion, or "Apacheria" (Gori and Enquist 2003), and the proximity of the monument to this major transition is reflected in its diverse flora and fauna (Albrecht et al. 2007).

Tonto NM lies on the southeastern flanks of the rugged Matzatzal Mountains, facing the even more precipitous Sierra Ancha Mountains to the northeast. These steep, angular mountains are typical of the Basin and Range physiographic province (Scarborough 2000), with northwest–southeast aligned ranges separated by the Salt River Valley, which was the focus of prehistoric human uses in the region. The reach of the Salt River just north of Tonto NM now contains Roosevelt Lake, a 7,015-ha reservoir created by the completion of Roosevelt Dam in 1911—at the time, the largest masonry dam in the world (Hiett and Halvorson 1999).

The northeastern third of the park is composed of alluvial outwash fans and bajadas emanating from the steep mountains that comprise the remainder of the monument. Lying between 690 and 1,245 m (~2,264–4,085'), Tonto contains three steep-gradient ephemeral riparian systems: Cave Canyon, Deadman Canyon, and the smaller Cholla Canyon. Cave Canyon contains the two cliff dwellings, all administrative and visitor facilities, and the only perennial surface water in the park, Cave Canyon Spring. Though riparian systems are not considered in this protocol, we did explore geomorphologic and landscape relationships with vegetation and dynamic soil monitoring parameters.

1.4.3 Local geology and soils

The Tonto Basin is an intermontane basin filled with a mixture of marine sediments and debris eroded from nearby mountains. The mountains in the region present today are the result of cycles of deposition, uplift, and erosion. During the most recent uplift, the Salt River eroded canyons and valleys (NPS 2006).

In addition to the mountains, landforms within the Tonto Basin include alluvial fans, bajadas, and pediments. The sediment carried by mountain stream channels during rare, heavy rain events forms alluvial fans. As the stream channel enters the relatively flat valley floor, it spreads out, streamflow decreases dramatically, the water loses its ability to suspend sediments, and the stream deposits sand, gravel, and silt. Sediment from the stream channel forms a delta-shaped pile of roughly stratified particles, known as an alluvial fan. When several alluvial fans combine to form a sloping surface along a mountain front, the surface is known as a bajada (Nations and Stump 1996). Pediments stretch from the edge of the mountain toward the large fault and adjacent valley and are formed as the stream channels wear the mountain front away. Subsequently, the shoulders are buried by a thin layer of gravel (Scarborough 2000).

The geologic strata at Tonto NM are composed of the Precambrian Apache Group, and the entire Precambrian section is exposed in the monument. From oldest to youngest, the group includes Pioneer shale, Dripping Spring quartzite, Mescal limestone, and basalt. The Dripping Springs quartzite is notable because it houses the alcoves with cliff dwellings. The alcoves were created by weathering and erosional processes that likely started 50,000–400,000 years ago. The people of the Salado culture utilized sedimentary and igneous rocks in the area to form tools and building materials (NPS 2006).

Lindsay and others (1994) mapped 10 soil families within Tonto NM (Figure 1-3). The soil families can be grouped based on where they occur on the landscape: hills, bajadas, or drainageways. The Boedecker and Tonto families occur in drainageways, with the Boedecker family in the Cave Creek riparian area and the Tonto family in areas of active

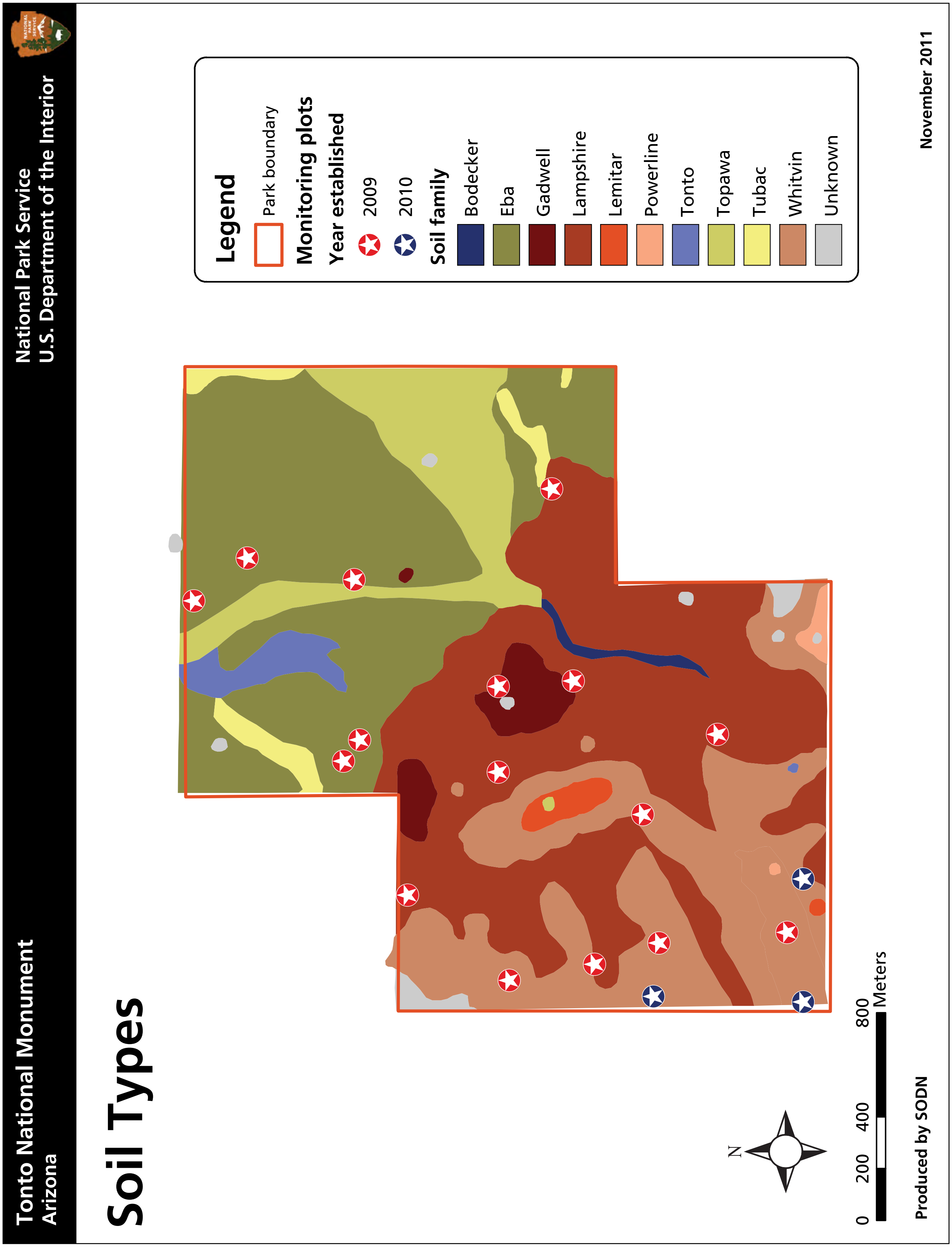

Figure 1-3. Soil families at Tonto National Monument. From Lindsay and others (1998).

wash cutting and sediment movement. The bajada or alluvial fan soils include older surfaces that are mapped as Eba and Topawa families and the Tubac family, formed by erosion uncovering old, fine-grained lacustrine sediments. Hill or mountain soils include unstable steep colluvial sideslope soils mapped as Lampshire family, and several more stable summit soils that differ in composition based on age and composition of parent materials (Gadwell, Lemitar, Powerline, and Whitvin families; Nauman 2007). All but two soil families (Tubac and Tonto) are classified as containing more than 35% rock fragments by volume in the surface layer of the soil profile (Lindsay et al. 1998). Large rock contents often make soils more resistant to water erosion processes (Belnap et al. 2007).

1.4.4 Biological soil crusts

Open spaces on the soils at Tonto NM, and in the Sonoran Desert more generally, are typically covered by biological soil crusts, a community of cyanobacteria, algae, lichens, and bryophytes. Lichens are a composite, symbiotic organism composed of a fungus and either a cyanobacteria or a green algae. Bryophytes are small, non-vascular plants, including mosses and liverworts.

Biological soil crusts provide key ecosystem functions, such as increasing water and wind erosion resistance, contributing organic matter, and fixing atmospheric nitrogen. Cyanobacteria weave through the upper few millimeters of soil, binding together soil particles by secreting polysaccharides. In addition to reducing water erosion, the polysaccharides contribute to soil aggregate structure, which is directly correlated with soil erosion resistance (Belnap et al. 2003; Herrick et al. 2005b). Mosses and lichens have small, anchoring structures that help them protect the soil surface (Belnap et al. 2003). On many soils, biological soil crusts increase infiltration. However, on sandy soils, cyanobacteria-dominated biological soil crusts tend to reduce infiltration rates due to interception of percolating precipitation (Warren 2003).

Biological soil crusts contribute fixed carbon to soil through decaying and leaching processes (Lange 2003). Cyanobacteria and cyanolichens have the ability to fix atmospheric nitrogen. This process reduces atmospheric nitrogen (N_2) to ammonia (NH^{4+}), which is usable by vascular plants (Belnap 2003). Biological soil crusts can be the dominant source of nitrogen for desert ecosystems. The distribution and species composition of biological soil crusts is influenced by soil chemistry and disturbance (Belnap et al. 2001).

In general, lichens with the same growth form have similar ecological functions. Squamulose lichens provide the most protection of the soil from water erosion, followed by crustose, foliose, and fruticose lichens. Gelatinous lichens provide the least protection from water erosion. Having some vertical growth allows lichens to provide additional protection from wind erosion by increasing surface roughness and decreasing the erosive power of wind. Crustose and gelatinous lichens are effective at resisting detachment but do not provide as much resistance to wind erosion as other growth forms. All gelatinous lichens fix nitrogen, whereas nitrogen fixation is species-dependent for the other growth forms.

The recovery of biological soil crusts from disturbance depends on factors that include the climatic regime and type of disturbance. Generally, crusts recover slowly in areas with high annual temperature and low annual precipitation (Belnap and Eldridge 2003), such as Tonto NM. Biological soil crusts follow a recovery sequence in which, typically, cyanobacteria first colonize a site, followed by cyanolichens, other lichens, and then moss (Belnap et al. 2001). Following disturbance, gelatinous lichens tend to recover relatively quickly, followed by crustose, squamulose, foliose, and fruticose lichens.

1.4.5 Site and soil stability

Site stability is the resistance of a site to localized wind and water erosion of soils—with tremendous consequences for park ecosystems and the protection of finite aboveground and subsurface cultural resources. Soil factors mediate water relations for plants in semi-arid environments (McAuliffe 1999), thereby controlling patch-scale ecological composition and net primary productivity (Herrick et al. 2005b). As recovery of disturbed soils is particularly slow in dry and seasonally dry environments (Aber and Melillo 1991), avoiding erosion is of paramount importance to effective natural resource management in SODN parks, including Tonto NM. Soil loss and subsequent damage to surface and near-surface archaeological materials is an obvious management concern given the importance and abundance of cultural resources at Tonto NM.

Static and dynamic factors determine the vulnerability of a site to water erosion (Herrick et al. 2005b). Static factors are generally not affected by management actions and include soil texture and rock-fragment content, depth and parent material, slope, aspect, and climate (Herrick et al. 2005b). These factors can be combined to estimate site erosion potential (Davenport et al. 1998). In this way, static factors set the range of erosion potential within which dynamic factors may be influenced by disturbance and management action to determine actual erosion.

Dynamic factors that affect water erosion include soil disturbance, soil structure, total cover, and plant basal cover. The amount of total cover (soil cover and vegetation cover) is the single most important dynamic factor affecting water erosion (Herrick et al. 2005b). Most soil loss occurs in "unprotected" areas with uncovered bare soils (Davenport et al. 1998). Rock, gravel, vegetation, biological soil crusts, and even plant debris (litter and duff) can "armor" the soil, slowing the flow of water and permitting increased infiltration of water into the soil profile (Belnap et al. 2007).

1.4.6 Climate and hydrology

Tonto NM experiences climate typical of the Sonoran Desert ecoregion: highly variable, bimodal precipitation with a considerable range in daily and seasonal air temperature, and relatively high potential evapotranspiration rates (Ingram 2000). From 1981 to 2010, 29% of the annual precipitation near Tonto NM fell during summer thunderstorms from July through September (NCDC 2011), when maximum air temperatures can exceed 40°C and lead to violent (and often localized) rainstorms. The thunderstorms are highly variable in time and space and primarily derive their moisture from the Gulf of California and the tropical Pacific Ocean (Sheppard et al. 2002). The bulk of the remaining annual precipitation falls in relatively gentle events of broad extent from November through March (Ingram 2000).

Because the winter storms originate in the Pacific Ocean, sea-surface temperatures affect the amount of winter precipitation the park receives. In El Niño years, sea-surface temperatures in the eastern Pacific Ocean, near the equator, are warmer than normal and the Sonoran Desert receives more precipitation than average. In contrast, winter precipitation tends to be lower than average in La Niña years, due to cooler sea-surface temperatures.

Sea-surface temperatures in the northern Pacific Ocean also influence winter precipitation. The Pacific Decadal Oscillation (PDO), when the temperatures in the northern Pacific Ocean are warmer or cooler than usual, can last for several decades. When temperatures are warmer than normal during the PDO, the Sonoran Desert experiences increased winter precipitation (Sheppard et al. 2002).

Occasionally, tropical storms move into the Sonoran Desert in early fall. While infrequent, tropical storms have produced some of the largest rainfall events recorded and can result in widespread flooding and severe erosion (Ingram 2000).

To determine departure from baseline climate conditions, seasonal and annual precipitation are compared to the average precipitation received during a historic, or "normal," period (Gray 2008). The most recent 30-year normal computed for the weather station near Tonto NM (ROOSEVELT 1 WNW) spans 1981–2010. Therefore, monthly precipitation and temperature data from 2006 to 2010 are presented in the context of that time period (Figure 1-4; NCDC 2011). The average annual precipitation from 2006 to 2010 was similar to the 1981–2010 precipitation normals (16.3" vs. 16.5"). While monthly average precipitation from 2006 to 2010 differed from the 1981–2010 normals, the precipitation averages for the winter rainy season (November through March) and summer monsoon (July through September) were similar. The 2006–2010 period had slightly less-rainy winters and somewhat more-rainy monsoons, which accounted for one-third of the average annual precipitation.

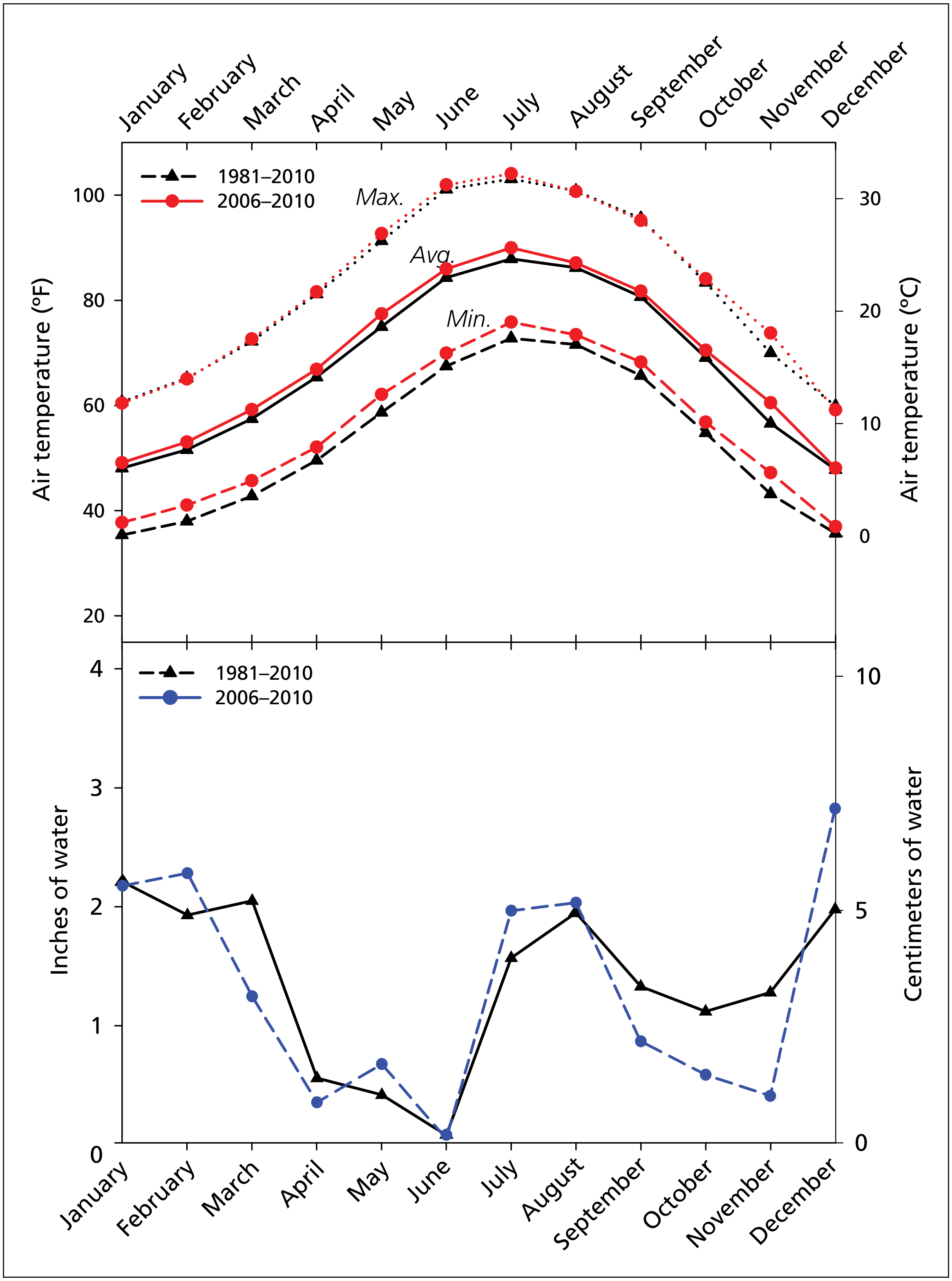

Figure 1-4. Climate data from 2006 to 2010 in the context of 30-year normals for Tonto National Monument.

Ephemeral stream channels run through Tonto NM, with the exception of a small perennial section near Cave Canyon Spring. Cave Canyon Spring emerges in Cave Creek, below the Upper Ruin. Hydrologists speculate that Cave Canyon Spring was the water source for the Upper Cliff Dwellings (Sprouse et al. 2002). From 1942 to 1963, Cave Canyon Spring served as the monument's domestic water source and from 1942 to 1974, the spring delivered water to stock troughs (Martin 2001 *in* Sprouse et al. 2002).

A spring at the confluence of Cave and Cholla canyons was likely the water source for the Lower Cliff Dwelling. However, the spring has not flowed since the early 1960s, likely due to regional drought and the installation of the domestic water well in 1963 (Martin 2001 *in* Sprouse et al. 2002).

The quasi-perennial Hidden Spring appears to support a woodland community of velvet mesquite (*Prosopis velutina*) and hackberry (*Celtis laevigata* var. *reticulata*) on what is called Hidden Ridge, an area covering approximately eight hectares within the northwestern bajada. The area is unusual, as it occurs upon a rise between two small drainages and is notably more densely vegetated than surrounding inter-fluvial areas due to the increased subsurface water availability.

1.4.7 Human habitation of the Tonto Basin

Archaic people arrived in the Tonto Basin up to 10,000 years ago. Initially subsisting as hunters and gatherers, they eventually adopted agriculture and a more sedentary lifestyle (Dallett 2008). Irrigation of food crops along the upper Salt River and Tonto Creek by the Hohokam from the Salt and Gila river valleys began approximately 1,200 years ago (Dallett 2008).

From 1150 to around 1450, the Salado (Spanish for "salt," as named by archeologists working in the Salt River valley in the 1930s) lived in the Tonto Basin and occupied the monument's cliff dwellings (NPS 2005, 2006). The Salado practiced subsidence agriculture along the river valleys and hunting and gathering on the higher elevations of the Tonto Basin (NPS 2005). In the mid-1400s, the Salado migrated away from the Tonto Basin, an event which may have coincided with the arrival of the Apache. The Tonto Apache grew squash, corn, and beans, and there is evidence that they utilized fire to generate favorable conditions for hunting and gathering (Dallett 2008).

The local Apache and U.S. military began to clash in 1863, following the discovery of gold in the area. Subsequently, the U.S. military built several forts in the area, including Fort McDowell and Camp Reno (15 miles north of the monument), which was destroyed by San Carlos Apache in 1869. By 1875, the Tonto Apache were extirpated from the Tonto Basin, with many removed to the San Carlos Reservation (Dallett 2008). Decreasing violence in the Tonto Basin favored an influx of prospectors, and the resulting mineral discoveries and mine development led to the founding of Globe in 1876. The 1880 gold rush in nearby Payson drew additional Anglo settlement by merchants, farmers, and ranchers (Dallett 2008).

The construction of Roosevelt Dam from 1903 to 1911 brought more people to the area and resulted in several boomtowns, such as Roosevelt, located east of the monument. Following the dam's completion, most of the workers left the basin (Dallett 2008). Today, Globe and Payson are home to more than 7,500 and 15,000 people, respectively, while more than four million people reside in the Phoenix metropolitan area (USCB 2011).

1.4.8 Natural resource inventories

The National Park Service has authorized and funded 12 basic natural resource inventories for 270 park units deemed to have "significant" natural resources, including Tonto NM (NPS 2009). At time of writing (2012), eight of those inventories had been completed at Tonto NM, three others were in progress, and one was being updated (Table 1-1). Coordinated at the national level, most of these inventories rely on existing information and deliver products ranging from electronic datasets to short reports. However, three inventories—species lists, species occurrence and distribution, and vegetation characterization—involved extensive fieldwork culminating in detailed reports. See NPS (2009) for additional information.

Table 1-1. Status of natural resource inventories for Tonto National Monument, 2012.

Inventory	Description and products	Status (2013)
Air Quality Data	Baseline air quality data collected both on and off-park. Products: http://www.nature.nps.gov/air/maps/AirAtlas/	Complete
Air Quality Related Values	An evaluation of resources sensitive to air quality. Products: http://www.nature.nps.gov/air/Permits/ARIS/	Complete
Base Cartographic Data	A compilation of basic electronic cartographic materials. Products: http://science.nature.nps.gov/nrdata/	Complete
Baseline Water Quality	Assessment of water chemistry at the Cave Canyon Spring. Products: http://www.nature.nps.gov/water/horizon.cfm	Complete
Climate	A basic assessment of nearby climate stations and instrumentation. Products: http://www1.nrintra.nps.gov/NPClime/	Complete
Geologic Resources	A synthesis of existing geologic data, resulting in a report and electronic map.	In Progress
Natural Resource Bibliography	An electronic catalog of natural resource-related information. Products: http://science.nature.nps.gov/im/apps/nrbib/	Complete
Soil Resources	Electronic geospatial data regarding basic soil properties. Products: http://www.nature.nps.gov/geology/soils/	Not scheduled
Species Lists Species Occurrence and Distribution	Documentation of the occurrence and distributions of >90% of the vertebrates & vascular plant species, based on prior research and fieldwork. Products: Albrecht et al. 2007	Complete
Vegetation Characterization	Description, classification, and mapping of vegetation communities, based on fieldwork.	In Progress (complete 2014)
Water Body Location and Classification	Basic geographic data on hydrologic units.	Complete

1.4.9 Other long-term monitoring and related ecological research

In addition to terrestrial vegetation and soils monitoring, the Sonoran Desert Network conducts long-term monitoring on air quality, birds, climate, exotic plants-early detection, groundwater, springs (Cave Canyon and Hidden Ridge springs), and washes (Upper and Lower Cave Canyon) at Tonto NM. Details on these efforts are provided in NPS (2005) and on the Sonoran Desert Network website, http://science.nature.nps.gov/im/units/sodn/.

Tonto NM has also been the focus of other ecological research relevant to terrestrial vegetation and soils monitoring. Burgess (1965) conducted the first inventory of plants in the monument, prior to the first major fire recorded in the park. Phillips (1997) investigated the effects of fire on cacti, succulents, and special-status plants across the monument. This study relocated and replicated 20 photo stations set up after the 1964 Schultz fire and also established five monitoring plots in a "variety of vegetation associations" in burned and un-burned areas.

Jenkins and others (1995) produced the monument's first vegetation map and annotated plant list utilizing the Brown (1982) system of vegetation classification at the sub-association level. Employing 60 temporary relevé plots and aerial photographs, they delineated 10 vegetation sub-associations and established one permanent monitoring plot per type. These plots were recently relocated by park and SODN staff in 2010, and mapped via GPS in order to better enable potential resampling.

Brian (1991) revisited burned line-point intercept transects (originally established by Strong in 1961), after 25 years. Phillips (1992), Halvorson and Guertin (2003), and Studd and others (2011) mapped the distribution of non-native invasive plants.

From 2006 to 2008, the Sonoran Institute evaluated the relative risk of surface cultural site destabilization due to water erosion and estimated the impact(s) of vegetation removal on water-erosion potential (Nauman 2007; Nauman and McIntyre 2008; McIntyre 2008). The study applied the same methods used by SODN for vegetation and soils monitoring but in a different spatial configuration. The Sonoran Institute applied both the Water Erosion Prediction Project (WEPP) model and an index model to evaluate erosion risk and the impact of vegetation removal.

SODN initiated a vegetation mapping inventory in 2009, with an intensive field data collection period designed to develop a vegetation classification meeting the current standard of the National Vegetation Classification System. Field polygon mapping and accuracy assessment work were completed in late 2010. Final products are in development and will be available through the Sonoran Desert Network website (http://science.nature.nps.gov/im/units/sodn) and the national inventory website (http://science.nature.nps.gov/im/inventory/veg/products.cfm).

The vegetation inventory data provide community-level classifications that detail the species combinations and abundances of all vegetation types found across the park landscape. In addition, the products include digital databases with spatial representations (maps) of where each vegetation type was recorded as occurring. These map data will provide a broader landscape context in which to consider the uplands data and potentially can provide additional locations or comparative sites should uplands data indicate drastic changes occurring on a landscape level.

At time of writing, Sonoran Desert Network and park staff were conducting a natural resource condition assessment (NRCA) for Tonto NM. This detailed assessment should identify additional information on resources and resource conditions relevant to terrestrial vegetation and soils of the park. See http://science.nature.nps.gov/im/units/sodn/inventory/nrca.cfm for additional information.

1.5 Natural resource management issues at Tonto NM

1.5.1 Invasive exotic plants

Biological invasions into new regions, whether accidental or deliberate, have increased at unprecedented rates in the past few hundred years (D'Antonio and Vitousek 1992). Once established, non-native plant species often lead to changes in ecosystem processes that are self-maintaining and evolving, leading to functional as well as compositional change. Several studies have implicated environmental and climatic variables as potential drivers for sustaining or accelerating non-native plant dominance in semi-arid ecosystems (Shinneman and Baker 2009). In the American Southwest, historic and current land-use practices, such as livestock grazing and fire suppression, are thought to have contributed to the susceptibility of arid lands to invasion and subsequent loss of native species, as well as decreased biodiversity (Brown and Archer 1999).

As part of the U.S. Geological Survey's Weeds in the West project (Halvorson and Guertin 2003), the presence and abundance of 50 pre-selected introduced plants were assessed and mapped in Arizona. During that survey effort (1999–2001), 28 non-native, introduced plant species were recorded at Tonto NM, 13 of which were grasses (Table 1-2). Most of the other species were forbs, with one tree (tree tobacco; *Nicotiana glauca*) and one subshrub (horehound; *Marrubium vulgare*).

During 2005, the Sonoran Institute and Sonoran Desert Network mapped the spatial location, abundance, and distribution of 16 of 79 target invasive species, most of which had been identified as high-priority by the Arizona Wildlands Invasive Plant Working Group (Studd et al. 2011; Table 1-2). Seven of the species observed by Halvorson and Guertin (2003) were not target species for Studd and others (2011). Of the seven species observed by Halvorson and Guertin (2003) that were not observed by Studd and others (2011), two were winter or spring annuals not seen during the 2005 summer survey:

Table 1-2. Non-native invasive plants detected at Tonto National Monument, 1999–2005.

Scientific name	Common name	Survey year(s)	
		1999–2001[a]	2005[b]
Forb/Herb			
Boerhavia coccinea	scarlet spiderling	present	non-target species
Brassica tournefortii	Sahara mustard	absent	present
Centaurea melitensis	starthistle	present	absent
Conyza spp.	horseweed	present	non-target species
Erodium cicutarium	redstem filaree	present	absent
Galium aparine	stickywilly	present	present
Heterotheca subaxillaris	camphorweed	present	non-target species
Lactuca serriola	prickly lettuce	present	non-target species
Malva parviflora	little mallow	present	absent
Melilotus indicus	Indian sweetclover	present	present
Salsola kali	Russian thistle	present	present
Sisymbrium irio	London rocket	present	present
Sonchus spp.	sowthistles	present	absent
Tribulus terrestris	puncturevine	absent	present
Graminoid			
Avena fatua	wild oat	present	present
Bromus rigidus	ripgut brome	present	present
Bromus rubens	red brome	present	present
Bromus trinii	Chilean chess	present	non-target species
Cynodon dactylon	Bermudagrass	present	absent
Eragrostis cilianensis	stinkgrass	present	non-target species
Eragrostis curvula	weeping lovegrass	present	present
Eragrostis curvula var. *conferta*	Boer lovegrass	present	non-target species
Eragrostis lehmanniana	Lehmann lovegrass	present	present
Hordeum spp.	barley	present	present
Pennisetum ciliare	buffelgrass	absent	present
Pennisetum setaceum	fountain grass	present	absent
Phalaris spp.	canarygrass	present	present
Schismus spp.	Mediterranean grass	present	absent
Sorghum halepense	Johnsongrass	present	present
Subshrub			
Marrubium vulgare	horehound	present	present
Tree			
Nicotiana glauca	tree tobacco	present	non-target species

[a] Halvorson and Guertin (2003)
[b] Studd and others (2011)

redstem storksbill (*Erodium cicutarium*) and little mallow (*Malva parviflora*). Additionally, sowthistles (*Sonchus* spp.) and Maltese star-thistle (*Centaurea melitensis*) were removed between the two survey efforts. Manual control of horehound was largely successful between the surveys. While Studd and others (2011) did not observe Bermudagrass (*Cynodon dactylon*), it is likely that the grass is still present within the monument.

Studd and others (2011) identified four problematic grass species that were widespread in 2005, had relatively high densities, are difficult to control, and pose a threat to the monument, particularly through an increase in fire risk: wild oat (*Avena fatua*), red brome (*Bromus rubens*), ripgut brome (*Bromus rigidus*), and Lehmann lovegrass (*Eragrostis lehmanniana*). In addition, Studd and others (2011) recommended persistent control of the small patches of buffelgrass (*Pennisetum ciliare*) and Sahara mustard (*Brassica tournefortii*).

1.5.2 Natural and cultural resource conflicts

Like many NPS units, Tonto NM contains substantial and spectacular natural and cultural resources whose respective management practices sometimes come into conflict. One example is the management of backcountry archeology sites. In 2004, Tonto NM began an intensive assessment of backcountry archeological site conditions. The assessment was initiated in response to two perceived threats to park resources: vegetation that was adversely impacting standing architecture, and surface erosion (intense surface flow and gully formation) that was impacting park soils (Duane Hubbard, personal communication).

Because unmanaged vegetation growth can damage architecture, displace artifacts, and create fire hazards, it is often necessary to remove and thin vegetation in and around architectural elements in order to protect the structural integrity and information potential of archeological sites. However, removing vegetation can exacerbate erosion problems by decreasing the amount of total cover. McIntyre (2008) provided several options for managing the natural resources at sites that may protect the cultural resource values.

1.5.3 Sensitive aquatic and riparian resources

Albrecht and others (2007) identified the small riparian area along Cave Creek, associated with Cave Canyon Spring, as the most important biological resource in the monument. While riparian areas account for 1% of the land cover in the Southwest (Skagen et al. 1998), most animals depend on riparian areas for all or part of their life cycles. For example, bird species diversity tends to be high in riparian areas. Riparian vegetation also provides many other benefits (ecosystem services), such as slowing flood flows, stabilizing stream banks, enhancing aquifer recharge, filtering water, and providing wildlife habitat.

The riparian area at Tonto NM provides habitat for six species of frogs and toads (Sprouse et al. 2002). In addition, the yellow-billed cuckoo (*Coccyzus americanus*) has been identified in the riparian area. The yellow-billed cuckoo is listed as a threatened species by the State of Arizona (AGFD 1988), and a candidate species by the U.S. Fish and Wildlife Service (USFWS 2011).

Activities inside and outside the monument have consequences for the riparian area. The majority of the Cave Canyon watershed occurs upstream of the monument, on the Tonto National Forest. Therefore, activities occurring upstream, on the forest, impact Cave Canyon and its spring. Within the monument, a trail winds through the riparian area and provides access to the Upper Cliff Dwellings. This serves as a form of disturbance as well as a potential vector for invasive plant species.

1.5.4 Visitation

The construction of Roosevelt Dam brought an influx of people to the Tonto NM area and made the cliff dwellings a popular tourist attraction. By the time the dam was completed in 1911, the Southern Pacific Railroad had constructed a nearby hotel and Tonto NM was a featured attraction on the Apache Trail Tour (Dallett 2008).

In 1929, the Southern Pacific Railroad, in cooperation with the U.S. Forest Service (then the manager of the monument), graded a road to the mouth of Cholla Canyon and constructed a parking lot at the present-day location of the picnic area. In addition to the road and parking lot, a trail to the Lower Cliff Dwellings was also cut. By 1932, the road was extended to the current parking lot and visitor center (Dallett 2008). According to Dallett (2008), the cliff dwellings may have suffered more damage and loss of artifacts during the 1920s and early 1930s than at any other period.

When the National Park Service assumed responsibility for Tonto NM in 1934, 7,000 people visited the monument. Annual visitation exceeded 50,000 in 1961 and peaked at over 82,000 in 1986. Since 2001, Tonto NM has averaged over 60,000 visitors per year—a decline from the late 1990s. Visitation tends to peak from January through April (NPS 2011).

1.5.5 Adjacent land use

In 1905, President Roosevelt created the Tonto Forest Reserve, later known as the Tonto National Forest. A main purpose of the forest's establishment was the protection of watersheds of the Salt and Verde rivers and Tonto Creek (Dallett 2008). Today, the U.S. Forest Service manages the 2.8 million-acre Tonto National Forest, which surrounds Tonto NM and stretches from Phoenix north to the Mogollon Rim. As was mentioned in Section 1.5.3, land-use activity occurring upstream of the monument affects riparian systems within it.

Grazing began in the Tonto Basin around 1870. A so-called "ranchers' paradise," the Tonto Basin's ranges of the 1870s were described as having "Grama grass that brushed one's stirrups" (Croxen 1926 in Dallett 2008). However, drought and overgrazing depleted the quality of the rangeland in the 1880s and early 1890s. Both Tonto NM and Tonto National Forest continued to be grazed after their establishment. Grazing continued throughout the entire monument until 1942, when Cholla and lower Cave canyons, the cliff dwellings, and visitor center were fenced, leaving Deadman Canyon, Honey Butte, and upper Cave Canyon open to grazing (Dallett 2008; Jenkins et al. 1995). Cave Canyon Spring was modified to deliver water to a trough near Highway 88. In 1974, the NPS closed the entire monument to grazing. Construction of a boundary fence took place from 1979 to 1981, when non-native ungulates were excluded from the monument. Today, grazing continues on the adjacent Tonto National Forest.

2 Methods

2.1 Response design

The response design for this protocol employs permanent, 20×50-m sampling plots (Figure 2-1). The 50-m edges of the plot run parallel with the contours of the site. Vegetation sampling is done in conjunction with soil cover and stability measures along six transects within the plot. In the spaces between transects (subplots), within-plot frequency is estimated by noting the occurrence of any perennial or non-native annual plant species or lifeform not observed on the adjacent transects. See Hubbard and others (2012) for details on plot configuration and data collection.

2.1.1 Vegetation and soil cover: Line-point intercept

Line-point intercept is a common and efficient technique for measuring the vegetation cover of plants. Line-point intercept measures the number of "hits" of a given species out of the total number of points measured (Elzinga et al. 1998; Bonham 1989). Vegetation was recorded within three height categories along each of the six transects using the line-point intercept method, with points spaced every 0.5 m (240 points total). The three height categories were field (0.025–0.5 m), subcanopy (>0.5–2.0 m), and canopy (>2.0 m) (Table 2-1). Perennial vegetation was recorded to species. Annual vegetation was recorded to lifeform, with the exception of a suite of annual non-native plants that were recorded to the species level. Soil cover was recorded by substrate class (e.g., rock, gravel, litter; see SOP #5, Hubbard et al. 2012). Biological soil crust cover was recorded to morphological group (light cyanobacteria, dark cyanobacteria, lichen, moss).

Table 2-1. Vegetation height categories used in upland monitoring, Tonto National Monument.

Category	Height
Field	0.025–0.5 m
Subcanopy	>0.5–2.0 m
Canopy	>2.0 m

2.1.2 Vegetation frequency: Subplots

The area between any two adjacent transects formed the boundary of 10×20-m subplots that were used to estimate within-plot frequency of perennial plant species, annual and perennial exotic plants, and all lifeforms. The occurrence of any species/lifeform that was not measured on the adjacent line-point transect was recorded to determine a within-plot frequency of 0–5. Figure 2-1 shows the relationship between each subplot and its corresponding adjacent transect.

2.1.3 Soil aggregate stability

Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2005a). Within each plot, samples were attempted at 48 pre-determined points on either side of the six line-point intercept transects. The dominant vegetation canopy cover and substrate cover at each point were determined. A uniformly sized (2–3 mm thick and 6–8 mm on each side) sample was collected and samples were tested in groups of 16. Each sample was placed on a screen and soaked in water for five minutes. After five minutes, the samples were slowly dipped up and down in the water, with the remaining amount of soil recorded as an index of the wet aggregate stability of the sample. Samples were scored from 1 to 6, with 6 being the most stable.

2.1.4 Biological soil crust cover and frequency: Point-quadrats

In addition to line-point intercept measurements, biological soil crust cover was measured using 0.25-m^2 quadrats. Three quadrats were measured per transect using the point-quadrat method (similar in concept to line-point intercept), with 16 intercept measurements per quadrat, resulting in 18 quadrats and 288 measurements per plot. At each intercept, biological soil crusts were recorded as light cyanobacteria, dark cyanobacteria, bryophytes (moss and liverworts), and lichens by growth form (crustose, gelatinous, foliose, fruticose, and squamulose). The observer then visually surveyed the quadrat for any species or morphological group that was present. Soil-crust frequency by lichen species and morphological group was determined by the number of quadrats occupied

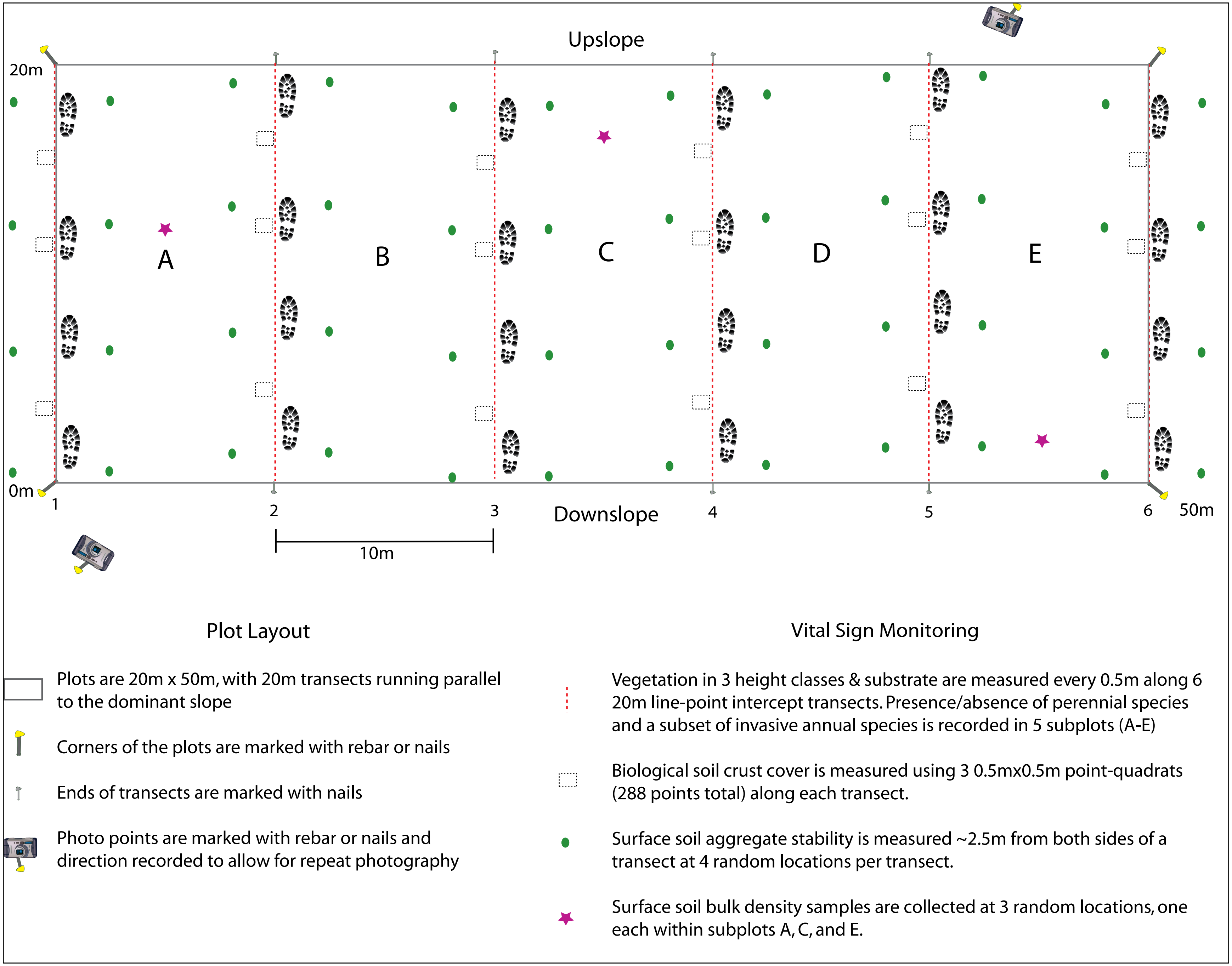

Figure 2-1. Terrestrial vegetation and soils monitoring plot design. See Hubbard and others (2012) for additional details on design and data collection.

relative to the total number of quadrats (i.e., 18). The SODN terrestrial vegetation and soils monitoring protocol provides a detailed description of the point-quadrat methodology (see SOP #6, Hubbard et al. 2012). The initial round of sampling at Tonto NM will help SODN to determine differences between the line-point intercept and point-quadrat methodologies.

2.1.5 Soil and site characterization

Proximate soil and landform factors are known to influence vegetation and dynamic soil function parameters at local scales (McAuliffe 1999). To characterize the soil and landscape attributes of each plot, a suite of topoedaphic variables was collected through site diagrams, repeat photo points, and collection of soil cores. Landform, slope position, and parent material were recorded at each plot. Slope measurements (%) and descriptions (type and position) were used to depict surface-flow patterns of the hillslope within each plot. Erosion features were described by estimating broad areal percentage classes of areas affected by tunneling, sheeting, rilling, gullying, pedestals, terracettes, and burrowing. Permanent photo points were established at each plot corner to characterize general site physiognomy and as an aid to interpreting quantitative trend data in successive sampling periods. In addition, general site descriptions (including observed disturbances such as fire) were collected for each plot.

2.2 Sampling design

2.2.1 Overview

Plots are all sampled in the winter of the same year, then revisited at five-year intervals. If a major disturbance (e.g., an extended drought, extreme frost, significant soil erosion event, major fire) occurs in the intervening years, then we may collect additional plot data to characterize and account for the potential effects of these important stochastic events.

Terrestrial vegetation and soils plots were proportionally allocated to three strata based on elevation and soil rock-fragment classes: valley (<2,501' elevation), bajada (2,501–3,700' elevation), and foothills (3,701–4,500' elevation) (Table 2-2). All strata had surface soil rock-fragment content of 35–90%. Stratification was employed to reduce spatial variability and increase sampling efficiency (Hubbard et al. 2012). Consequently, inference from the plots at Tonto NM is to all terrestrial areas of the park by stratum, except for the areas discussed in Section 2.2.3, below.

Initially, 15 permanent monitoring plots were allocated within Tonto NM and sampled in 2009. Sample sizes were based on a priori expectations of required sample size to meet our criteria for statistical power and detectability (see Sections 2.2.5–2.2.6). Following initial data analysis, however, three high-elevation plots were added from the original RRQRR-ordered list (see Sections 2.2.2, 3.5.2). Table 2-2 shows the initial allocation of permanent monitoring plots by stratum.

2.2.2 Spatial balance

The spatial sampling design for this protocol employs permanent, 20×50-m sampling plots, allocated through a Reversed Randomized Quadrant Recursive Raster (RRQRR) spatially balanced design (Theobald et al. 2007), using the "spatially balanced sample" function in the STARMAP Spatial Sampling Toolbox in ArcGIS 9.0 (http://www.spatialecology.com/htools/index.php). This tool produces a design that is spatially well-balanced, probability-based, flexible, and simple (Theobald et al. 2007). Because it tries to maximize the spatial independence between plots, the spatially balanced sampling design should provide more information per plot, thus increasing efficiency (Theobald et al. 2007).

Spatially balanced designs, such as RRQRR (for polygon data) and the Generalized Random Tessellation Stratified (GRTS; for points and lines) approach (Stevens and Olsen 2004), are increasingly being applied to ecosystem monitoring (e.g., Environmental Protection Agency Ecological Monitoring and Assessment Program) because they provide the advantages of a probabilistic design (Stehman 1999) and also ensure spatial balance, regardless of overall sample size. RRQRR designs facilitate adding or removing sites in a spatially balanced manner if statistical power, financial considerations, or additional monitoring objectives warrant

Table 2-2. Initial allocation of permanent terrestrial vegetation and soils monitoring plots by strata, Tonto National Monument.

Stratum	Elevation	% rock fragments	Total area (acres)	Percentage of total		Plots per stratum	
				Park area	Frame area	Number (min. 3)	Number per year
0			435	39	0	0	0
101	<2,500'	<35%	14	1	2	0	0
102 (Valley)	<2,500'	35–90%	117	11	17	3	3
201	2,501–3,700'	<35%	1	0.1	0.2	0	0
202 (Bajada)	2,501–3,700'	35–90%	485	44	72	11	11
302 (Foothills)*	3,701–4,500'	35–90%	53	5	8	2*	2*

Strata with <5% of park area (shown in grey) were excluded. *Stratum 302 was initially allocated two plots. After the 2009 data were analyzed, three plots were added to the stratum (see Section 2.2.1).

adjusting the sample size. This scaling ability is an important advantage, as (1) the number of plots per park cannot be adequately estimated a priori (Hubbard et al. 2012) and (2) future changes in technology, objectives, and budgets may necessitate increasing or decreasing sample sizes.

2.2.3 Sampling frame

The sampling frame for Tonto NM includes all terrestrial areas within park boundaries, except for the following (Figure 2-2):

- Slopes of ≥45° (for crew safety),
- Roads and buildings (including a 100-m buffer),
- Trails, washes, and streams (including a 50-m buffer),
- Selected fragile cultural features (such as the cliff dwellings), and
- Elevation × soil strata types that constituted <5% of park area.

The total area excluded under these criteria was ~182 ha (450 ac), or 40% of the park area.

2.2.4 Management assessment points as the link between science and management

To achieve the NPS core mission of resource protection, resource management and monitoring must be explicitly linked (Bingham et al. 2007). We advocate the use of management assessment points as a bridge between science and management.

Management assessment points, which are "... pre-selected points along a continuum of resource-indicator values where scientists and managers have agreed to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007), aid interpretation of ecological information within a management context. They do not define strict management or ecological thresholds, inevitably result in management actions, or reflect any legal or regulatory standard; they are only intended to serve as a potential early warning system allowing scientists and managers to pause, review the available information in detail, and consider options. Bennetts and others (2007) have provided a detailed explanation of this concept and its application to monitoring and management of protected areas.

Although no management assessment points have been formally established for Tonto NM, we propose some here, based on the ecological literature and our knowledge of these ecosystems and park management goals. We intend for these assessment points to (1) initiate a discussion of potential indicators and assessment points and (2) provide a useful framework for evaluating terrestrial vegetation and soils data in a broader ecological and managerial context. Proposed assessment points are summarized in Table 2-3 and discussed in Tables 3-6, 3-11, and 3-16 and Chapter 4.

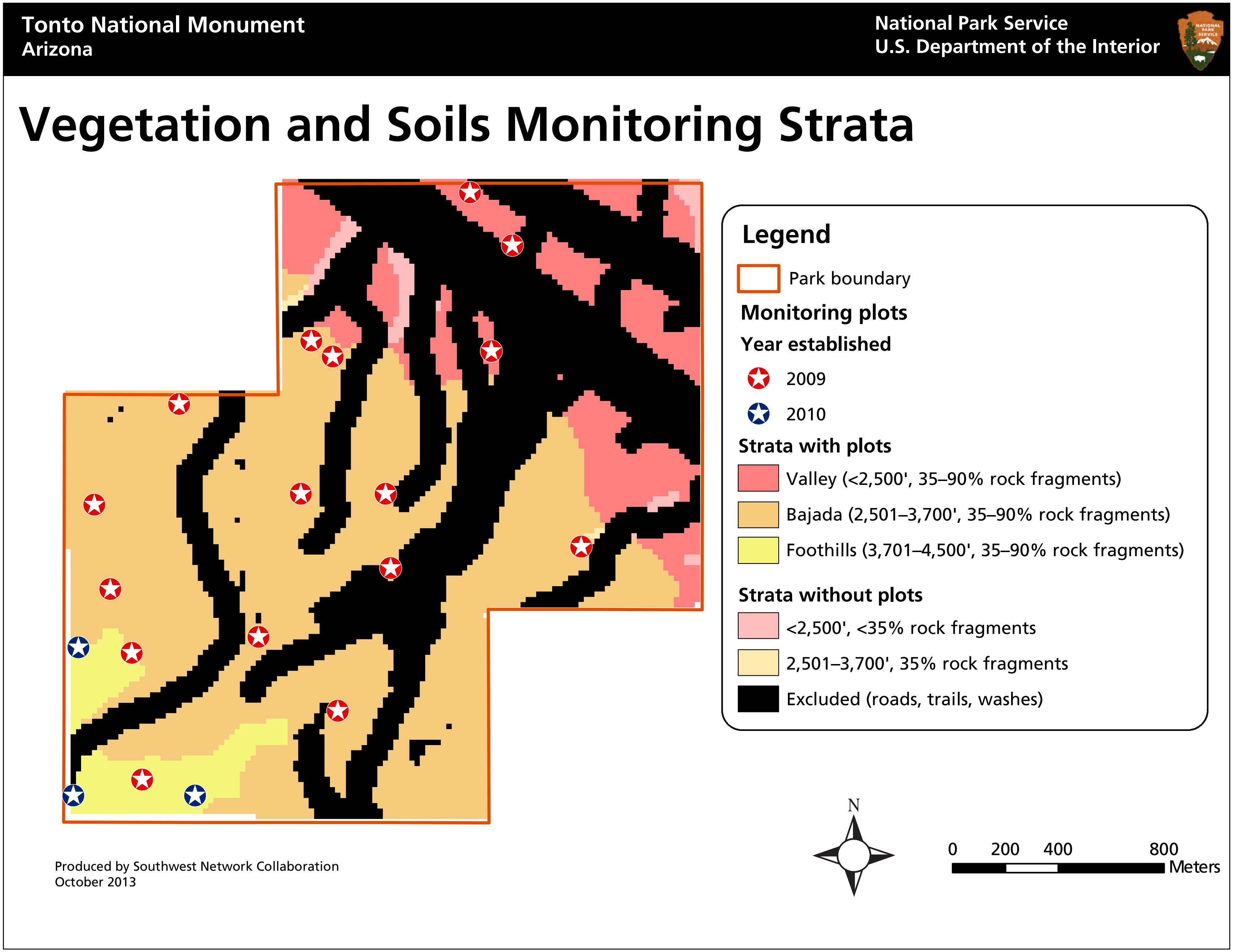

Figure 2-2. Sampling frame and allocation of monitoring plots for terrestrial vegetation and soils monitoring at Tonto National Monument.

Table 2-3. Proposed management assessment points for terrestrial vegetation and soils parameters.

Issue	Management assessment point	Stratum	Information source
Erosion hazard	Exposed bare ground cover >20%	All	Value is based on professional judgment of authors; modified from Las Cienegas National Conservation Area Management Plan (2003, as cited in Gori and Schussman 2005).
	Surface soil aggregate stability (with no overhead vegetation) <Class 3	All	Value is based on professional judgment of authors; issue is described in Herrick and others (2005).
	Biological soil crust cover < 10% of available habitat	Bajada	Value is based on professional judgment of authors.
Site resilience	Foliar cover of dead perennial plants > 15% (field)	All	Value is based on professional judgment of authors.
	Foliar cover of dead perennial plants > 15% (subcanopy)	All	Value is based on professional judgment of authors.
	Tree + shrub cover > 50% (subcanopy)	Foothills	Value is based on professional judgment of authors.
Saguaro cacti extent	Extent of saguaro cacti < 5%	Bajada	Value is based on professional judgment of authors.
Saguaro cacti recruitment	Cover of nurse plants (trees and shrubs in subcanopy) <15%	Bajada	Value is based on professional judgment of authors.
Exotic plant dispersal	Extent of invasive exotic plants >50%	All	Professional judgment of authors; see SODN monitoring plan (NPS 2005) for an overview of the issue.
Exotic plant invasion	Total cover of exotic plants >10% (field)	All	Professional judgment of authors; see SODN monitoring plan (NPS 2005) for an overview of the issue.
	Exotic plant cover: total plant cover > 1:4 (0.25)	All	Professional judgment of authors; see SODN monitoring plan (NPS 2005) for an overview of the issue.
Fire hazard	Grasses + forbs >30% (field)	Bajada	Value is based on professional judgment of authors.
	Annual plant cover: total plant cover >1:4 (0.25)	Foothills	Value is based on professional judgment of authors.
	Litter + duff > 75%	Foothills	Value is based on professional judgment of authors.

2.2.5 Statistical power to distinguish status from management assessment points

Estimating our statistical power to distinguish current conditions (i.e., status) from management assessment points (see previous section) is important for both protocol design (especially determining adequate sample sizes) and data interpretation. Adequate sample size (number of plots) is estimated by Herrick and others (2005b):

$$n = \frac{(S)^2 (Z_\alpha + Z_\beta)^2}{(MDC)^2}$$

Where:

- S = standard deviation of the sample,
- Z_α = Z-coefficient for false change (Type I) error (we set at 90%),
- Z_β = Z-coefficient for missed-change (Type II) error (we set at 10%), and

MDC = minimum detectable change size between time 1 and time 2 (set at 5–20%).

Bonham (1989), Elzinga and others (1998), and Herrick and others (2005a) provide detailed discussions of statistical power to detect differences from a standard.

2.2.5 Statistical power to detect trends

Statistical power is also important for evaluating trends (change over time) in monitoring parameters. Adequate sample size (number of plots) for detecting a trend of a given size across a landscape with permanent plots is estimated from:

$$n = \frac{(S_{diff})^2 (Z_\alpha + Z_\beta)^2}{(MDC)^2}$$

Where:

- S_{diff} = Standard deviation of the differences between paired samples,
- Z_α = Z-coefficient for false change (Type I) error (we set at 90%),
- Z_β = Z-coefficient for missed-change (Type II) error (we set at 10%), and
- *MDC* = minimum detectable change size between time 1 and time 2 (set at 5–20%).

Because we only have one sampling interval for this report, we estimated "S_{diff}" using the following equation:

$$S_{diff} = (S_1)(\sqrt{(2(1-corr_{diff}))})$$

Where:

- S_1 = Sample standard deviation among sampling units at first time period, and
- $corr_{diff}$ = estimated correlation coefficient between time 1 and time 2, set at 0.75.

Bonham (1989), Elzinga and others (1998), and Herrick and others (2005a) provide detailed discussions of statistical power to detect trend.

2.2.6 Evaluation of strata

The terrestrial vegetation monitoring design apportions long-term monitoring sites to strata to improve the efficiency of parkwide estimation of monitoring parameters of interest. This stratification is based on the assumption that vegetation and dynamic soil functional attributes respond differently to environmental factors that can be clearly defined and are immutable over management and monitoring timescales (Bonham 1989).

To evaluate the efficiency and pertinence of our preselected elevation strata, we contrasted the similarity of the vegetation communities on each stratum using permutational multivariate analysis of variance analysis (PERMANOVA+) on Bray-Curtis similarity values for vegetation cover, non-metric multidimensional scaling (MDS), and similarity percentages (SIMPER). These nonparametric multivariate community analysis techniques make few assumptions about the data, yielding a simple yet powerful analysis tool (Clarke and Warwick 2001; Anderson et al. 2008).

3 Results

3.1 Parkwide summaries of selected information

3.1.1 Cover and frequency of exotic species

Parkwide, three exotic grass species were found on line-point transects: red brome (*Bromus rubens*), wild oat (*Avena fatua*), and Lehmann lovegrass (*Eragrostis lehmanniana*) (Figure 3-1). None of these species had foliar cover of >3%, although red brome was one of the most widespread plants found in the park (14 of 19 plots) (Table 3-1). These species were present at Tonto NM during the 1999–2001 (Halvorson and Guertin 2003) and 2005 (Studd et al. 2011) exotic plant surveys.

Two additional exotic species were detected only in the frequency subplots: the forb, marsh parsley (*Cyclospermum leptophyllum*), and the grass, redtop (*Agrostis gigantea*) (Figure 3-1). A total of 15 plots had exotic species, 14 of which had red brome (Table 3-1, Figure 3-2).

3.1.2 Soil and site characterization

All surface soil samples were loams (sandy loam, silt loam, or loam), and were rocky (35–90% surface soil rock fragments), with at least 36% rock fragments (fraction of soil sample >2 mm in diameter by mass). This information is congruent with the park-specific soil survey and suggests that the stratification based on rock-fragment content was accurate. The sites tended to have low organic contents (<3% total organic carbon). Bulk density ranged from 0.6 to 1.2 grams/cm^3. Plot-specific information for the soil characterization is provided in Appendix A, Table A-1.

Fremont's barberry (*Berberis fremontii*).

Sixteen of 19 sites exhibited evidence of active soil erosion. Fourteen sites had relatively minor (1–5%) burrowing, while two sites had more extensive burrowing (6–25%). Signs of tunneling were rare, occurring on a single site. Five sites had rills present, while four sites (including three of the sites with rills) had well-developed gullies. Only two sites showed modest amounts (1–5%) of sheet erosion. Plot 302_V04 had the most evidence of erosion among the 19 plots sampled. Plot-specific information for the site characterization is given in Appendix A, Table A-1. Photographs of the plots are presented in Appendix B.

3.1.3 New species

Our 2009–2010 monitoring detected one new plant species that had not been previously documented at Tonto NM. The evergreen shrub, Fremont's barberry (*Berberis fremontii*) (inset) was detected on plot 302_V02.

Figure 3-1. Photographs of (clockwise from top left): redtop (*Agrostis gigantea*), red brome (*Bromus rubens*), marsh parsley (*Cyclospermum leptophyllum*), Lehmann lovegrass (*Eragrostis lehmanniana*), and wild oat (*Avena fatua*).

Table 3-1. Frequency and cover (average and SE%) of non-native plants sampled at Tonto National Monument, 2009–2010.

Scientific name	Common name	Extent (%)	Parkwide cover (%)	Within-plot frequency (%) by stratum			Within-plot cover (%) by stratum			Present during previous survey(s)	
				Valley	Bajada	Foothills	Valley	Bajada	Foothills	1999–2001[a]	2005[b]
Forb/Herb											
Cyclospermum leptophyllum	marsh parsley	5%	---	---	---	4% (± 4)			---	Unknown (non-target species)	Unknown (non-target species)
Agrostis gigantea	redtop	5%	---	---	---	4% (± 4)			---	Unknown (non-target species)	Unknown (non-target species)
Avena fatua	wild oat	16%	0.8% (± 0.5)	13% (± 13)	15% (± 10)	---	0.1% (± 0.1)	1.3% (± 0.9)	---	Yes	Yes
Bromus rubens	red brome	74%	2.3% (± 0.7)	67% (± 33)	47% (± 13)	60% (± 14)	0.6% (± 0.3)	2.4% (± 1.0)	3% (± 1.4)	Yes	Yes
Eragrostis lehmanniana	Lehmann lovegrass	11%	0.3% (± 0.3)	---	4% (± 4)	20% (± 20)	---	0.1% (± 0.1)	1.1% (± 1.1)	Yes	Yes

[a] Halvorson and Guertin (2003)

[b] Studd and others (2011)

Strata: Valley = <2,500'; Bajada = 2,501–3,700'; Foothills = 3,701–4,500'

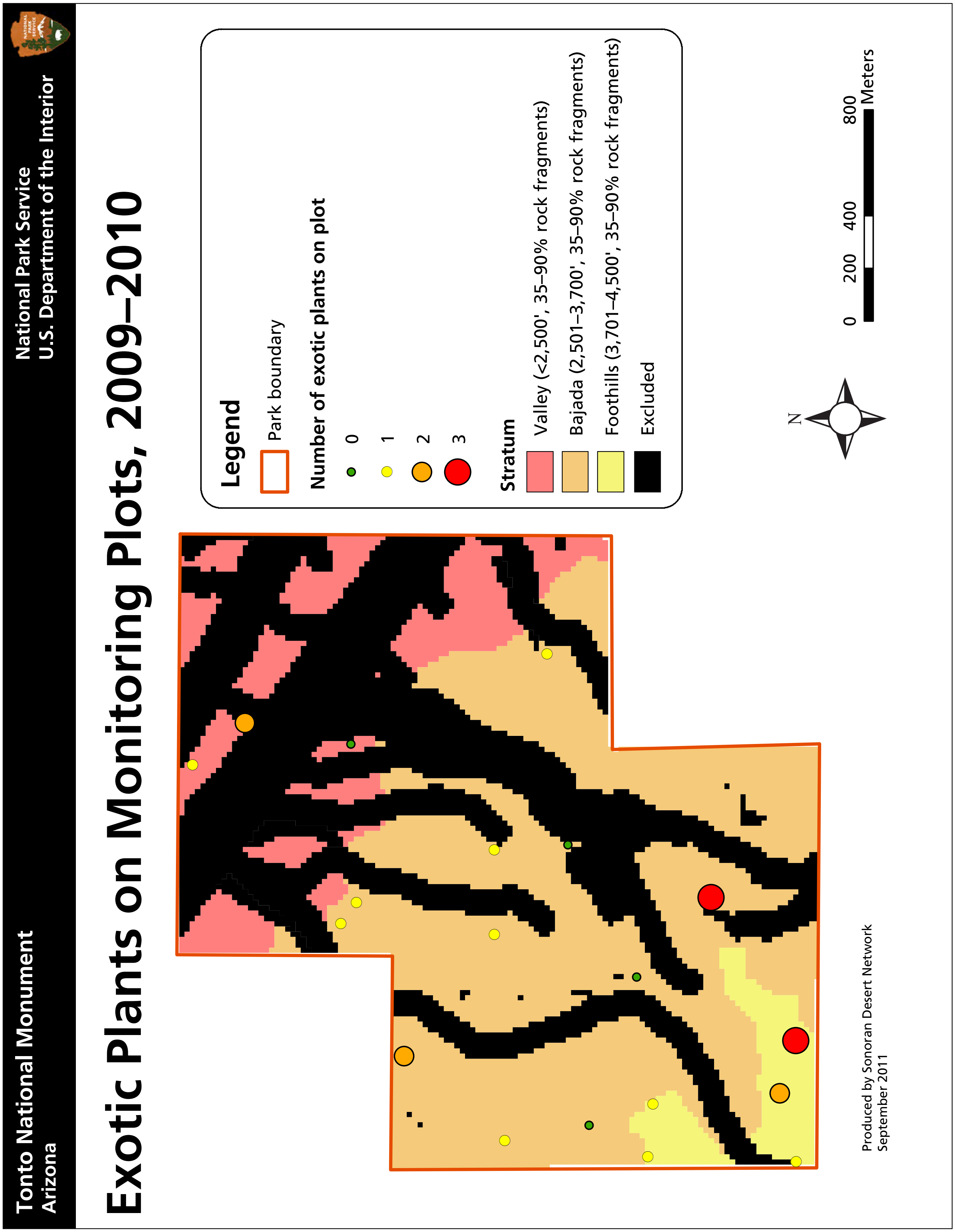

Figure 3-2. Number of exotic plant species detected per monitoring plot, Tonto National Monument, 2009–2010.

3.2 Valley stratum

Comprising about 17% of the terrestrial uplands of Tonto NM, the valley stratum (<2,501' elevation, 35–90% surface soil rock fragments, aka stratum 102) occurs in the northern and northeastern sections of the monument (Figure 3-3). This stratum is found extensively throughout desert ecosystems of the American Southwest, including Casa Grande Ruins NM, Montezuma Castle NM (Well unit), Organ Pipe Cactus NM, and Saguaro NP (Tucson Mountain District) in the Sonoran Desert, and at Big Bend NP in the Chihuahuan Desert (Hubbard et al. 2012).

3.2.1 Vegetation formations and lifeforms

Two of the three plots sampled were wooded shrublands, and the other (102_V02) was a shrubland (Figure 3-3). The former were characterized by a sparse canopy of short-statured trees over a matrix of low-growing shrubs and subshrubs, with a diffuse field layer of annual grasses and forbs. Trees were nearly absent on plot 102_V02. For all plots, succulents and perennial grasses and forbs and were absent and annual forbs and grasses were sparse.

Lifeform cover was comparable between field and subcanopy heights. Canopy cover was only about one-seventh that of either the field or subcanopy heights, reflecting the generally short-statured nature of the lifeforms encountered (Figure 3-4). See Appendix A, Table A-2 for plot-specific information.

3.2.2 Cover and extent of perennial plant species

Valley monitoring sites were co-dominated by the subshrub, turpentine bush (*Ericameria laricifolia*), and the shrub, jojoba (*Simmondsia chinensis*) (Table 3-2), although cover of the former varied widely between the monitoring sites (see Appendix A, Table A-2). Tree cover was dominated by yellow paloverde (*Parkinsonia microphylla*), with small contributions from catclaw acacia (*Acacia greggi*) and velvet mesquite (*Prosopis velutina*).

The most widespread species on valley sites were the trees, yellow paloverde and velvet mesquite, and the shrub, jojoba, each of which was found on every monitoring plot (Table 3-2). Also common were the tree, catclaw acacia, the shrubs, Fremont's desert thorn (*Lycium fremontii*) and turpentine bush, and the non-native annual grass, red brome, which were encountered at two of the three monitoring plots (Table 3-2). See Appendix A, Table A-2 for plot-specific information.

3.2.3 Frequency and extent of uncommon plant species

An additional 10 perennial species were detected only on frequency subplots of valley sites (Table 3-3). All of the species were native forbs, grasses, subshrubs, or succulents, and none was found on more than one monitoring site. See Appendix A, Table A-3 for plot-specific information.

3.2.4 Cover and frequency of exotic species

Two invasive exotic species were found on valley monitoring plots: the annual grasses, red brome and wild oat, each with foliar cover of <1% in the field layer (see Table 3-2). Red brome was found on two valley monitoring plots, while wild oat was found on one valley monitoring plot. No additional exotic species were detected on the frequency subplots (see Table 3-3).

3.2.5 Soil cover and biological soil crusts

Nearly half of the soil cover along the line-point intercept transects consisted of gravels (2–75-mm rock fragments), with leaf litter and bare soil (no overhead vegetation cover) also common (Table 3-4). Rocks (76–600 mm fragments) and bare soil under vegetation were not uncommon. Bedrock and duff (partially decomposed organic matter) were absent.

Along the transects, total biological crust cover on valley plots was only 4.2% (± 5.5%), with light cyanobacteria (2.5% ± 1.9%) comprising the bulk of the cover (Table 3-4). Mosses (0.8% ± 0.6%), dark cyanobacteria (0.7% ± 0.7%), and lichens (0.1% ± 0.1%) were minor constituents on the transects on valley plots (Table 3-4).

In contrast, bryophytes (mosses and liverworts) dominated the biological soil crust cover within the point-quadrats (Table 3-5). Bryophytes covered 6.0% (± 2.5%) of the total soil in the point-quadrats and 8.1% (± 4.0%) of the total habitat available to biological soil crusts (available habitat excludes areas covered by duff, rock, bedrock, embedded litter, and vegetation). Within the point-quadrats, lichen and cyanobacteria cover were sparse. However, three lichen growth forms (crustose, gelatinous, and squamulose) were detected on the valley plots (Table 3-5). See Appendix A, Tables A-4, A-5, and A-6 for plot-specific information.

3.2.6 Soil stability

Overall, average stability of surface soil aggregates was 4.27 (± 0.12) (out of a possible 6), or "moderately stable." Stability tended to be higher under vegetation (5.30 ± 0.23; "stable") than in areas lacking vegetative cover (3.57 ± 0.28; "moderately stable"). See Appendix A, Table A-4 for plot-specific information.

3.2.7 Management assessment points

Only one parameter crossed an assessment-point threshold: the extent of exotic plants, which were found on two of the three valley monitoring plots (Table 3-6). Within the stratum and at individual plots, most indicators did not approach the management assessment point. However, plot 102_V02 had over 18% bare soil that was not protected by vegetation, suggesting a potential site-specific erosion issue. See Appendix A, Table A-7 for plot-specific information.

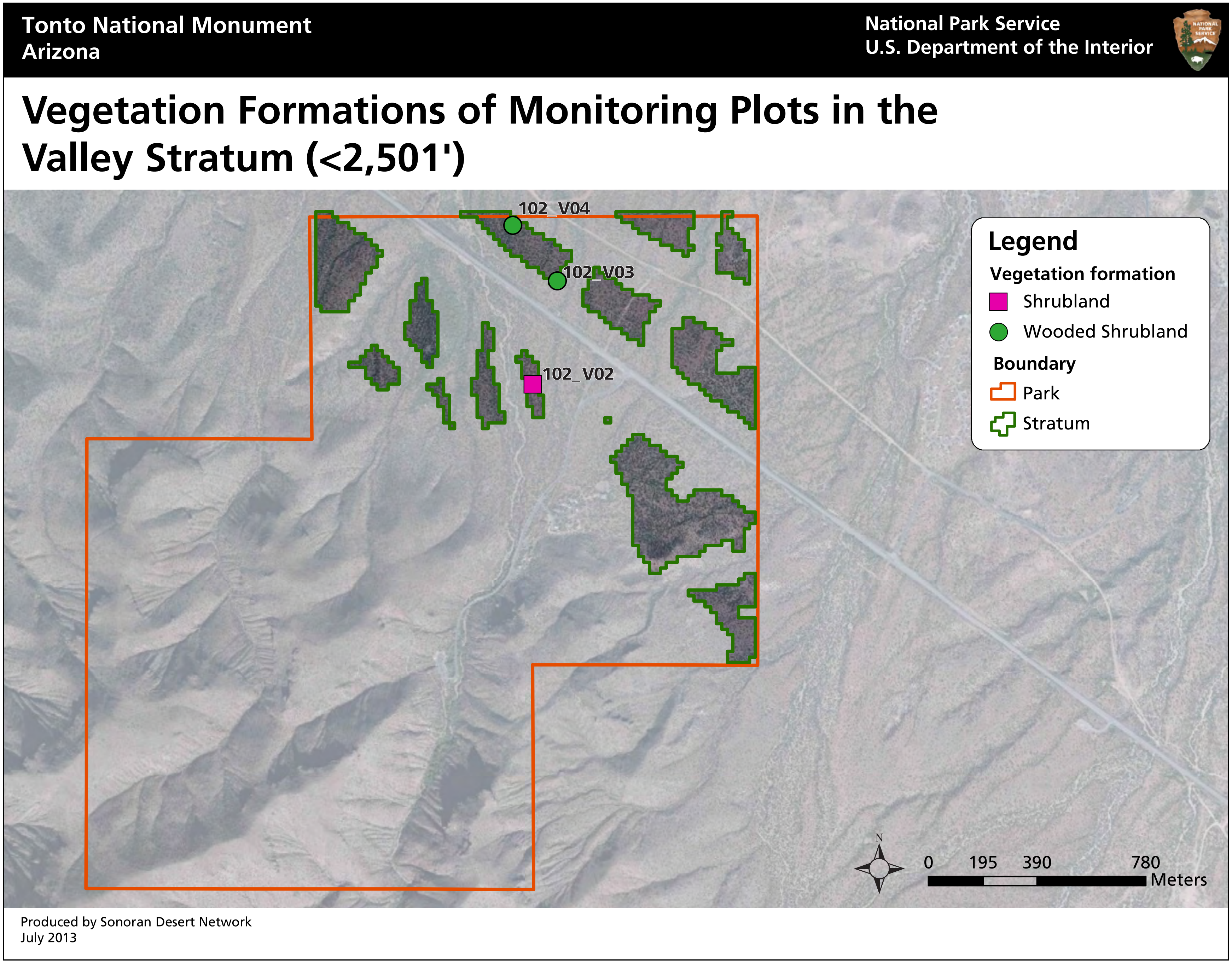

Figure 3-3. Location of monitoring plots within the valley stratum, Tonto National Monument, sampled in 2009.

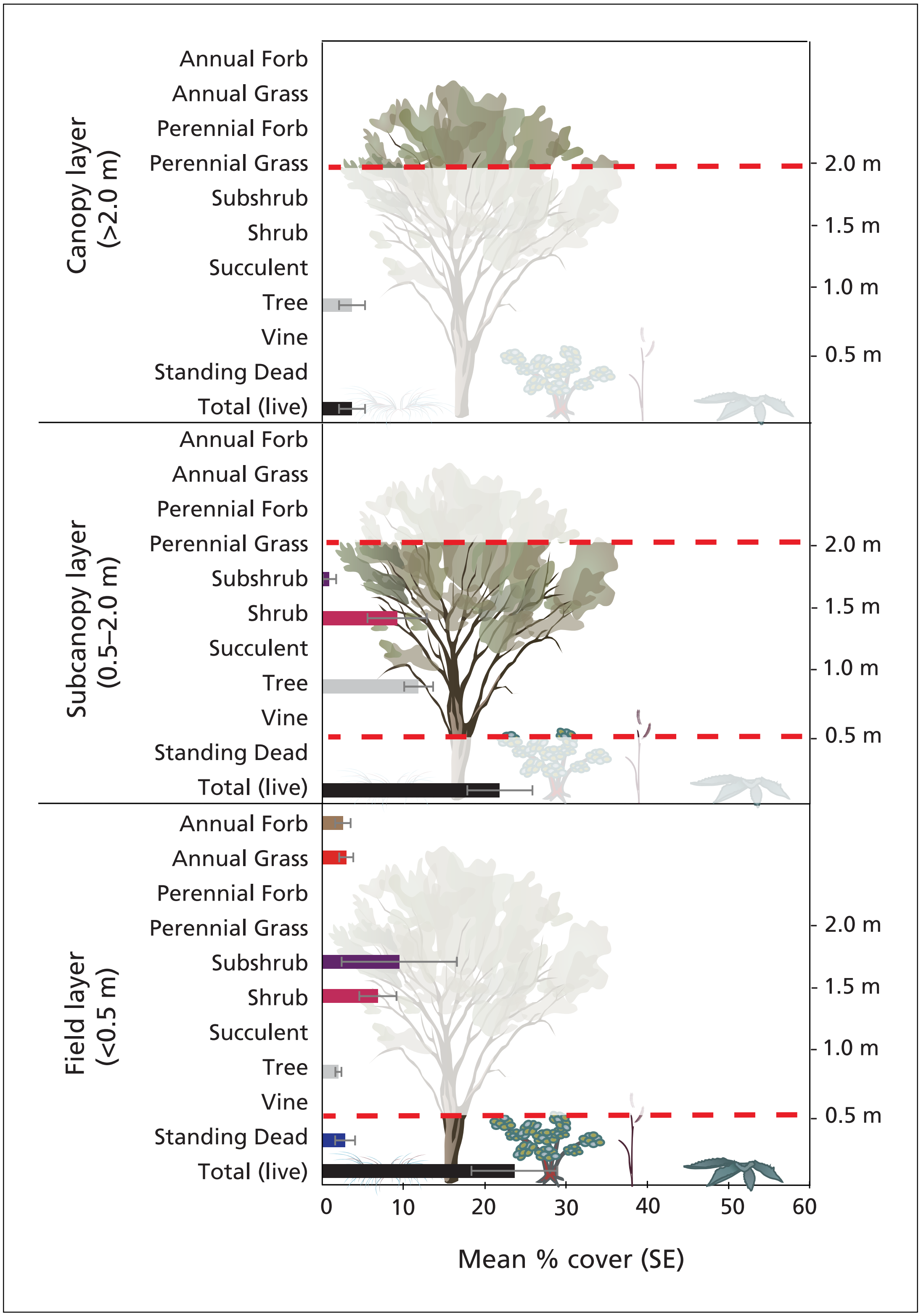

Figure 3-4. Lifeform cover in terrestrial vegetation monitoring plots in the valley stratum, Tonto National Monument, 2009.

Table 3-2. Vegetation cover values (%) measured in the field, subcanopy, and canopy layers of valley monitoring sites, Tonto National Monument, 2009.

Scientific name	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Graminoid													
Avena fatua	**wild oat**	**0.1%**	**0.1%**	**5%**	**1**	**---**	**---**	**5%**	**---**	**---**	**---**	**5%**	**---**
Bromus rubens	**red brome**	**0.6%**	**0.3%**	**5%**	**2**	**---**	**---**	**5%**	**---**	**---**	**---**	**5%**	**---**
Subshrubs													
Ericameria laricifolia	turpentine bush	8.9%	7.3%	16%	2	0.8%	0.8%	5%	1	---	---	5%	---
Eriogonum fasciculatum	Eastern Mojave buckwheat	0.3%	0.3%	5%	1	---	---	5%	---	---	---	5%	---
Gutierrezia microcephala	threadleaf snakeweed	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Krameria grayi	white ratany	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Shrub													
Celtis pallida	spiny hackberry	---	---	5%	---	0.3%	0.3%	5%	1	---	---	5%	---
Lycium fremontii	Fremont's desert-thorn	0.4%	0.2%	5%	2	0.8%	0.4%	5%	2	---	---	5%	---
Simmondsia chinensis	jojoba	6.3%	2.5%	6%	3	8.1%	3.3%	7%	3	---	---	5%	---
Ziziphus obtusifolia	lotebush	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Tree													
Acacia greggii	catclaw acacia	0.6%	0.4%	5%	2	1.9%	1.7%	5%	2	---	---	5%	---
Parkinsonia microphylla	yellow paloverde	1.1%	0.4%	5%	3	8.6%	2.2%	5%	3	3.33%	1.7%	5%	2
Prosopis velutina	velvet mesquite	0.3%	0.1%	5%	2	1.3%	0.4%	5%	3	0.28%	0.1%	5%	2
Vegetation type													
Annual forb		2.5%	1.0%	5%	3	---	---	5%	---	---	---	5%	---
Annual grass		2.9%	0.9%	5%	3	---	---	5%	---	---	---	5%	---
Perennial forb		---	---	5%	---	---	---	5%	---	---	---	5%	---
Perennial grass		---	---	5%	---	---	---	5%	---	---	---	5%	---
Subshrub		9.4%	7.1%	15%	2	0.8%	0.8%	5%	1	---	---	5%	---
Shrub		6.8%	2.3%	5%	3	9.2%	3.6%	8%	3	---	---	5%	---
Succulent		---	---	5%	---	---	---	5%	---	---	---	5%	---
Tree		1.9%	0.4%	5%	3	11.8%	1.8%	5%	3	3.61%	1.6%	5%	3
Snag		2.8%	1.2%	5%	3	---	---	5%	---	---	---	5%	---
Vine		---	---	5%	---	---	---	5%	---	---	---	5%	---
Total (live)		23.6%	5.3%	11%	3	21.8%	4.0%	9%	3	3.61%	1.6%	5%	3
Exotics		0.7%	0.4%	5%	2	---	---	5%	---	---	---	5%	---
Annuals		5.4%	0.2%	5%	3	---	---	5%	---	---	---	5%	---

Field layer = 0.5 m; subcanopy = 0.5–2.0 m; canopy = >2.0 m. Valley stratum = <2,501′, 35–90% rock fragments in surface soils. "MDC" = minimum detectable change (% cover). "Extent" = number of plots species was detected (out of 3). Exotic species are bold, annuals are shaded. Highlighted variables did not meet our statistical power criteria.

Table 3-3. Within-plot frequency and extent of uncommon perennial species encountered only on subplots of valley monitoring plots at Tonto National Monument, 2009.

Scientific name	Common name	Lifeform	Within-plot frequency (5 subplots)		Extent (3 plots)
			Mean (%)	SE (%)	
Croton texensis	Texas croton	Forb/Herb	7%	6.7%	1
Ipomoea sp.	morning glory	Forb/Herb	7%	6.7%	1
Parkinsonia floridana	blue paloverde	Forb/Herb	7%	6.7%	1
Aristida purpurea	purple threeawn	Graminoid	13%	13.3%	1
Aristida ternipes	spidergrass	Graminoid	7%	6.7%	1
Bebbia juncea	sweetbush	Subshrub	13%	13.3%	1
Eriogonum wrightii	bastardsage	Subshrub	7%	6.7%	1
Porophyllum gracile	slender poreleaf	Subshrub	7%	6.7%	1
Sphaeralcea sp.	globemallow	Subshrub	13%	13.3%	1
Cylindropuntia acanthocarpa	buckhorn cholla	Succulent	27%	26.7%	1
Ferocactus wislizeni	candy barrelcactus	Succulent	13%	13.3%	1
Opuntia bigelovii	teddybear cholla	Succulent	13%	13.3%	1

Valley stratum = <2,501′, 35–90% rock fragments in surface soils.

Table 3-4. Soil cover on transects, valley monitoring plots, Tonto National Monument, 2009.

Decreasing erosion hazard ↓

Substrate	AVG	SE	MDC	n=
Bare soil (<2 mm): no overhead cover	11.1%	4.6%	10%	3
Bare soil (<2 mm): under vegetation	6.9%	0.5%	5%	1
Total bare soil	18.1%	5.1%	11%	3
Light cyanobacteria: no overhead cover	1.7%	1.3%	5%	1
Light cyanobacteria: under vegetation	0.8%	0.6%	5%	1
Total light cyanobacteria	2.5%	1.9%	5%	2
Litter	27.1%	4.2%	9%	3
Dark cyanobacteria	0.7%	0.7%	5%	1
Gravel (2–75 mm)	42.5%	4.8%	10%	3
Duff	---	---	5%	---
Lichen	0.1%	0.1%	5%	1
Moss	0.8%	0.6%	5%	1
Rock (76–600 mm)	7.6%	2.8%	6%	3
Plant base	0.6%	0.3%	5%	1
Bedrock	---	---	5%	---

Valley stratum = <2,501′, 35–90% rock fragments in surface soils.
"MDC" = mean detectable change with the specified sampling intensity ("n").
Highlighted variables did not meet our statistical power criteria..
Values are rounded.

Table 3-5. Biological soil crust cover measured by point-quadrats, valley monitoring plots, Tonto National Monument, 2009.

Morphological group	Growth form	Absolute cover				Cover in available habitat				Extent
		AVG	SE	MDC	n=	AVG	SE	MDC	n=	
Lichen	Crustose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	1
	Gelatinous lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	2
	Foliose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	0
	Fruticose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	0
	Squamulose lichen	0.1%	0.1%	5%	1	0.1%	0.1%	5%	1	3
	Total lichen	0.1%	0.1%	5%	1	0.1%	0.1%	5%	1	3
Light cyanobacteria soil crust		0.1%	0.1%	5%	1	0.1%	0.1%	5%	1	1
Dark cyanobacteria soil crust		0.1%	0.1%	5%	1	0.2%	0.2%	5%	1	2
Bryophyte-dominated soil crust		6.0%	2.5%	6%	3	8.1%	4.0%	9%	3	3
Total biological soil crust cover		**6.4%**	**2.6%**	**6%**	**3**	**8.6%**	**4.1%**	**9%**	**3**	**3**

Valley stratum = <2,501′, 35–90% rock fragments in surface soils.
"Extent" = number of plots class was detected (out of 3).
"MDC" = mean detectable change with the specified sampling intensity ("n").
"n" = number of plots required to meet statistical power criteria. All variables met our statistical power criteria.
Available habitat excludes areas covered by duff, rock, bedrock, embedded litter, and vegetation.

Table 3-6. Terrestrial vegetation and soils monitoring data in the context of proposed management assessment points, valley monitoring sites, Tonto National Monument, 2009.

Issue	Management assessment point	Mean (± SE)	Recommendation
Erosion hazard	Exposed bare ground cover >20%	11.1% (± 4.6%)	Continue monitoring
	Surface soil aggregate stability (with no overhead vegetation) < Class 3	3.57 (± 0.28)	Continue monitoring
Site resilience	Foliar cover of perennial dead plants > 15% (field)	2.8% (± 1.2%)	Continue monitoring
	Foliar cover of perennial dead plants > 15% (subcanopy)	---	Continue monitoring
Exotic plant dispersal	Extent of invasive exotic plants >50%	67%	Meet and consider
Exotic plant invasion	Total cover of exotic plants >10% (field)	0.7% (± 0.4%)	Continue monitoring
	Exotic plant cover: total plant cover > 1:4 (0.25)	0.03	Continue monitoring

Valley stratum = <2,501′, 35–90% rock fragments in surface soils.
Red entries fell outside the range of the assessment point.

3.3 Bajada stratum

Comprising about 72% of the terrestrial uplands of Tonto NM, the bajada (2,501–3,700' elevation, 35–90% surface soil rock fragments, aka stratum 202) is the most widely distributed stratum within the monument, including the vicinity of the visitor center and Lower Cliff Dwellings (Figure 3-5). This stratum is one of the most common in the American Southwest, and is also found at Montezuma Castle NM (Castle unit), Organ Pipe Cactus NM, and Saguaro NP (Rincon and Tucson mountain districts) in the Sonoran Desert, and at Big Bend NP in the Chihuahuan Desert (Hubbard et al. 2012). The term "bajada" refers to the outwash from multiple mountain stream channels (alluvial fans) that merge to form a slope along the mountain front (Nations and Stump 1996).

3.3.1 Vegetation formations and lifeforms

Six of the eleven plots were wooded shrublands. Four others were shrublands, and one (202_V16) was a shrub savanna (Figure 3-5). Wooded shrublands were characterized by a sparse canopy of short-statured trees over a matrix of low-growing shrubs and subshrubs, with a diffuse field layer of grasses and forbs. By contrast, very few mature trees were detected on shrublands, and the shrub savanna consisted of occasional large shrubs in a mat of annual and perennial grasses and annual forbs (Figure 3-6).

Unlike the valley monitoring sites, bajada sites contained all major lifeforms (Figure 3-6). Diversity of lifeforms was highest in the field layer, where overall vegetative cover was about twice that of the subcanopy, and approximately 20 times that of the canopy. This reflects the generally short-statured nature of the lifeforms encountered (Figure 3-6). See Appendix A, Table A-8 for plot-specific information.

3.3.2 Cover and extent of perennial plant species

Bajada monitoring sites were dominated by the shrub, jojoba, in the field and subcanopy layers (Table 3-7). The tree, yellow paloverde, was the primary subdominant, and common associates included the exotic annual grass, red brome; the fern ally, Arizona spikemoss (*Selaginella arizonica*); the shrub, button brittlebush (*Encelia frutescens*); and the subshrubs, globemallow (*Sphaeralcea* sp.), brittlebush (*Encelia farinosa*), bastardsage (*Eriogonum wrightii*), Eastern Mojave buckwheat (*Eriogonum fasciculatum*), and threadleaf snakeweed (*Gutierrezia microcephala*) (Table 3-7). The extremely sparse canopy was composed of the trees, yellow paloverde, velvet mesquite, and redberry juniper (*Juniperus coahuilensis*)—all at <1% foliar cover—and the large succulents, saguaro (*Carnegiea gigantea*) and ocotillo (*Fouquieria splendens*) (Table 3-7).

Jojoba was found on every bajada monitoring site (Table 3-7). Other widespread species included globemallow, yellow paloverde, Eastern Mojave buckwheat, button brittlebush, and the succulent, cactus apple (*Opuntia engelmannii*). See Appendix A, Table A-8 for plot-specific information.

3.3.3 Frequency and extent of uncommon plant species

An additional 22 uncommon species were detected in the frequency subplots of bajada sites (Table 3-8). Only five uncommon species had within-plot frequencies above 10%: the forbs, brownfoot (*Acourtia wrightii*) and sandmat (*Chamaesyce* sp.); and the cacti, Graham's nipple cactus (*Mammillaria grahamii*), pinkflower hedgehog cactus (*Echinocereus fendleri*), and candy barrelcactus (*Ferocactus wislizeni*) (Table 3-8). All three cacti were also the most extensively distributed uncommon species in the stratum, found at more than half of the bajada monitoring sites (Table 3-8). See Appendix A, Table A-3 for plot-specific information.

3.3.4 Cover and frequency of exotic species

The non-native annual grass, red brome, was among the most abundant (2.4% ± 1.0%) and widely distributed (6 of 11 sites) species in the field layer of bajada monitoring sites (see Table 3-7). In addition, two other non-native species—the annual grass, wild oat (1.3% ± 0.9%), and the perennial grass, Lehmann lovegrass (0.1% ± 0.1%)—were detected on the line-point intercept transects of bajada monitoring sites (see Table 3-7, Figure 3-5). No additional exotic species were detected on frequency subplots located on bajada monitoring sites (see Table 3-8).

3.3.5 Soil cover and biological soil crusts

Leaf litter and gravels co-dominated the surface soil cover of bajada sites (Table 3-9), with other erosion-resistant substrates, such as rock and, to a lesser extent, bedrock and plant stems also common. The cover of bare soil was comparable under vegetation versus out in the open. Duff was absent from bajada plots (Table 3-9).

Along the line-point intercept transects, biological soil crusts accounted for 8.7% (± 3.0%) of the soil cover. Surprisingly for a semi-arid ecosystem, mosses dominated the crust community and comprised more than 7% of the soil cover of bajada plots (Table 3-9), whereas lichens and light and dark cyanobacteria were minor components.

Total crust cover (8.4% ± 1.6%) and dominance of bryophytes, including mosses, was similar within the point-quadrats (Table 3-10). Within the bajada sites, biological soil crusts covered over 15% of the available habitat within the point-quadrats. Within the point-quadrats, lichen and cyanobacteria cover were relatively sparse (Table 3-10) but were higher than on the valley plots (see Table 3-5). In addition, four lichen growth forms (crustose, gelatinous, foliose, and squamulose) were detected on the bajada plots (Table 3-10), indicating a diverse biological soil crust community. See Appendix A, Tables A-4, A-5, and A-6 for plot-specific information.

3.3.6 Soil stability

Overall, average stability of surface soil aggregates was 4.60 (± 0.13) (out of a possible 6), or "stable." Stability tended to be somewhat higher under vegetation (4.78 ± 0.15; "stable") than in areas lacking vegetative cover (4.37 ± 0.15; "moderately stable"). See Appendix A, Table A-4 for plot-specific information.

3.3.7 Management assessment points

Only one parameter crossed an assessment-point threshold: the extent of exotic plants, which were found on six of the eleven bajada monitoring plots (Table 3-11). Within the stratum and at individual plots, most indicators did not approach the management assessment point. Exceptions included plot 202_V05, which had >10% total cover of exotic plants in the field layer and a relative cover of exotic plants of 0.35. In addition, less than 10% of the habitat available to biological soil crusts was covered by crusts at plot 202_V05. Plots 202_V08 and 202_V16 also did not meet the management assessment point for biological soil crusts. At plot 202_V16, the cover of grasses and forbs was nearly 30%, indicating potential fire hazard. See Appendix A, Table A-9 for plot-specific results in the context of management assessment points.

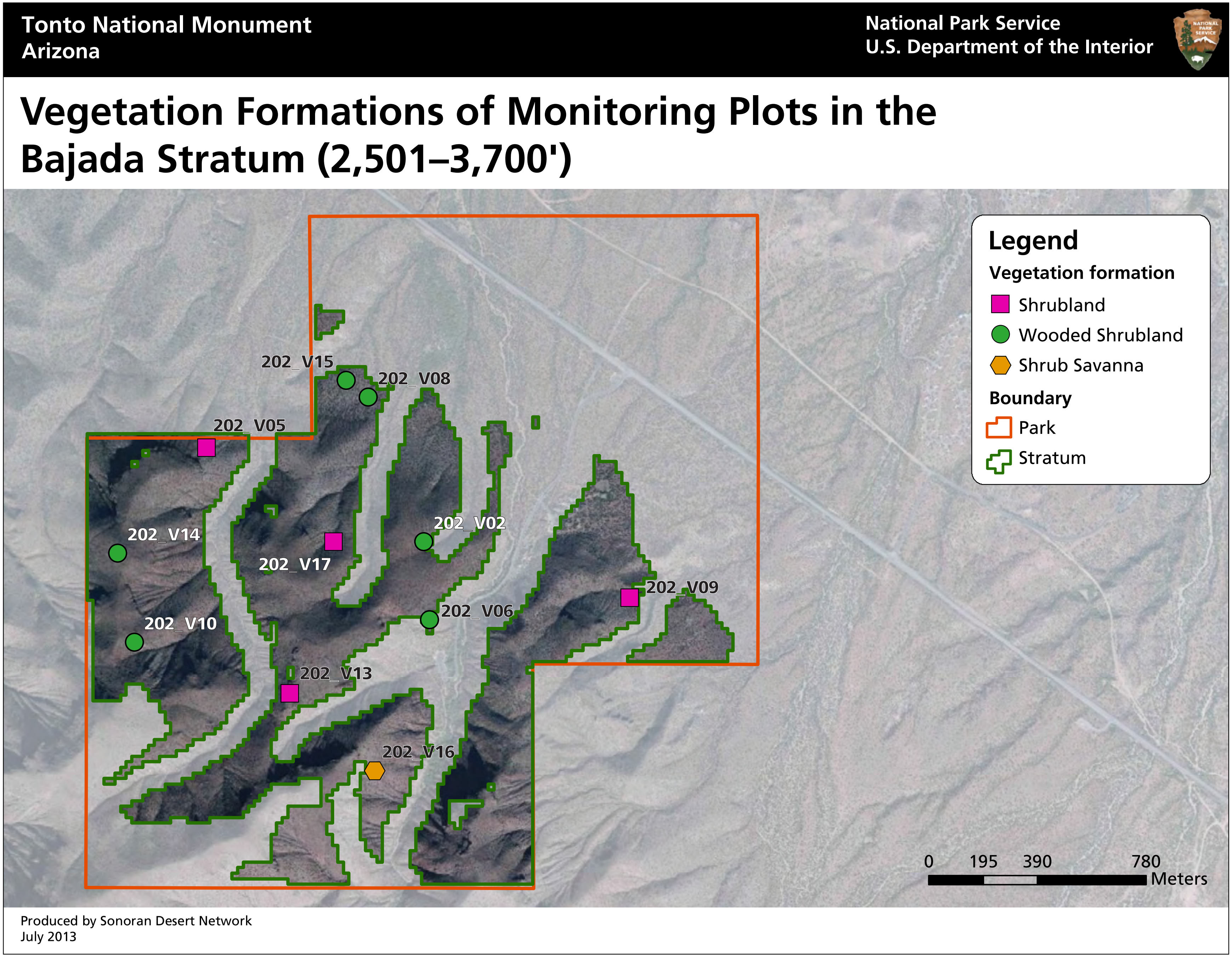

Figure 3-5. Location of monitoring plots within the bajada stratum, Tonto National Monument, sampled in 2009.

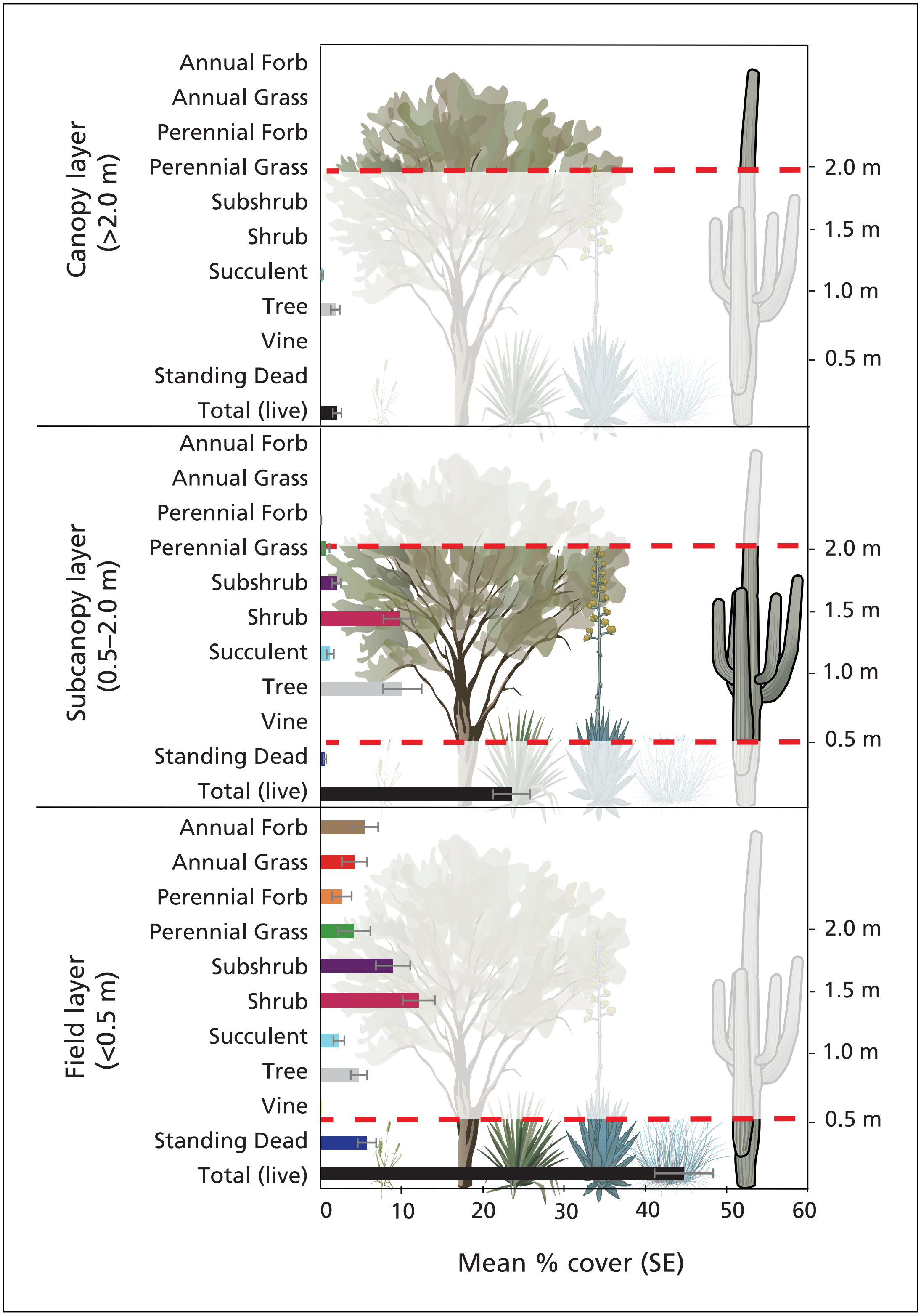

Figure 3-6. Lifeform cover in terrestrial vegetation monitoring plots in the bajada stratum, Tonto National Monument, 2009.

Table 3-7. Vegetation cover values (%) measured in the field, subcanopy, and canopy layers of bajada monitoring sites, Tonto National Monument, 2009.

Scientific name	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Forb/Herb													
Ambrosia confertiflora	weakleaf bur ragweed	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Astrolepis cochisensis	Cochise scaly cloakfern	0.1%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Cheilanthes fendleri	Fendler's lipfern	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Dudleya collomiae	Gila County liveforever	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Gaillardia arizonica	Arizona blanketflower	0.0%	0.0%	5%	1	0.04%	0.04%	5%	1	---	---	5%	---
Selaginella arizonica	Arizona spikemoss	2.3%	1.2%	5%	4	---	---	5%	---	---	---	5%	---
Graminoid													
Achnatherum speciosum	desert needlegrass	0.4%	0.2%	5%	4	0.3%	0.2%	5%	3	---	---	5%	---
Aristida purpurea	purple threeawn	1.3%	0.7%	5%	6	0.2%	0.2%	5%	1	---	---	5%	---
Aristida ternipes	spidergrass	0.2%	0.2%	5%	1	---	---	5%	---	---	---	5%	---
Avena fatua	**wild oat**	**1.3%**	**0.9%**	**5%**	**2**	**---**	**---**	**5%**	**---**	**---**	**---**	**5%**	**---**
Bouteloua curtipendula	sideoats grama	1.4%	1.1%	5%	3	0.2%	0.2%	5%	2	---	---	5%	---
Bromus rubens	**red brome**	**2.4%**	**1.0%**	**5%**	**6**	**---**	**---**	**5%**	**---**	**---**	**---**	**5%**	**---**
Digitaria californica	Arizona cottontop	0.2%	0.2%	5%	1	---	---	5%	---	---	---	5%	---
Eragrostis lehmanniana	**Lehmann lovegrass**	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Heteropogon contortus	tanglehead	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Muhlenbergia porteri	bush muhly	0.2%	0.1%	5%	3	0.04%	0.04%	5%	1	---	---	5%	---
Poa fendleriana	muttongrass	0.2%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Vulpia octoflora	sixweeks fescue	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Subshrub													
Adenophyllum porophylloides	San Felipe dogweed	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Encelia farinosa	brittlebush	1.6%	0.8%	5%	5	0.3%	0.2%	5%	2	---	---	5%	---
Ericameria laricifolia	turpentine bush	0.2%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Eriogonum fasciculatum	Eastern Mojave buckwheat	1.3%	0.6%	5%	7	0.1%	0.1%	5%	3	---	---	5%	---
Eriogonum wrightii	bastardsage	1.4%	1.3%	5%	2	0.2%	0.2%	5%	1	---	---	5%	---
Galium stellatum	starry bedstraw	0.1%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Gutierrezia microcephala	threadleaf snakeweed	1.4%	0.9%	5%	3	0.3%	0.2%	5%	2	---	---	5%	---
Melampodium leucanthum	Plains blackfoot	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Menodora scabra	rough menodora	0.3%	0.2%	5%	2	0.04%	0.04%	5%	1	---	---	5%	---
Phoradendron californicum	mesquite mistletoe	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Porophyllum gracile	slender poreleaf	0.3%	0.1%	5%	5	---	---	5%	---	---	---	5%	---

Table 3-7. Vegetation cover values (%) for species measured in the field, subcanopy, and canopy layers of bajada monitoring sites, Tonto National Monument, 2009, cont.

Scientific name	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Senecio lemmonii	Lemmon's ragwort	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Senna covesii	Coues' cassia	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Sphaeralcea sp.	globemallow	2.0%	0.8%	5%	8	0.9%	0.3%	5%	8	---	---	5%	---
Stephanomeria pauciflora	brownplume wirelettuce	0.2%	0.1%	5%	2	0.1%	0.1%	5%	1	---	---	5%	---
Shrub													
Aloysia wrightii	Wright's beebrush	0.1%	0.1%	5%	1	0.2%	0.2%	5%	2	---	---	5%	---
Celtis pallida	spiny hackberry	0.0%	0.0%	5%	0	0.0%	0.0%	5%	1	---	---	5%	---
Encelia frutescens	button brittlebush	2.2%	0.9%	5%	7	0.6%	0.2%	5%	6	---	---	5%	---
Keckiella antirrhinoides	snapdragon penstemon	0.0%	0.0%	5%	1	0.04%	0.04%	5%	1	---	---	5%	---
Lycium fremontii	Fremont's desert-thorn	0.5%	0.2%	5%	5	0.8%	0.4%	5%	5	---	---	5%	---
Simmondsia chinensis	jojoba	9.0%	2.0%	5%	11	7.8%	1.9%	5%	11	---	---	5%	---
Ziziphus obtusifolia	lotebush	0.2%	0.2%	5%	1	0.2%	0.2%	5%	1	---	---	5%	---
Succulent													
Agave chrysantha	goldenflower century plant	0.2%	0.1%	5%	4	---	---	5%	---	---	---	5%	---
Carnegiea gigantea	saguaro	---	---	5%	---	---	---	5%	---	0.11%	0.1%	5%	1
Cylindropuntia acanthocarpa	buckhorn cholla	0.5%	0.2%	5%	5	0.3%	0.1%	5%	4	---	---	5%	---
Dasylirion wheeleri	sotol	0.2%	0.2%	5%	2	0.2%	0.1%	5%	3	---	---	5%	---
Fouquieria splendens	ocotillo	0.0%	0.0%	5%	1	0.1%	0.1%	5%	1	0.08%	0.1%	5%	1
Opuntia bigelovii	teddybear cholla	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Opuntia chlorotica	dollarjoint pricklypear	0.0%	0.0%	5%	1	---	---	5%	---	---	---	5%	---
Opuntia engelmannii	cactus apple	0.8%	0.3%	5%	6	0.6%	0.3%	5%	4	---	---	5%	---
Opuntia leptocaulis	Christmas cactus	0.1%	0.1%	5%	3	---	---	5%	---	---	---	5%	---
Yucca baccata	banana yucca	0.4%	0.2%	5%	3	0.04%	0.04%	5%	1	---	---	5%	---
Tree													
Acacia greggii	catclaw acacia	0.6%	0.4%	5%	3	0.7%	0.6%	5%	2	---	---	5%	---
Canotia holacantha	crucifixion thorn	0.2%	0.2%	5%	3	0.3%	0.2%	5%	3	---	---	5%	---
Dodonaea viscosa	Florida hopbush	0.3%	0.3%	5%	1	0.3%	0.3%	5%	1	---	---	5%	---
Juniperus coahuilensis	redberry juniper	0.1%	0.1%	5%	1	0.2%	0.2%	5%	1	0.15%	0.2%	5%	1
Parkinsonia florida	blue paloverde	0.2%	0.1%	5%	2	0.4%	0.3%	5%	2	---	---	5%	---
Parkinsonia microphylla	yellow paloverde	2.5%	0.9%	5%	7	5.8%	1.9%	5%	7	0.95%	0.3%	5%	7
Prosopis velutina	velvet mesquite	0.8%	0.6%	5%	2	2.3%	1.4%	5%	3	0.68%	0.4%	5%	3

Table 3-7. Vegetation cover values (%) for species measured in the field, subcanopy, and canopy layers of bajada monitoring sites, Tonto National Monument, 2009, cont.

Scientific name	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Vine													
Janusia gracilis	slender janusia	0.2%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Vegetation type													
Annual Forb		5.5%	1.7%	5%	10	---	---	5%	---	---	---	5%	---
Annual Grass		4.2%	1.5%	5%	10	0.0%	0.0%	5%	0	---	---	5%	---
Perennial Forb		2.7%	1.2%	5%	7	0.04%	0.04%	5%	1	---	---	5%	---
Perennial Grass		4.1%	2.0%	5%	8	0.6%	0.4%	5%	4	---	---	5%	---
Subshrub		8.9%	2.1%	5%	11	1.9%	0.5%	5%	11	---	---	5%	---
Shrub		12.1%	2.0%	5%	11	9.7%	2.0%	5%	11	---	---	5%	---
Succulent		2.3%	0.7%	5%	7	1.1%	0.4%	5%	6	0.19%	0.1%	5%	2
Tree		4.7%	1.0%	5%	9	10.0%	2.4%	5%	9	1.78%	0.6%	5%	8
Snag		5.7%	1.1%	5%	11	0.5%	0.2%	5%	6	---	---	5%	---
Vine		0.2%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Total		44.7%	3.6%	8%	11	23.4%	2.3%	5%	11	2.01%	0.5%	5%	8
Exotics		3.8%	1.6%	5%	6	---	---	5%	---	---	---	5%	---
Annuals		9.7%	2.7%	6%	11	---	---	5%	---	---	---	5%	---

Field layer = 0.5 m; subcanopy = 0.5–2.0 m; canopy = >2.0 m.
Bajada stratum = <2,501–3,700', 35–90% rock fragments in surface soils.
"MDC" = minimum detectable change (% cover).
"Extent" = number of plots species was detected (out of 11).
Exotic species are bold, and annuals are shaded.

Table 3-8. Within-plot frequency and extent of uncommon perennial species encountered only on subplots of bajada monitoring plots, Tonto National Monument, 2009.

Scientific name	Common name	Lifeform	Within-plot frequency (5 subplots)		Extent (11 plots)
			Mean (%)	SE (%)	
Acourtia wrightii	brownfoot	Forb/Herb	15%	6.7%	4
Artemisia ludoviciana	white sagebrush	Forb/Herb	4%	2.4%	2
Chamaesyce sp.	sandmat	Forb/Herb	13%	9.1%	3
Cirsium neomexicanum	New Mexico thistle	Forb/Herb	2%	1.8%	1
Dichelostemma capitatum	bluedicks	Forb/Herb	4%	3.6%	1
Pellaea truncata	spiny cliffbrake	Forb/Herb	2%	1.8%	1
Achnatherum eminens	southwestern needlegrass	Graminoid	2%	1.8%	1
Bothriochloa barbinodis	cane bluestem	Graminoid	5%	3.9%	2
Muhlenbergia microsperma	littleseed muhly	Graminoid	2%	1.8%	1
Ayenia filiformis	Trans-Pecos ayenia	Subshrub	2%	1.8%	1
Bebbia juncea	sweetgrass	Subshrub	5%	3.9%	2
Brickellia atractyloides	spearleaf brickellbush	Subshrub	2%	1.8%	1
Brickellia coulteri	Coulter's brickellbush	Subshrub	2%	1.8%	1
Trixis californica	American threefold	Subshrub	2%	1.8%	1
Matelea parvifolia	Woodson spearleaf	Shrub	2%	1.8%	1
Phoradendron pauciflorum	fir mistletoe	Shrub	2%	1.8%	1
Echinocereus fendleri	pinkflower hedgehog cactus	Succulent	24%	8.9%	6
Ferocactus wislizeni	candy barrelcactus	Succulent	13%	4.9%	5
Mammillaria grahamii	Graham's nipple cactus	Succulent	33%	10.9%	6
Opuntia phaeacantha	cactus apple	Succulent	4%	3.6%	1
Rhus ovata	sugar sumac	Tree	2%	1.8%	1
Cuscuta indecora	bigseed alfalfa dodder	Vine	2%	1.8%	1

Bajada stratum = <2,501–3,700', 35–90% rock fragments in surface soils.

Table 3-9. Soil cover (% by class) as measured on the transects for bajada monitoring plots, Tonto National Monument, 2009.

Decreasing erosion hazard ↓

Substrate	AVG	SE	MDC	n=
Bare soil (<2 mm): no overhead cover	5.3%	0.8%	5%	2
Bare soil (<2 mm): under vegetation	6.3%	1.0%	5%	3
Total bare soil	11.7%	1.8%	5%	6
Light cyanobacteria: no overhead cover	0.3%	0.3%	5%	1
Light cyanobacteria: under vegetation	0.2%	0.2%	5%	1
Total light cyanobacteria	0.5%	0.4%	5%	1
Litter	30.0%	2.5%	6%	9
Dark cyanobacteria	0.7%	0.2%	5%	1
Gravel (2–75 mm)	29.1%	2.7%	6%	10
Duff	0.0%	0.0%	5%	0
Lichen	0.2%	0.2%	5%	1
Moss	7.3%	3.0%	7%	9
Rock (76–600 mm)	14.8%	2.5%	6%	9
Plant base	2.2%	0.6%	5%	1
Bedrock	3.5%	1.3%	5%	4

Bajada stratum = <2,501–3,700′, 35–90% rock fragments in surface soils.
"MDC" = mean detectable change with the specified sampling intensity ("n").
All variables met or exceeded our statistical power criteria.

Table 3-10. Biological soil crust cover as measured by point-quadrats, bajada monitoring plots, Tonto National Monument, 2009.

Morphological group	Growth form	Absolute cover				Cover in available habitat				Extent
		AVG	SE	MDC	n=	AVG	SE	MDC	n=	
Lichen	Crustose lichen	0.3%	0.1%	5%	1	0.6%	0.3%	5%	1	9
	Gelatinous lichen	0.2%	0.1%	5%	1	0.4%	0.2%	5%	1	9
	Foliose lichen	0.6%	0.5%	5%	1	1.1%	0.8%	5%	2	7
	Fruticose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	0
	Squamulose lichen	0.3%	0.1%	5%	1	0.4%	0.2%	5%	1	7
	Total lichen	1.3%	0.4%	5%	1	2.5%	0.8%	5%	2	11
Light cyanobacteria soil crust		0.9%	0.4%	5%	1	1.5%	0.6%	5%	1	6
Dark cyanobacteria soil crust		0.8%	0.2%	5%	1	1.5%	0.3%	5%	1	11
Bryophyte-dominated soil crust		5.4%	1.2%	5%	3	9.8%	1.6%	5%	5	11
Total biological soil crust cover		**8.4%**	**1.6%**	**5%**	**5**	**15.3%**	**2.2%**	**5%**	**10**	**11**

Bajada stratum = <2,501–3,700′, 35–90% rock fragments in surface soils.
"Extent" = number of plots class was detected (out of 11).
"MDC" = mean detectable change with the specified sampling intensity ("n").
"n" = number of plots required to meet statistical power criteria. All variables met our statistical power criteria.
Available habitat excludes areas covered by duff, rock, bedrock, embedded litter and vegetation.

Table 3-11. Terrestrial vegetation and soils monitoring data in the context of proposed management assessment points, bajada sites, Tonto National Monument, 2009.

Issue	Management assessment point	Mean (± SE)	Recommendation
Erosion hazard	Exposed bare ground cover >20%	5.3% (± 0.8%)	Continue monitoring
	Surface soil aggregate stability (with no overhead vegetation) < Class 3	4.37 (± 0.15)	Continue monitoring
	Biological soil crust cover < 10% of available habitat	15.3% (± 2.2%)	Continue monitoring
Site resilience	Foliar cover of perennial dead plants > 15% (field)	5.7% (± 1.1%)	Continue monitoring
	Foliar cover of perennial dead plants > 15% (subcanopy)	0.5% (± 0.2%)	Continue monitoring
Saguaro cacti extent	Extent of saguaro cacti < 5%	9%	Meet and consider
Saguaro cacti recruitment	Cover of nurse plants (trees and shrubs in subcanopy) <15%	20%	Continue monitoring
Exotic plant dispersal	Extent of invasive exotic plants >50%	55%	Meet and consider
Exotic plant invasion	Total cover of exotic plants >10% (field)	3.8% (± 1.6%)	Continue monitoring
	Exotic plant cover: total plant cover > 1:4 (0.25)	0.08	Continue monitoring
Fire hazard	Grasses + forbs >30% (field)	16.4% (± 3.7%)	Continue monitoring

Bajada stratum = <2,501–3,700', 35–90% rock fragments in surface soils.
Red entries fell outside the range of the assessment point.

3.4 Foothills stratum

Comprising about 8% of the terrestrial uplands of Tonto NM, the foothills stratum (3,501–4,500' elevation, 35–90% surface soil rock fragments, aka stratum 302) occurs at the higher extent of the monument, above Cave and Deadman canyons (Figure 3-7). This stratum is found in many other mountain systems of the American Southwest, including the Tucson and Rincon Mountains of Saguaro NP, the Chisos Mountains of Big Bend NP, and the eastern extent of the Guadalupe Mountains in Carlsbad Caverns NP (Hubbard et al. 2012).

3.4.1 Vegetation formations and lifeforms

Vegetation formations varied greatly over the foothills monitoring sites, with two sites containing wooded shrublands and one each containing tree savanna, shrub savanna, and shrubland (see Figure 3-7). Wooded shrublands were characterized by a sparse canopy of short-statured trees over a matrix of subshrubs, tree seedlings and saplings, and occasional shrubs (Figure 3-8). The tree savanna was similar, although subshrubs were largely replaced by perennial grasses. The shrub savanna was composed of large, emergent shrubs in a matrix of perennial grasses. The shrubland was a two-phase community of low-growing subshrubs with larger shrubs in the subcanopy (Figure 3-8).

All major lifeforms were encountered on foothills monitoring sites, with the greatest lifeform diversity in the field layer (Figure 3-8). Field layers also contained nearly three times the vegetative cover of subcanopies, and approximately 12 times more than canopies (Figure 3-8), again reflecting the generally short-statured nature of the lifeforms encountered. See Appendix A, Table A-10 for plot-specific information.

3.4.2 Cover and extent of perennial plant species

Foothills monitoring sites were co-dominated by the perennial grass, sideoats grama (*Bouteloua curtipendula*), and the shrub, mountain mahogany (*Cercocarpus montanus*), with the tree, crucifixion thorn (*Canotia holacantha*) as an important sub-dominant (Table 3-12). Important associates included the small trees, Florida hopbush (*Dodonaea viscosa*), catclaw acacia, and Sonoran scrub oak (*Quercus turbinella*); the subshrubs, bastardsage, globemallow, broom snakeweed (*Gutierrezia sarothrae*), and threadleaf snakeweed; the succulent, sotol (*Dasylirion wheeleri*); and the perennial grass, desert needlegrass (*Achnatherum speciosum*) (Table 3-12).

The most widespread species on foothills sites were globemallow, sideoats grama, desert needlegrass, and the non-native annual grass, red brome, each of which was found at four of the five foothills monitoring sites (Table 3-12). See Appendix A, Table A-10 for plot-specific information.

3.4.3 Frequency and extent of uncommon plant species

An additional 49 uncommon species were detected only on frequency subplots (Table 3-13), nearly doubling the total species count for foothills sites. Twelve uncommon species had within-plot frequencies of 10% or more (Table 3-13), with the forbs, Arizona sandmat (*Chamaesyce arizonica*), Gila County liveforever (*Dudleya collomiae*), and spiny cliffbrake (*Pellaea truncate*), the subshrubs, brittlebush, Eastern Mojave buckwheat, and Plains blackfoot (*Melampodium leucanthum*), and the cacti, Engelmann's hedgehog cactus (*Echinocereus engelmannii*) and pinkflower hedgehog cactus having at least 20% within-plot frequencies. Gila County liveforever and Eastern Mojave buckwheat were also the most extensively distributed uncommon species, found on more than half of the foothills monitoring sites (Table 3-13). See Appendix A, Table A-3 for plot-specific information.

3.4.4 Cover and frequency of exotic species

Non-native invasive plants were found on all five of the foothills monitoring plots. Two non-native grasses—the annual, red brome, and the perennial, Lehmann lovegrass—were detected along line-intercept transects on foothills monitoring plots (see Figure 3-7). Red brome and Lehmann lovegrass were the second and fifth most abundant grasses (3.0% ± 1.4% and 1.1% ± 1.1%, respectively) encountered on foothills sites (see Table 3-12). Red brome was found on all five foothills sites.

Two uncommon non-native plants—the forb, marsh parsley, and the grass, redtop—were found in the frequency subplots of foothills monitoring sites (see Figure 3-7). Each was restricted to a single monitoring site, and had within-plot frequencies of <10% (see Table 3-13).

3.4.5 Soil cover and biological soil crusts

Gravel (2–75-mm rock fragments) and leaf litter co-dominated surface soil cover of foothills monitoring sites, accounting for nearly two-thirds of the soil cover on the higher-elevation plots (Table 3-14). Rock (76–600-mm rock fragments), bare soil, and bedrock were also common on foothills soil surfaces. Bare soil under vegetation cover versus out in the open were comparable: 6.8% (± 1.5%), and 5.8% (± 0.8%), respectively. Duff was a minor constituent of foothills soil cover, whereas duff was absent on valley and bajada monitoring sites. Vegetation stems (plant bases) comprised almost 8% of soil surface cover (Table 3-14), reflecting the greater overall abundance of vegetation on foothills plots compared to lower-elevation sites.

Along the line-point intercept transects, biological soil crusts accounted for 1.3% (± 0.8%) of the soil cover, with mosses dominating the crust community (Table 3-14). Bryophytes (e.g., moss and liverworts) were ubiquitous across the foothills plots. Cover of bryophytes was higher in the point-quadrats than along the transects. Bryophytes covered 3.2% (± 1.2) of the total soil in the point-quadrats and 5.6% (± 1.8) of the total habitat available to biological soil crusts.

Within the point-quadrats, lichen and cyanobacteria cover were sparse (Table 3-15). However, three lichen growth forms (crustose, gelatinous, and foliose) were detected on the foothills plots (Table 3-15). See Appendix A, Tables A-4, A-5, and A-6 for plot-specific information.

3.4.6 Soil stability

Overall, average stability of surface soil aggregates was 4.23 (± 0.34) (out of a possible 6), or "moderately stable." As in the other strata, stability tended to be higher under vegetation (4.58 ± 0.43; "stable") than in areas lacking vegetative cover (3.79 ± 0.28; "moderately stable"). See Appendix A, Table A-4 for plot-specific information.

3.4.8 Management assessment points

Only one parameter crossed an assessment-point threshold: the extent of exotic plants, which were found all five of the foothills monitoring plots (Table 3-16). Within the stratum and at individual plots, most indicators did not approach the management assessment point. However, plot 302_V01 had average soil aggregate stability of just under 3 ("somewhat unstable") for samples not under vegetation cover.

Plot 302_V03 exceeded three management assessment points: (1) total cover of exotic plants >10%, (2) exotic plant cover: total plant cover >1:4, and (3) annual plant cover: total plant cover >1:4. Two non-native grasses drove the exceedance of the assessment points on this plot: the annual, red brome, and the perennial, Lehmann lovegrass, which each covered 5% or more of the plot (as measured on the transects). See Appendix A, Table A-11 for plot-specific information.

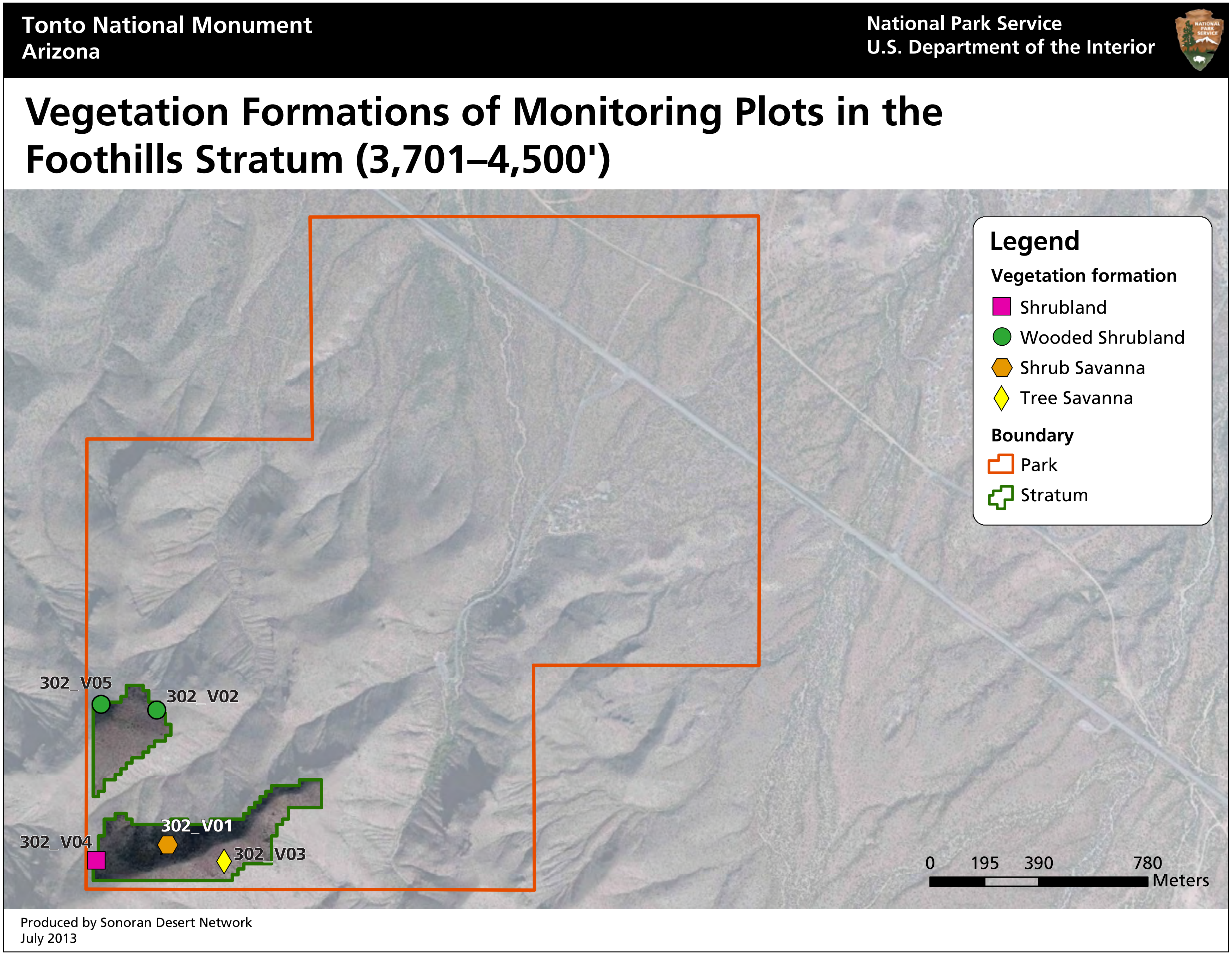

Figure 3-7. Location of monitoring plots within the foothills stratum, Tonto National Monument, sampled in 2009 and 2010.

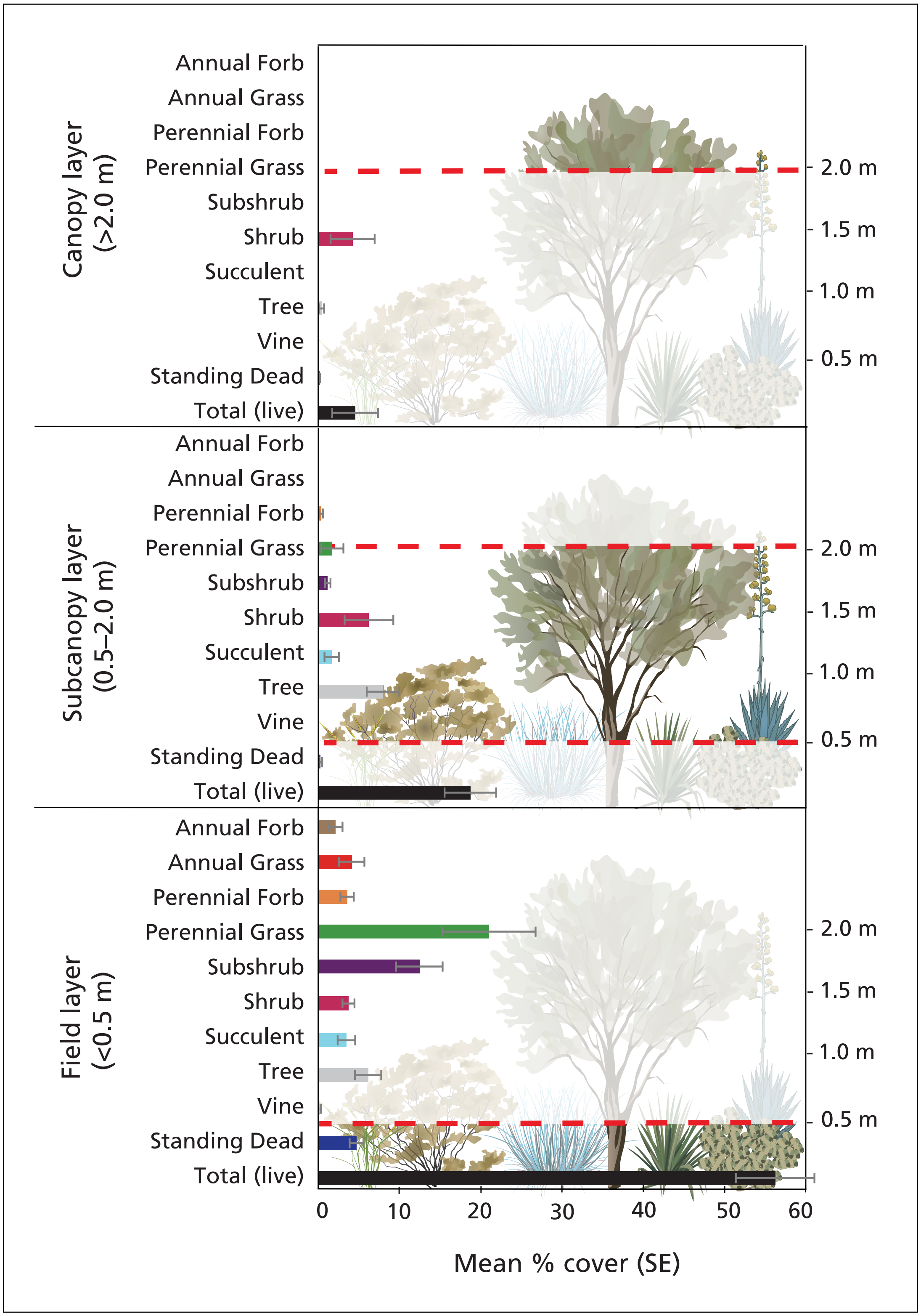

Figure 3-8. Lifeform cover for field, subcanopy, and canopy layers in the foothills stratum, Tonto National Monument, 2009–2010.

Table 3-12. Vegetation cover values (%) measured in the field, subcanopy, and canopy layers of foothills monitoring sites, Tonto National Monument, 2009–2010.

Species	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Forb/Herb													
Ambrosia confertiflora	weakleaf bur ragweed	0.5%	0.4%	5%	2	---	---	5%	---	---	---	5%	---
Artemisia ludoviciana	white sagebrush	0.4%	0.4%	5%	1	0.3%	0.3%	5%	1	---	---	5%	---
Astrolepis cochisensis	Cochise scaly cloakfern	0.2%	0.2%	5%	1	---	---	5%	---	---	---	5%	---
Cheilanthes fendleri	Fendler's lipfern	1.4%	0.8%	5%	3	---	---	5%	---	---	---	5%	---
Eriogonum polycladon	sorrel buckwheat	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Penstemon eatonii	firecracker penstemon	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Selaginella arizonica	Arizona spikemoss	0.8%	0.8%	5%	1	---	---	5%	---	---	---	5%	---
Graminoid													
Achnatherum speciosum	desert needlegrass	2.6%	2.1%	5%	4	0.1%	0.1%	5%	1	---	---	5%	---
Aristida purpurea	purple threeawn	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Bothriochloa barbinodis	cane bluestem	0.3%	0.3%	5%	1	---	---	5%	---	---	---	5%	---
Bouteloua curtipendula	sideoats grama	14.8%	7.3%	16%	4	1.6%	1.4%	5%	2	---	---	5%	---
Bromus rubens	**red brome**	**3.0%**	**1.4%**	**5%**	**4**	**---**	**---**	**5%**	**---**	**---**	**---**	**5%**	**---**
Digitaria californica	Arizona cottontop	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Eragrostis lehmanniana	**Lehmann lovegrass**	1.1%	1.1%	5%	1	---	---	5%	---	---	---	5%	---
Leptochloa dubia	tanglehead	0.4%	0.4%	5%	1	---	---	5%	---	---	---	5%	---
Muhlenbergia microsperma	littleseed muhly	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Muhlenbergia porteri	bush muhly	0.3%	0.3%	5%	1	---	---	5%	---	---	---	5%	---
Poa fendleriana	muttongrass	1.3%	1.1%	5%	2	---	---	5%	---	---	---	5%	---
Subshrub													
Abutilon incanum	pelotazo	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Adenophyllum porophylloides	San Felipe dogweed	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Bebbia juncea	sweetbush	0.6%	0.5%	5%	2	0.1%	0.1%	5%	1	---	---	5%	---
Brickellia atractyloides	pungent brickellbush	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Eriogonum wrightii	bastardsage	3.2%	2.1%	5%	3	0.2%	0.2%	5%	1	---	---	5%	---
Galium stellatum	starry bedstraw	0.3%	0.2%	5%	3	---	---	5%	---	---	---	5%	---
Gutierrezia microcephala	threadleaf snakeweed	1.8%	1.5%	5%	2	0.4%	0.4%	5%	1	---	---	5%	---
Gutierrezia sarothrae	broom snakeweed	2.3%	1.4%	5%	2	0.3%	0.2%	5%	2	---	---	5%	---
Krameria grayi	white ratany	0.2%	0.2%	5%	1	---	---	5%	---	---	---	5%	---
Menodora scabra	rough menodora	0.3%	0.3%	5%	1	---	---	5%	---	---	---	5%	---
Porophyllum gracile	slender poreleaf	0.6%	0.5%	5%	2	---	---	5%	---	---	---	5%	---

Table 3-12. Vegetation cover values (%) for species measured in the field, subcanopy, and canopy layers of foothills monitoring sites, Tonto National Monument, 2009–2010, cont.

Species	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Senna covesii	Coues' cassia	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Sphaeralcea sp.	globemallow	2.5%	0.9%	5%	4	0.1%	0.1%	5%	1	---	---	5%	---
Stephanomeria pauciflora	brownplume wirelettuce	0.4%	0.3%	5%	2	0.1%	0.1%	5%	1	---	---	5%	---
Shrub													
Cercocarpus montanus	mountain mahogany	1.3%	0.9%	5%	2	5.2%	3.3%	7%	2	4.2%	2.7%	6%	2
Encelia frutescens	button brittlebush	0.8%	0.4%	5%	3	0.4%	0.3%	5%	2	---	---	5%	---
Encelia virginensis	Virgin River brittlebush	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Keckiella antirrhinoides	snapdragon penstemon	0.6%	0.6%	5%	1	0.1%	0.1%	5%	1	---	---	5%	---
Mahonia fremontii	Fremont's mahonia	0.3%	0.3%	5%	1	0.3%	0.3%	5%	1	---	---	5%	---
Rhus trilobata	skunkbush sumac	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Simmondsia chinensis	jojoba	0.5%	0.4%	5%	2	0.3%	0.2%	5%	2	---	---	5%	---
Succulent													
Agave chrysantha	goldenflower century plant	0.2%	0.1%	5%	2	---	---	5%	---	---	---	5%	---
Cylindropuntia acanthocarpa	buckhorn cholla	0.8%	0.5%	5%	2	0.1%	0.1%	5%	1	---	---	5%	---
Dasylirion wheeleri	sotol	1.5%	0.9%	5%	2	1.3%	0.8%	5%	2	---	---	5%	---
Opuntia engelmannii	cactus apple	0.6%	0.3%	5%	3	0.2%	0.1%	5%	2	---	---	5%	---
Yucca baccata	banana yucca	0.3%	0.3%	5%	1	---	---	5%	---	---	---	5%	---
Tree													
Acacia greggii	catclaw acacia	1.5%	1.4%	5%	2	1.4%	1.3%	5%	2	---	---	5%	---
Canotia holacantha	crucifixion thorn	2.4%	1.5%	5%	3	2.9%	2.3%	5%	3	---	---	5%	---
Dodonaea viscosa	Florida hopbush	1.6%	1.6%	5%	1	2.3%	2.3%	5%	1	---	---	5%	---
Fraxinus anomala	singleleaf ash	---	---	5%	---	0.3%	0.3%	5%	1	0.3%	0.3%	5%	1
Quercus turbinella	Sonoran scrub oak	0.6%	0.6%	5%	1	0.9%	0.9%	5%	1	---	---	5%	---

Table 3-12. Vegetation cover values (%) for species measured in the field, subcanopy, and canopy layers of foothills monitoring sites, Tonto National Monument, 2009–2010, cont.

Species	Common name	Field				Subcanopy				Canopy			
		AVG	SE	MDC	Extent	AVG	SE	MDC	Extent	AVG	SE	MDC	Extent
Vine													
Galium aparine	stickwilly	0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Vegetation type													
Annual Forb		2.1%	0.8%	5%	5	---	---	5%	---	---	---	5%	---
Annual Grass		4.1%	1.6%	5%	4	---	---	5%	---	---	---	5%	---
Perennial Forb		3.5%	0.8%	5%	5	0.3%	0.3%	5%	1	---	---	5%	---
Perennial Grass		21.0%	5.8%	12%	5	1.7%	1.4%	5%	3	---	---	5%	---
Subshrub		12.4%	2.9%	6%	5	1.1%	0.3%	5%	4	---	---	5%	---
Shrub		3.7%	0.7%	5%	5	6.2%	3.0%	7%	5	4.2%	2.7%	6%	2
Succulent		3.4%	1.1%	5%	4	1.6%	0.9%	5%	3	---	---	5%	---
Tree		6.1%	1.6%	5%	4	7.9%	2.0%	5%	5	0.3%	0.3%	5%	1
Snag		4.7%	0.9%	5%	5	0.2%	0.2%	5%	1	0.1%	0.1%	5%	1
Vine		0.1%	0.1%	5%	1	---	---	5%	---	---	---	5%	---
Total		56.3%	4.8%	11%	5	18.7%	3.2%	7%	5	4.5%	2.8%	6%	2
Exotics		4.1%	2.0%	5%	4	---	---	5%	---	---	---	5%	---
Annuals		6.2%	2.1%	5%	4	---	---	5%	---	---	---	5%	---

Foothills stratum = <3,501–4,500′, 35–90% rock fragments in surface soils.
"MDC" = minimum detectable change (% cover).
"Extent" = number of plots species was detected (out of 5).
Exotic species are bold, annuals are shaded.
Highlighted variables did not meet our statistical power criteria.

Table 3-13. Within-plot frequency and extent of uncommon perennial species encountered only on subplots of foothills monitoring plots, Tonto National Monument, 2009–2010.

Scientific name	Common name	Within-plot frequency (5 subplots)		Extent (5 plots)
		Mean (%)	SE (%)	
Forb/Herb				
Acourtia wrightii	brownfoot	4%	4.0%	1
Bahia absinthifolia	hairyseed bahia	4%	4.0%	1
Brickellia betonicifolia	betonyleaf brickellbush	4%	4.0%	1
Chamaesyce sp.	sandmat	8%	8.0%	1
Chamaesyce arizonica	Arizona sandmat	20%	20.0%	1
Chamaesyce melanadenia	red-gland spurge	4%	4.0%	1
Cheilanthes sp.	lipfern	16%	11.7%	2
Cirsium neomexicanum	New Mexico thistle	8%	8.0%	1
Cyclospermum leptophyllum	**marsh parsley**	**4%**	**4.0%**	**1**
Dudleya collomiae	Gila County liveforever	28%	15.0%	3
Euphorbia sp.	sandmat	4%	4.0%	1
Heliomeris longifolia	longleaf false goldeneye	8%	8.0%	1
Packera neomexicana	New Mexico groundsel	4%	4.0%	1
Parkinsonia floridana	blue paloverde	4%	4.0%	1
Pellaea truncata	spiny cliffbrake	24%	14.7%	2
Stephanomeria minor var. *minor*	narrowleaf wirelettuce	4%	4.0%	1
Stephanomeria tenuifolia	narrowleaf wirelettuce	4%	4.0%	1
Graminoid				
Agrostis gigantea	**redtop**	**4%**	**4.0%**	**1**
Elymus elymoides	squirreltail	4%	4.0%	1
Elymus glaucus	blue wildrye	4%	4.0%	1
Enneapogon desvauxii	nineawn pappusgrass	4%	4.0%	1
Heteropogon contortus	tanglehead	4%	4.0%	1
Hilaria mutica	tobosagrass	4%	4.0%	1
Panicum hirticaule	Mexican panicgrass	4%	4.0%	1
Tridens muticus	slim tridens	4%	4.0%	1
Subshrub				
Abutilon sp.	Indian mallow	4%	4.0%	1
Abutilon parishii	Parish's Indian mallow	4%	4.0%	1
Arenaria macradenia	Mojave sandwort	4%	4.0%	1
Brickellia californica	California brickellbush	4%	4.0%	1
Dalea formosa	featherplume	8%	8.0%	1
Encelia farinosa	brittlebush	20%	15.5%	2
Ericameria laricifolia	turpentine bush	12%	8.0%	2
Eriogonum fasciculatum	Eastern Mojave buckwheat	20%	8.9%	3
Heterotheca villosa	hairy false goldenaster	4%	4.0%	1
Melampodium leucanthum	Plains blackfoot	20%	15.5%	2
Nolina microcarpa	beargrass	16%	16.0%	1
Perityle saxicola	Roosevelt Dam rockdaisy	4%	4.0%	1
Senecio lemmonii	Lemmon's ragwort	4%	4.0%	1
Xanthisma spinulosum	lacy tansyaster	4%	4.0%	1
Shrub				
Aloysia wrightii	Wright's beebrush	4%	4.0%	1

Table 3-13. Within-plot frequency and extent of uncommon perennial species encountered only on subplots of foothills monitoring plots, Tonto National Monument, 2009–2010.

Scientific name	Common name	Within-plot frequency (5 subplots)		Extent (5 plots)
		Mean (%)	SE (%)	
Succulent				
Echinocereus engelmannii	Engelmann's hedgehog cactus	20%	15.5%	2
Echinocereus fendleri	pinkflower hedgehog cactus	20%	12.6%	2
Fouquieria splendens	ocotillo	4%	4.0%	1
Mammillaria barbata	greenflower nipple cactus	8%	8.0%	1
Mammillaria grahamii	Graham's nipple cactus	4%	4.0%	1
Opuntia chlorotica	dollarjoint pricklypear	8%	8.0%	1
Opuntia phaeacantha	cactus apple	12%	8.0%	2
Tree				
Rhus ovata	sugar sumac	12%	8.0%	2
Vine				
Janusia gracilis	slender janusia	4%	4.0%	1

Foothills stratum = <3,501–4,500', 35–90% rock fragments in surface soils.
"Extent" = number of plots species was detected (out of 5).
Exotic species are bold.

Table 3-14. Soil cover (% by class) as measured on the transects for foothills monitoring plots, Tonto National Monument, 2009–2010.

	Substrate	AVG	SE	MDC	n=
	Bare soil (<2 mm): no overhead cover	5.8%	0.8%	5%	1
	Bare soil (<2 mm): under vegetation	6.8%	1.5%	5%	2
	Total bare soil	12.6%	1.6%	5%	3
Decreasing erosion hazard ↓	Light cyanobacteria: no overhead cover	0.1%	0.1%	5%	1
	Light cyanobacteria: under vegetation	---	---	5%	---
	Total light cyanobacteria	0.1%	0.1%	5%	1
	Litter	28.7%	4.0%	9%	5
	Dark cyanobacteria	0.1%	0.1%	5%	1
	Gravel (2–75 mm)	30.1%	4.8%	11%	5
	Duff	2.3%	1.0%	5%	1
	Lichen	0.1%	0.1%	5%	1
	Moss	1.0%	0.4%	5%	1
	Rock (76–600 mm)	13.9%	2.5%	7%	3
	Plant base	7.4%	1.7%	5%	3
	Bedrock	3.8%	2.7%	6%	5

Foothills stratum = <3,501–4,500', 35–90% rock fragments in surface soils.
"MDC" = mean detectable change with the specified sampling intensity ("n").
Highlighted variables did not meet our statistical power criteria.

Table 3-15. Biological soil crust cover as measured by point-quadrats, foothills monitoring plots, Tonto National Monument, 2009–2010.

Morphological group	Growth form	Absolute cover				Cover in available habitat				Extent
		AVG	SE	MDC	n=	AVG	SE	MDC	n=	
Lichen	Crustose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	2
	Gelatinous lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	1
	Foliose lichen	0.1%	0.1%	5%	1	0.2%	0.2%	5%	1	2
	Fruticose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	0
	Squamulose lichen	0.0%	0.0%	5%	0	0.0%	0.0%	9%	0	0
	Total lichen	0.1%	0.1%	5%	1	0.2%	0.2%	5%	1	2
Light cyanobacteria soil crust		0.1%	0.1%	5%	1	0.2%	0.2%	5%	1	2
Dark cyanobacteria soil crust		0.0%	0.0%	5%	0	0.0%	0.0%	5%	0	1
Bryophyte-dominated soil crust		3.2%	1.2%	5%	2	5.6%	1.8%	5%	3	5
Total biological soil crust cover		**3.4%**	**1.3%**	**5%**	**2**	**6.0%**	**1.9%**	**5%**	**4**	**5**

Foothills stratum = <3,501–4,500’, 35–90% rock fragments in surface soils.
“Extent” = number of plots species was detected (out of 5).
“MDC” = mean detectable change with the specified sampling intensity (“n”).
“n” = number of plots required to meet statistical power criteria.
All variables met our statistical power criteria.
Available habitat excludes areas covered by duff, rock, bedrock, embedded litter and vegetation.

Table 3-16. Terrestrial vegetation and soils monitoring data in the context of proposed management assessment points, foothills sites, Tonto National Monument, 2009–2010.

Issue	Management assessment point	Mean (± SE)	Recommendation
Erosion hazard	Exposed bare ground cover >20%.	5.8% (± 0.8)	Continue monitoring
	Surface soil aggregate stability (with no overhead vegetation) < Class 3	3.79 (± 0.28)	Continue monitoring
Site resilience	Foliar cover of perennial dead plants > 15% (field)	4.7% (± 0.9)	Continue monitoring
	Foliar cover of perennial dead plants > 15% (subcanopy)	0.2% (± 0.2)	Continue monitoring
	Tree + shrub cover > 50% (subcanopy)	14.1% (± 2.5)	Continue monitoring
Exotic plant dispersal	Extent of invasive exotic plants >50%	100%	Meet and consider
Exotic plant invasion	Total cover of exotic plants >10% (field)	4.1% (± 2.0)	Continue monitoring
	Exotic plant cover: total plant cover > 1:4 (0.25)	0.08	Continue monitoring
Fire hazard	Annual plant cover: total plant cover >1:4 (0.25)	0.12	Continue monitoring
	Litter + duff > 75%	30.9% (± 4.7)	Continue monitoring

Foothills stratum = <3,501–4,500’, 35–90% rock fragments in surface soils.
Red entries fell outside the range of the assessment point.

3.5 Design considerations

3.5.1 Evaluation of strata

PERMANOVA results indicated strong differentiation (Pseudo-F = 3.1819, P = 0.001) in plant communities between the three a priori strata. Pairwise tests (Figure 3-9) revealed that each of the three strata was distinct from all others. Non-metric multidimensional scaling (MDS; Figure 3-9) illustrates the PERMANOVA results. Plots from all three strata are arranged in a gradient along Axis 1, showing slightly more overlap of the low- and mid-elevation sites as compared to the high-elevation sites. Based on this analysis, we maintained the original stratification design (the three elevation groups) on all subsequent data presentation and analysis. Species similarity permutation (SIMPER) was used to determine which species contributed most to the within-group similarity of each stratum, and the between-group dissimilarity of each stratum (Clarke and Warwick 2001). SIMPER results are shown in Figure 4-1.

3.5.2 Power to detect trends in common species and lifeforms

In the valley stratum, we exceeded our design criteria (i.e., to detect a 10% absolute change in foliar cover with 90% power and 10% chance of a false change error) for the subshrub lifeform and total cover, likely due to the small number of plots in the stratum (see Table 3-2). The subshrub, turpentine bush, drove these exceedences. All other lifeforms in the valley stratum met our statistical power criteria (see Table 3-2).

In the bajada stratum (2,501–3,700'), our proposed sampling design always met or exceeded our expectations for statistical power to detect trends in common perennial species and lifeforms, based on the goals of our design criteria. In fact, our data indicate that we will be able to detect a 5% change (absolute foliar cover) for most lifeforms and perennial species in the three vegetation height categories (see Table 3-7).

After analyzing all of the 2009 data, we determined that our power to detect trend was poor for three important, common native species on sites above 3,700' (foothills stratum): sideoats grama, hopbush, and mountain mahogany. After discussion with park staff, we decided to add three high-elevation plots (plots V03, V04, and V05 in the foothills stratum) (see Section 2.2.1). These plots were sampled in 2010, and are incorporated into all subsequent analyses and discussion.

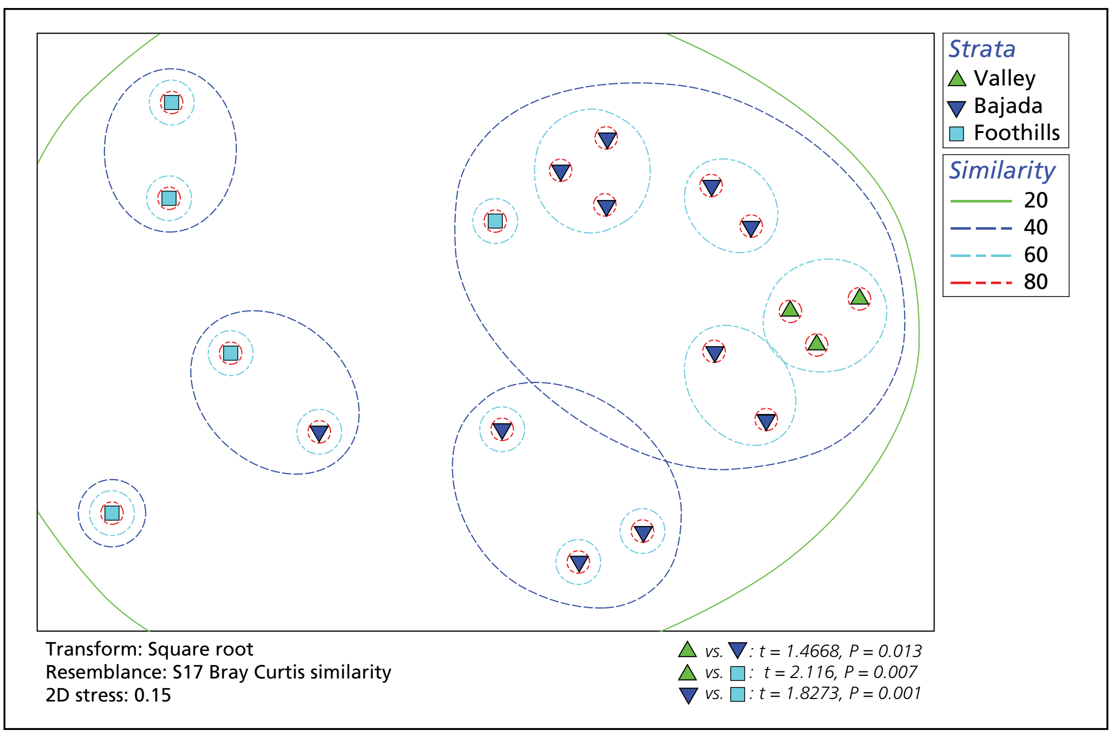

Figure 3-9. Non-metric multidimensional scaling showing similarity of vegetation communities within monitoring plots.

After this sample-size augmentation, trend detection for sideoats grama in the field layer of high-elevation plots still failed to meet our criteria. We estimate that we will be able to detect a 16% change (Table 3-17) in foliar cover for this species. Similarly, we just missed our target criteria for perennial grass lifeforms and total cover in the foothills stratum, likely due to the pervasive influence of the variance in sideoats grama, a common perennial bunchgrass (see Table 3-12). Power to detect trend improved for our other problematic species in the foothills stratum, as we estimate change detection at 11% and 9% for mountain mahogany and hopbush, respectively (Table 3-17). Power to detect trends in all other lifeforms in the foothills strata exceeded our criteria (see Table 3-12).

3.5.3 Plant species detectability and power for trend in uncommon perennial species

Line-point intercept transects on the original 16 plots detected 71 species (68 native perennial species, 1 non-native perennial, and 2 non-native annuals). Employing the frequency subplots added 38 perennial species (36 native perennial species, 1 non-native perennial, and 1 non-native annual). The three plots added to the foothills stratum in 2010 contributed 8 (line-intercept) and 21 (frequency-subplot) species to the total number of species detected on the monitoring plots. Of the 138 species detected, 33 were exclusive to plots in the foothills stratum.

Our design met or exceeded our sampling objectives for detecting trends in frequency for about half of the perennial species found. However, for species found only in the frequency subplots, our design met or exceeded our sampling objectives (i.e., to detect at least a 10% change in within-plot frequency with 90% power and 10% chance of false change error) for about 70% of the species. For the species on both transects and subplots, the line-point intercept transect provided a far more precise estimate of abundance and improved statistical power than did frequency.

3.5.4 Power to detect trends in soil parameters

Our design met or exceeded our sampling objectives (i.e., to detect at least a 10% change or 1 stability class change, with 90% power and 10% chance of false change error) for nearly all soil cover and surface soil aggregate stability class parameters at the proposed sampling intensity. There was one exception: we estimate that we can detect an 11% change in gravel cover along the transects for the foothills stratum. Average soil stability estimates always exceeded our criteria.

Within the point-quadrats, cover of biological soil crusts by morphological group and lichen growth form consistently outperformed our statistical power criteria. We estimate that we will be able to detect at least a 5% change in all groups and growth forms for all strata, with the exception of bryophytes in the

Table 3-17. Comparison of cover values for three important and common native species measured in all height categories following the addition of three plots to the foothills stratum, Tonto National Monument.

Scientific name	Common name	Primary growth habit	Vegetation height category	Two plots in stratum (2009 data only)				Five plots in stratum (2009 and 2010 data)			
				AVG	SE	MDC	n=	AVG	SE	MDC	n=
Bouteloua curtipendula	sideoats grama	Graminoid	Field	24.0%	17.7%	37%	2	14.8%	7.3%	16%	5
			Subcanopy	4.0%	3.1%	7%	2	1.6%	1.4%	5%	2
			Canopy	---	---	5%	0	---	---	5%	0
Cercocarpus montanus	mountain mahogany	Shrub	Field	1.0%	1.0%	5%	1	1.3%	0.9%	5%	1
			Subcanopy	5.0%	5.0%	11%	2	5.2%	3.3%	7%	5
			Canopy	3.8%	3.8%	8%	2	4.2%	2.7%	6%	5
Dodonaea viscosa	Florida hopbush	Tree	Field	4.0%	4.0%	9%	2	1.6%	1.6%	5%	3
			Subcanopy	5.8%	5.8%	13%	2	2.3%	2.3%	5%	5
			Canopy	---	---	5%	0	---	---	5%	0

Highlighted variables did not meet our statistical power criteria.

valley plots. For bryophytes in the valley plots, we will be able to detect at least a 6% change. However, we failed to meet our power objectives for detecting changes in the frequencies of all growth forms and morphological groups, with the exception of light cyanobacteria crusts and crustose lichens.

3.5.5 Biological soil crust cover and frequency along transects vs. quadrats

In order to help evaluate the protocol, we compared the methods of estimating biological soil crust cover (line-point intercept vs. point-quadrat) using paired t-tests in which each plot was a sample (Table 3-18). Both sampling approaches resulted in similar values for the cyanobacteria morphological groups, but for lichens, the point-quadrat method yielded significantly higher cover than the line-point intercept method (P <0.05). On average, lichen cover was 0.6% higher in the quadrats than on the transects (Table 3-18). Although bryophyte cover tended to be higher in the point-quadrats, the difference in bryophyte cover was not statistically significant.

Table 3-18. Paired t-test results for line-point intercept and point-quadrat methods for biological soil crust and substrate cover measurements, Tonto National Monument, 2009–2010.

Morphological group	Mean difference (intercept - quadrat)			
	AVG	SE	t	P
Light cyanobacteria	0.1%	0.5%	0.241	0.813
Dark cyanobacteria	0.0%	0.2%	0.189	0.852
Lichen	**-0.6%**	**0.3%**	**-2.182**	**0.043**
Bryophyte	-2.68%	8.89%	-1.31434	0.205

degrees of freedom = 18 for all tests.

Morphological groups for which results are statistically significant (p<0.05) are bold.

t = t test statistic.

P = probability of obtaining a test statistic that is at least as extreme as the observed if the null hypothesis (=no difference) is true.

4 Discussion

4.1 A transition from the Sonoran Desert to the Mogollon Rim

Our data indicate three general classes of terrestrial vegetation at Tonto National Monument (Figure 4-1): (1) sparse wooded shrubland with low yellow paloverde and velvet mesquite cover over a matrix of jojoba, turpentine bush, and annual forbs and grasses occupying valley bottoms and low hillslopes, moving upslope into (2) the bajada (alluvial fans extending to the base of the hillslope), where jojoba, globemallow, and other perennial herbs increase, saguaro and other cacti appear, and tree cover decreases, rising to (3) the foothills, where perennial grasses, such as sideoats grama and desert needlegrass, dominate wooded shrublands and shrub savannas. Mountain mahogany and crucifixion thorn replace paloverde and mesquite in foothills canopies (see below). Jojoba, the most prevalent species in lower elevations of the monument, drops out at these cooler, wetter foothills climates.

The low-elevation desert shrublands and mid-elevation semi-desert grasslands/shrub savannas at Tonto NM are typical of the Sonoran Desert Upland subdivision of the desert scrub biome as described by Brown (1982). These types are widespread and emblematic vegetation of the Sonoran Desert ecoregion and are found at many other SODN parks, such as Organ Pipe Cactus NM and Saguaro National Park.

Unlike at those other parks, however, Tonto NM's proximity to the Mogollon Rim and strong topographic gradients have produced intermediate or transitional plant communities at higher elevations. Exhibiting characteristic species of both the Sonoran Desert and the northern subdivision of the Apache Highlands ecoregions, the high-elevation mountain mahogany/crucifixion thorn shrublands are an excellent example of a variant of interior chaparral vegetation that is somewhat unique to the Tonto Basin. Here, the more dominant and characteristic Sonoran Desert upland species (e.g., yellow paloverde, wolfberry, jojoba, and saguaro drop out at higher elevations, where they are replaced with more frost-hardy, yet still drought-tolerant, species representative of interior chaparral (Keeley and Davis 2000). This interesting and somewhat unusual vegetation type represents a substantial portion of the plant diversity of the monument, as well as an important topographic and ecological connection to the broader landscape of the Tonto Basin—one that is almost invisible to park visitors due to the steep terrain and lack of trails and viewpoints into this hidden habitat.

Mountain mahogany/crucifixion thorn chaparral at Tonto National Monument.

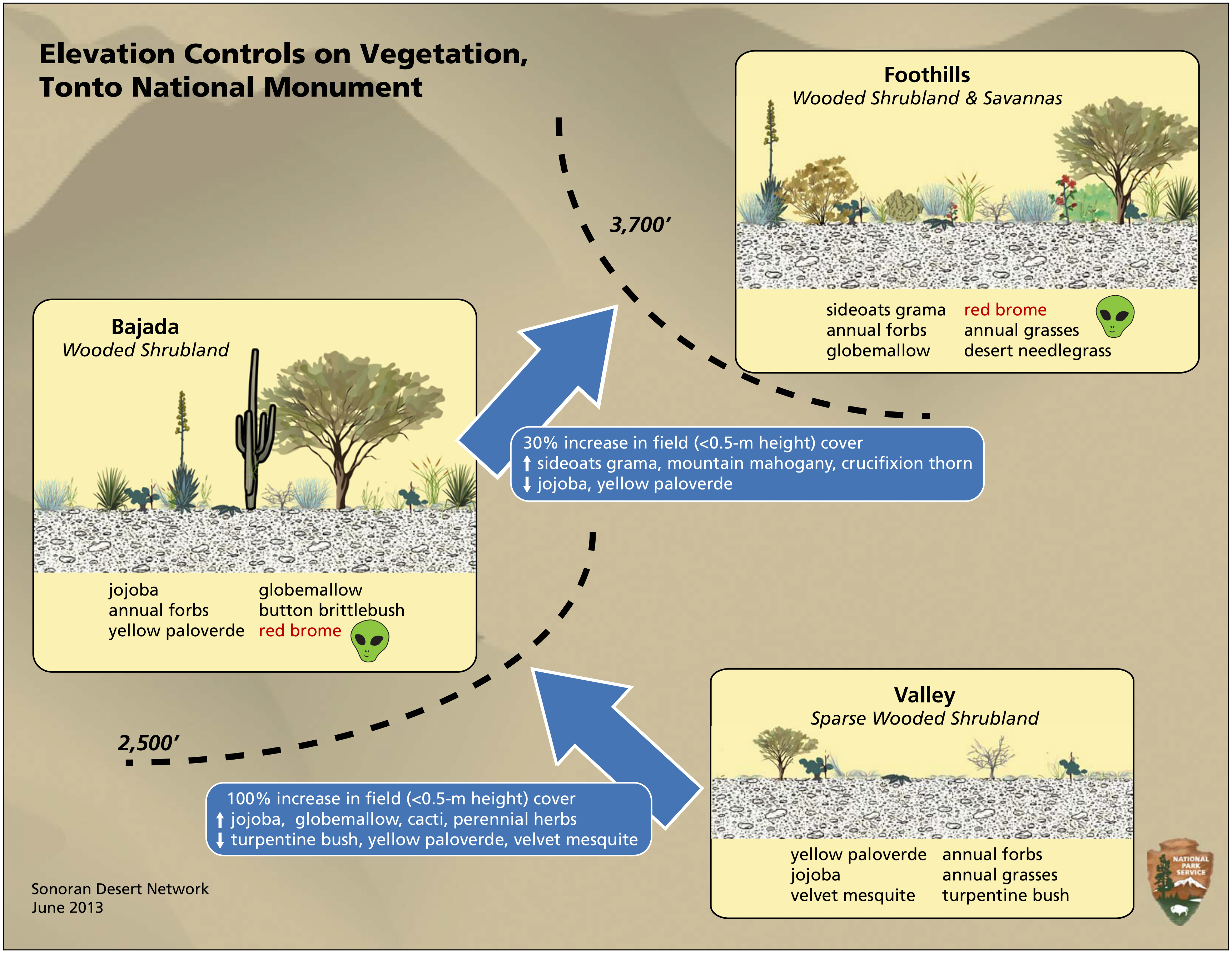

Figure 4-1. Elevation controls on terrestrial vegetation assemblages at Tonto National Monument. Characteristic species of each biome (tan boxes) and those most responsible for the dissimilarities between types (blue boxes) as determined by species similarity permutation procedure (SIMPER; see Section 3.5.1).

4.2 Invasive exotic plants

Exotic plant encroachment typically occurs in two phases: (1) colonization, the process by which a problematic species gradually disperses into suitable habitats, recruits into the system, and competes for resources with other members of the plant community; and (2) asymmetrical competition (often mediated through disturbance), in which the new species becomes a common or even dominant plant in the plant community, often with negative consequences for ecosystem structure and function. It is important to note that the second phase often requires a specific set of ecological triggers or conditions that may, in fact, never occur (this is why many exotic species are relatively innocuous under some environmental conditions) but also can occur after a species has existed in a relatively stable, non-invasive status for many years. Successful management strategies are largely determined by which phase has occurred.

4.2.1 Colonization by red brome

Our data indicate that one exotic grass, red brome, has completed the colonization phase across all strata within the monument. One of the most widely distributed of all plants across the monument, red brome is found throughout terrestrial portions of Tonto NM (see Table 3-1, Figure 4-2), suggesting that it is not dispersal-limited from suitable habitats within the park. Its extent throughout the park (79%) exceeds the management assessment point for exotic plant dispersal (see Table 2-3). Sites that are likely to be colonized have been colonized, without regard to elevation or soil type. Red brome is and will likely remain a ubiquitous species at Tonto NM for the foreseeable future.

However, with relatively low foliar cover (2.3% ± 0.68 parkwide, well below the 10% threshold of the exotic plant invasion management assessment point; see Table 3-1), red brome does not appear to dominate native flora at this time. As with many annual grasses in the Sonoran Desert, red brome occupies the interstices between native perennial species (Brooks and McPherson 2008), and generally competes more with native and non-native annuals than with the perennials that dominate the landscape of Tonto NM. Given the low cover of red brome, it appears that native species can effectively compete with this exotic under current conditions. The Eurasian annual grass, wild oat, follows a similar pattern—though to a much lesser extent, as it is limited to low elevations and found at even lower abundances (see Table 3-1, Figure 4-3).

4.2.2 Red brome and fire

Of great management concern is the potential of incipient red brome populations to dominate monument vegetation in the future, via disturbance-mediated or indirect competition. Like its close relative, cheatgrass (*Bromus tectorum*), red brome has a suite of favorable traits (e.g., avoidance via long-lived seedbank, rapid germination and flower production, effective wind dispersal of seeds) relative to many native species in response to disturbance, particularly wildfire (Brooks and Chambers 2011).

Prolific fine-fuel (e.g., red brome) production following pronounced wet/dry climate cycles can increase the occurrence, extent, and severity of wildfires in desert environments with limited evolutionary history of wildfire, supporting positive feedback loops (D'Antonio and Vitousek 1992) in which increased fire occurrence promotes red brome at the expense of less-fire tolerant natives. This in turn produces more fine fuels and, therefore, additional wildfires. Current climate-change predictions are expected to reinforce and even accelerate this feedback loop (Brooks et al. 2004).

Evaluating pre- vs. post-fire vegetation data following the surprisingly active twentieth-century fire history at Tonto NM, Phillips (1997) concluded that just such a shift from desert shrubland toward mixed native and non-native grasslands had occurred at mid-elevations along the south boundary of the monument (upper Cave Canyon/Honey Butte area). Phillips attributed this change directly to the repeated, high-intensity fires that occurred from 1947 to 1980. Although SODN has no terrestrial vegetation monitoring plots in that particular location, recent data from the vegetation mapping and characterization inventory (Studd et al. unpublished data) suggest that upland areas have partially recovered during the more than three decades since the last major wildfire.

4.2.3 Limited colonization by Lehmann lovegrass in uplands

The southern African perennial bunchgrass, Lehmann lovegrass, has a similar pattern of colonization to red brome, although this less drought-

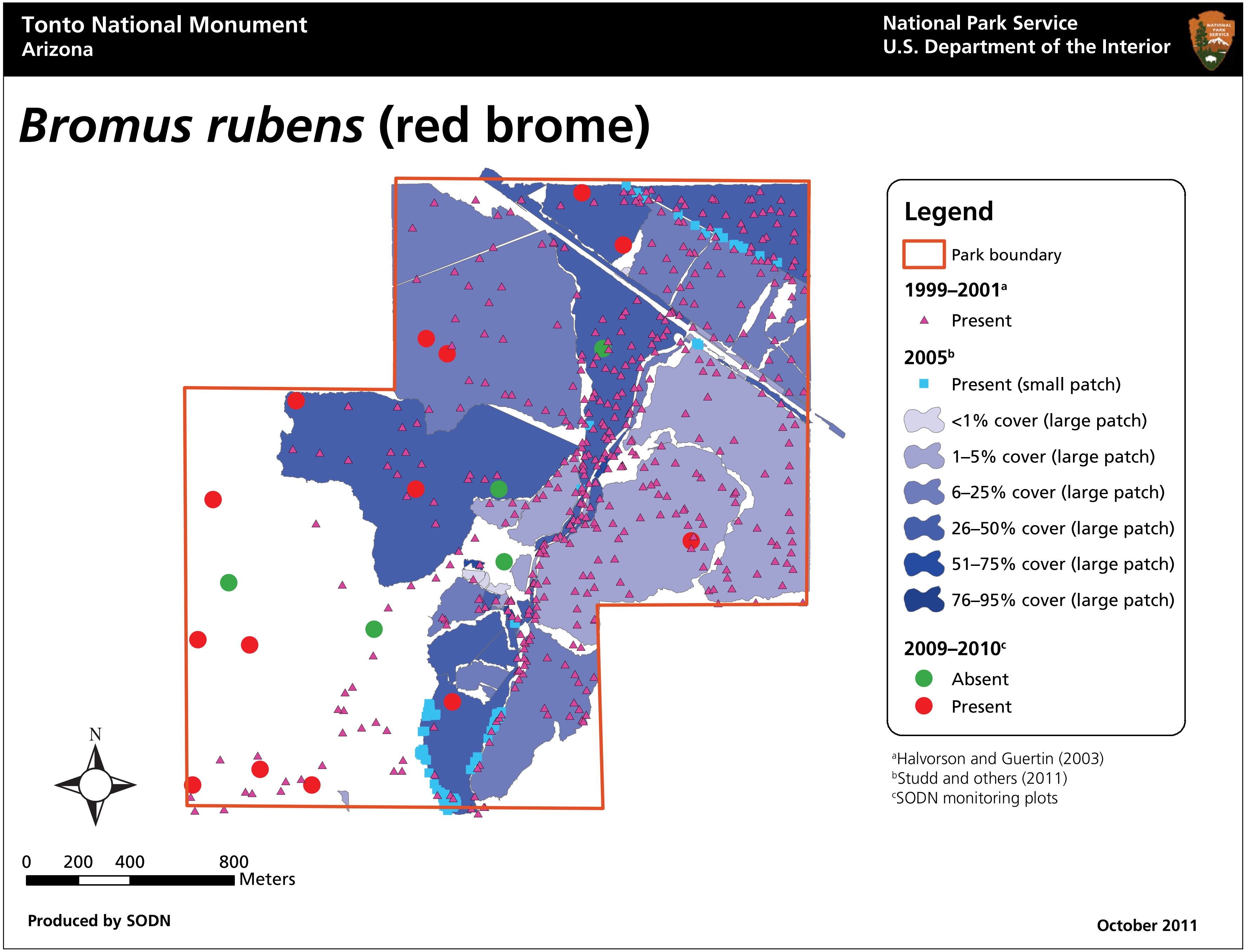

Figure 4-2. Distribution of the exotic annual grass, *Bromus rubens* (red brome), at Tonto National Monument, based on current and historical data.

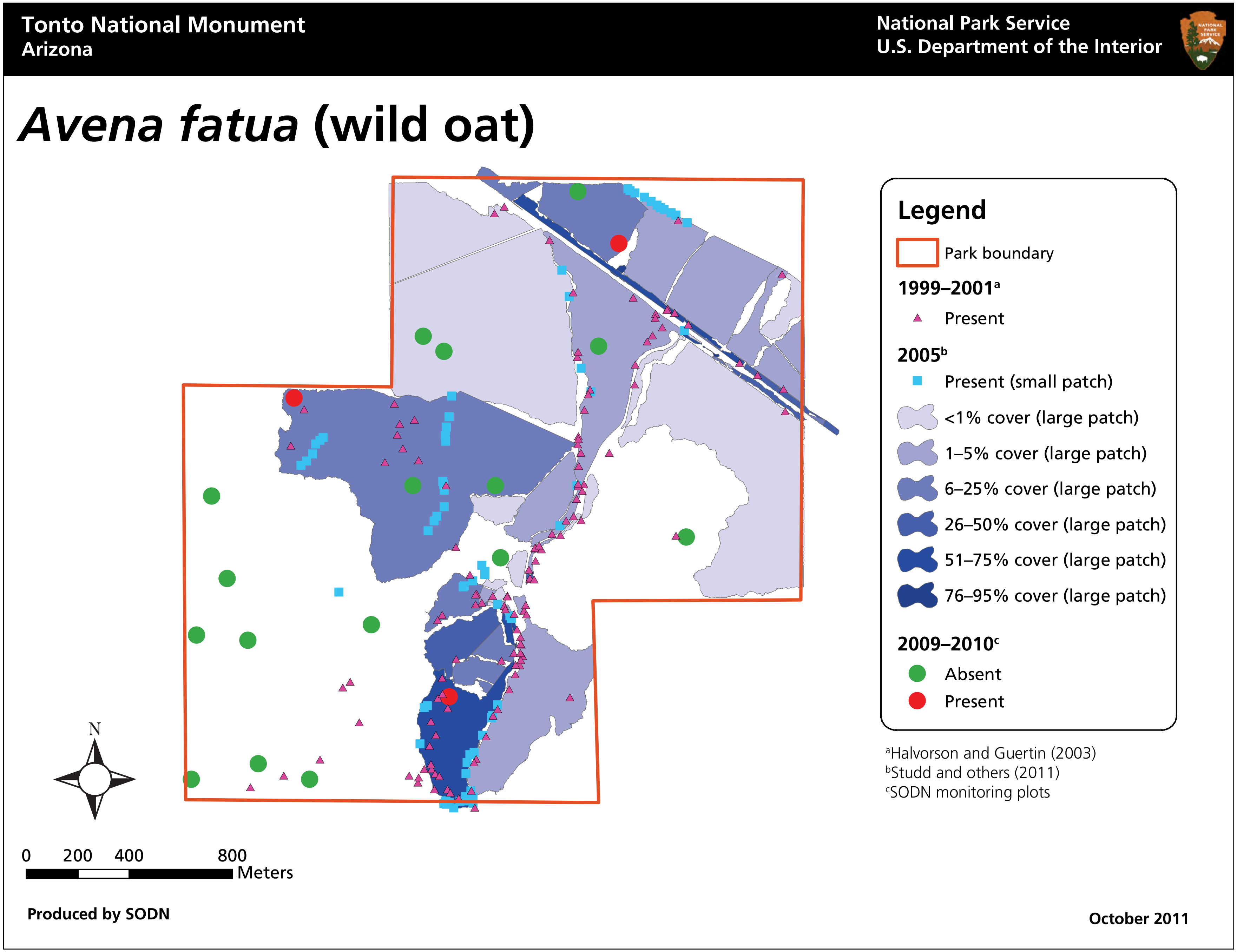

Figure 4-3. Distribution of the exotic annual grass, *Avena fatua* (wild oat), at Tonto National Monument, based on current and historical data.

tolerant invasive species is primarily restricted to higher-elevation locations and riparian corridors (see Table 3-1, Figure 4-4).

Introduced to the American Southwest in the 1930s as a forage grass, Lehmann lovegrass is a warm-season (C4 photosynthetic pathway) bunchgrass from southern Africa that acts more like a cool-season (C3 pathway) grass, often initiating new growth following late winter rains rather than during the monsoons of late summer (Anable et al. 1992). Lehmann lovegrass is relatively tolerant of grazing and drought (Wright and Dobrenz 1973), and derives a competitive advantage over many native species when these factors are present (Bock et al. 2007). Widely seeded in the American Southwest in the middle twentieth century, Lehmann lovegrass tends to eventually dominate even ungrazed sites where it has been planted (Bock et al. 2007), with major negative consequences for native flora and fauna (Bock et al. 1986).

Whereas red brome is found throughout the monument in a diffuse matrix, Lehmann lovegrass generally occurs in scattered, disjunct patches that can be locally dense—particularly on more marginal sites and those with recent and recurring disturbance (Studd et al. 2011) (Figure 4-4). In a stark contrast, however, Lehmann lovegrass is a common and, in places, even co-dominant species on the adjacent Tonto National Forest (NF) (Studd et al. 2011).

Why might this "fenceline" contrast be so sharp? The answer likely lays in the differences in livestock grazing and range restoration practices practiced on monument and forest lands. Grazing throughout the Tonto Basin peaked in the late nineteenth to early twentieth centuries (Croxen 1926)—the heyday of intensive livestock grazing in the American Southwest. Restricted in the 1940s, and completely retired in the 1970s, grazing within the monument appeared to be most intensive in the riparian area and adjacent slopes of upper Cave Canyon, portions of Deadman Canyon, and the lower bajada in the northern portion of the monument (Jenkins et al. 1995). However, the steep and challenging terrain of areas above 3,700' likely limited livestock use of these areas, even prior to livestock removal. By contrast, livestock production has remained an important land-management objective through to the present on adjacent Tonto NF lands, many of which are somewhat more accessible to grazing animals at higher elevations.

Post-fire restoration treatments have also differed across the boundary. Tonto NF extensively seeded Lehmann lovegrass adjacent to the park in upper Cave Canyon (following the 1964 Schultz Fire), whereas only the native shrub, jojoba, was seeded on the monument (Phillips 1997).

The combination of greatly reducing livestock grazing and the lack of active seeding within the monument appears to be a critical factor in the avoidance of a common problem in the American Southwest: degraded, Lehmann lovegrass-dominated rangelands (Bock et al. 2007). Neither future livestock grazing nor Lehmann lovegrass seeding is likely on monument lands, which bodes well for native vegetation at higher elevations of Tonto NM.

4.3 The surprising role of fire in a desert landscape

Wildfire has played a surprisingly active and pervasive role in terrestrial ecosystems at Tonto NM. From 1947 to 1980 (Phillips 1997), five intense wildfires of at least 10 ha (24 ac) each burned through the monument (Figure 4-5). This equates to a 21-year fire return interval from park establishment to the present, with an interval of less than seven years during the most active period. These return intervals are more characteristic of pre-settlement semi-desert grassland (McPherson 1995) than of Sonoran Desert shrubland, which typically has intervals of approximately 300 years (Rogers 1986). Although fire frequency in the greater Sonoran Desert ecoregion increased over the latter half of the twentieth century (Schmid and Rogers 1988), nothing like an increase of 15× has been observed elsewhere. Why has Tonto NM been the subject of such intense and recurrent fire? The answer is multi-faceted.

Tonto NM is often perceived as a classic Sonoran Desert park, replete with majestic saguaro cacti and other emblematic hot-desert plants. However, despite its small extent, Tonto NM actually comprises an important transition between (1) the Sonoran Desert scrub in the lower bajada that is most visible to visitors, (2) the lowest, most xeric extent of semi-desert grassland, and (3) at the highest and most mesic sites, interior chaparral (Jenkins et al. 1995). These three biomes roughly correspond with SODN's elevation strata for monitoring, and reflect the diversity and ecological dynamism that topography can create in the American Southwest. A more accurate way to

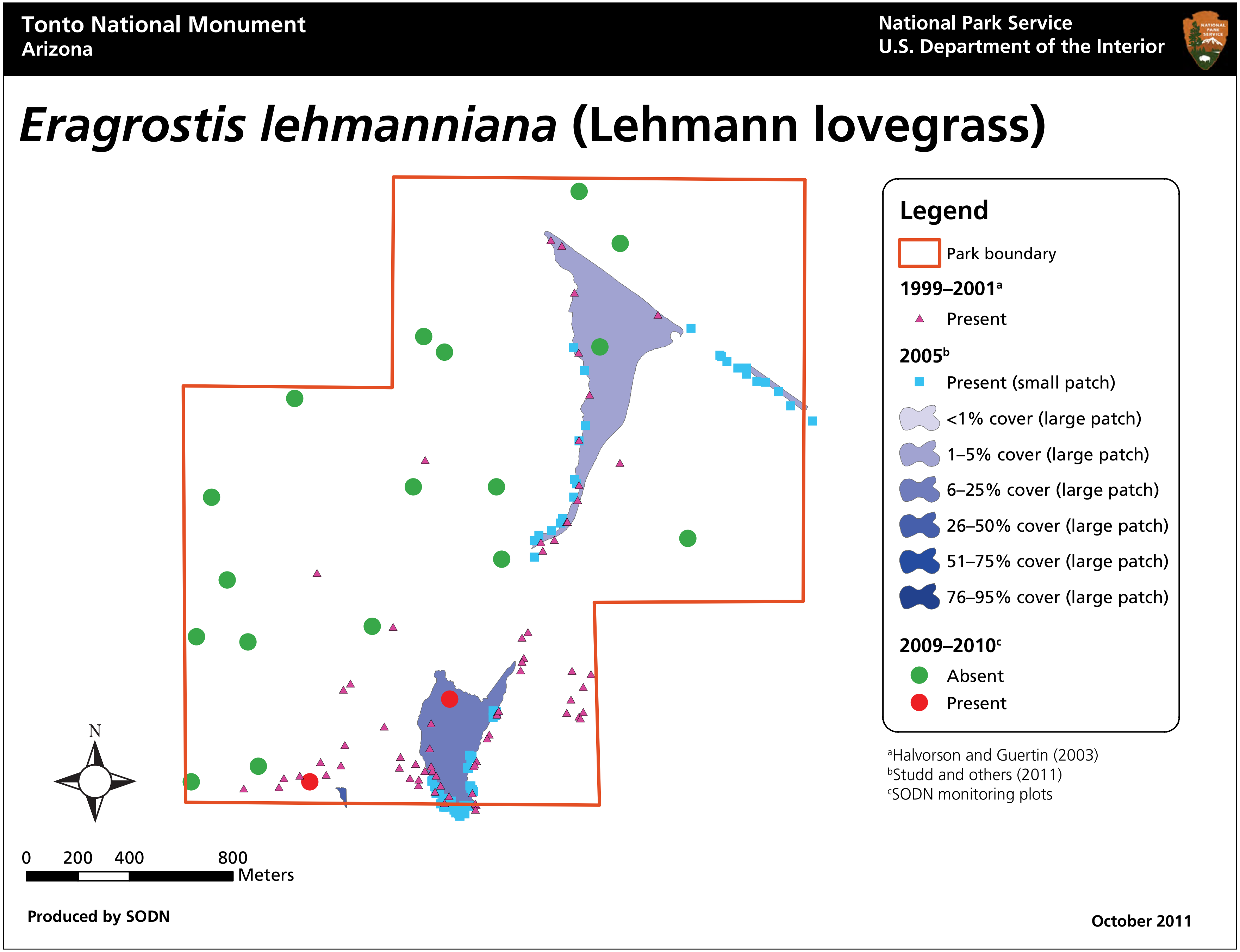

Figure 4-4. Distribution of the exotic perennial grass, *Eragrostis lehmanniana* (Lehmann lovegrass), at Tonto National Monument based on current and historical data.

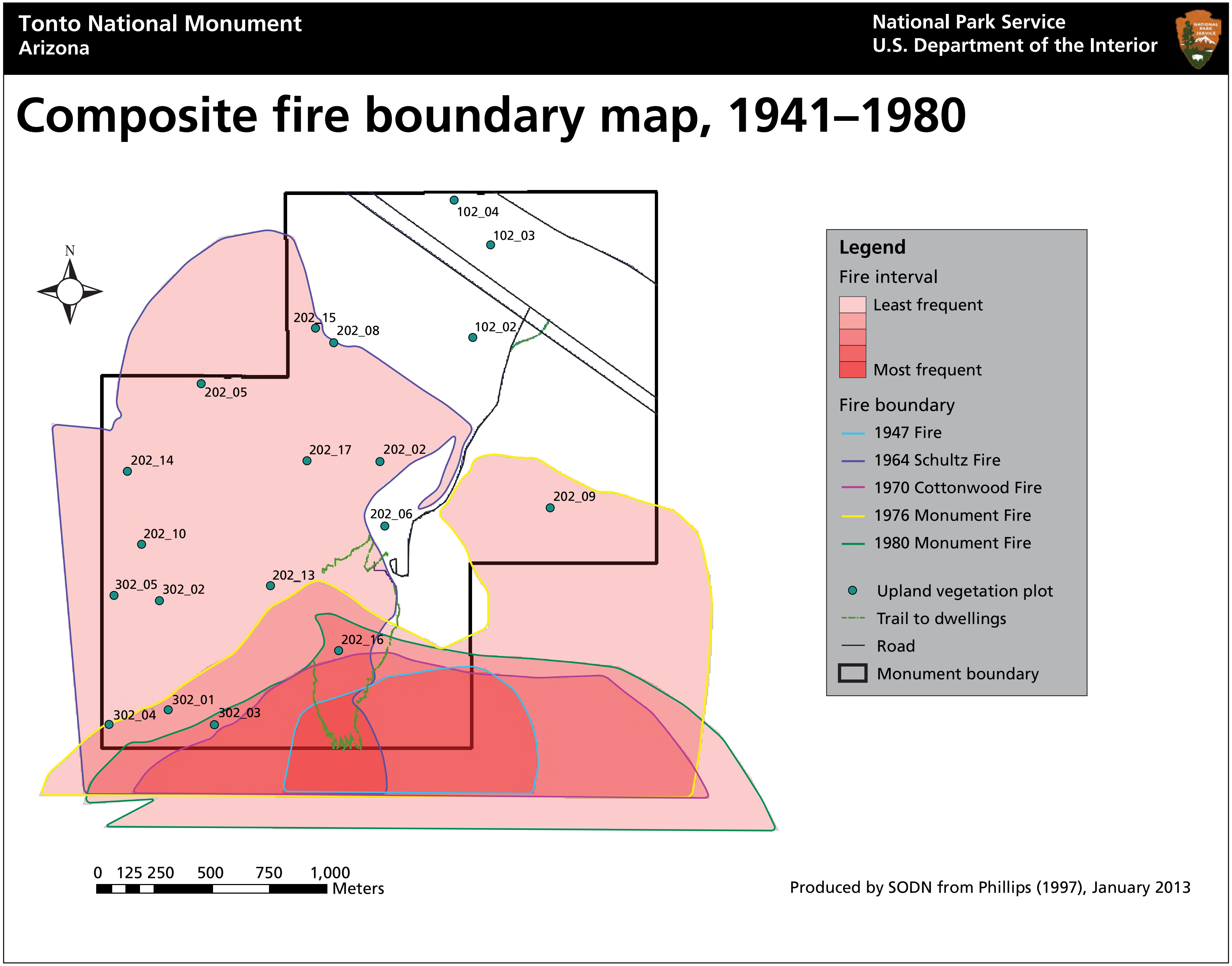

Figure 4-5. Distributions of the five large (>10-ha) wildfires that have occurred at Tonto National Monument since 1940. Fire boundaries are based on Phillips (1997).

think of Tonto NM is as a desert foothills park, with ecological connections to both the Salt River Valley and the Mogollon Rim.

Its connections with the Mogollon Rim likely drive the active fire ecology of Tonto NM. As illustrated in Figure 4-5, there was a high degree of overlap with all five fires from 1947 to 1980, generally centered along Cave Canyon, on the southern boundary. All but one of those fires (the 1976 Monument Fire) started from lightning strikes at higher elevations on Tonto NF, burning into the park from the south. With the exception of the more extensive Schultz Fire (1964), the same middle and higher elevations of the park were burned repeatedly. These areas generally correspond with the semi-desert grassland areas of the park (Jenkins et al. 1995; Studd unpublished data)—albeit with fire frequencies far shorter than those of many other semi-desert grassland parks. For example, fire has been absent from grasslands at Fort Bowie National Historic Site since at least the park's establishment in the early 1970s (Hubbard et al. 2010).

The fairly tight match between fire perimeters and the transition from semi-desert grassland to Sonoran Desert scrub suggests that fuel limitations effectively curtail fire from spreading to lower elevations during most years, supporting the view of Jenkins and others (1995) that mid-elevations are an ecotone between desert shrublands and grasslands/savanna, and suggesting a dynamic transition in which recent fire history plays a central role, such that increased fire frequency facilitates grassland/savanna expansion downslope by mediating competitive relationships between lifeforms. Grasses, forbs, and some shrubs are generally very tolerant of fire, whereas most desert plants (especially succulents) are intolerant of fire (Brooks and Chambers 2011). Frequent fire supports the establishment of grasslands and savannas (Scholes and Archer 1997), whereas a lack of fire permits more drought-tolerant desert vegetation to dominate the flora.

By contrast, lower-elevation locations have been relatively protected from wildfire since the monument's establishment. The only outlier (the Schultz Fire of 1964, which burned extensively through lower elevations) occurred during the dry season following one of the coolest, wettest monsoons recorded in the Tonto Basin (based on data from ROOSEVELT 1 WNW, a nearby NOAA weather station; Figure 4-6). August 1963, alone,

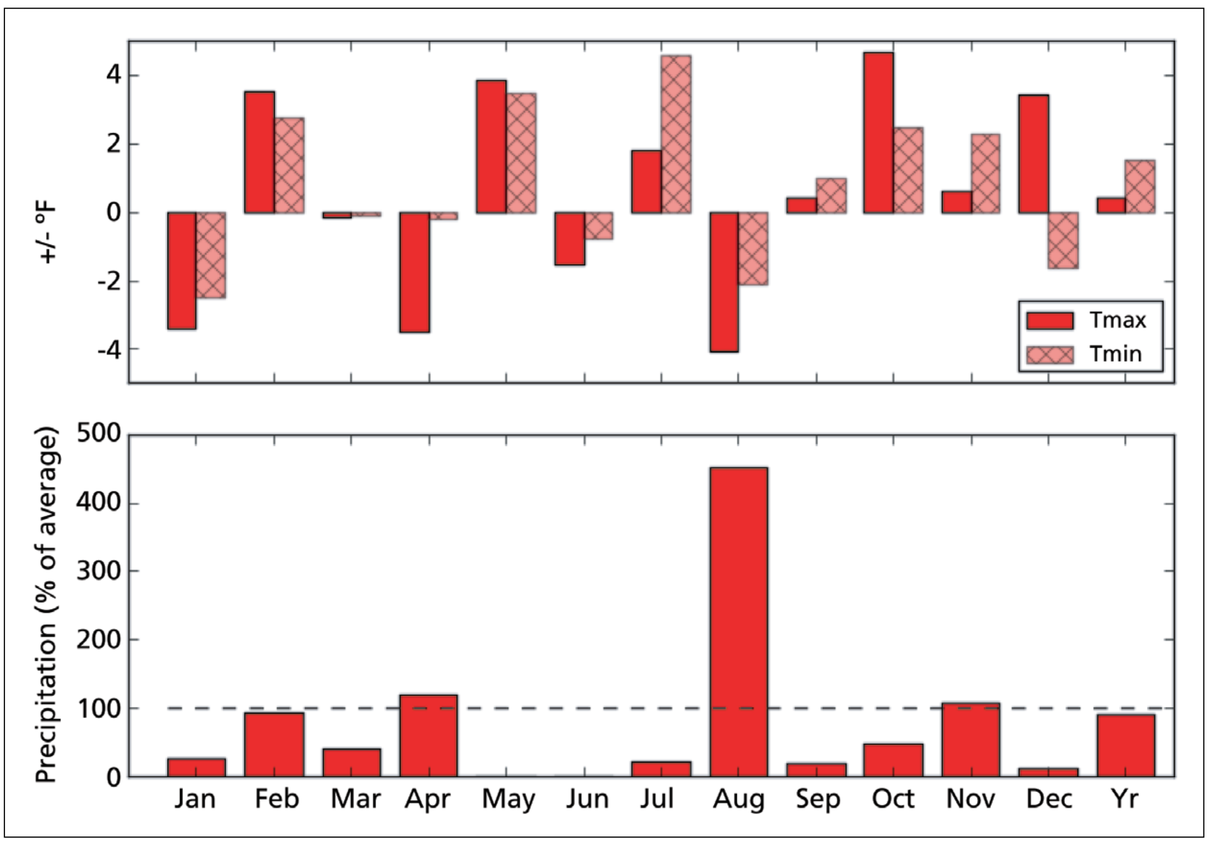

Figure 4-6. Departures from 30-year normals for precipitation and air temperature in 1963, as collected from a nearby weather station (ROOSEVELT 1 WNW). The massive Schultz Fire occurred during the following June.

had approximately 450% of the 30-year normal precipitation for that month, likely driving a profusion of grass and forb growth that, in turn, yielded an exceedingly high fine-fuel load, even in low-elevation, desert locations.

Unfortunately, fine-fuel load and continuity are not driven solely by unusual climate cycles. The colonization and spread of the non-native grasses, wild oat, red brome, and Lehmann lovegrass, have all been associated with increasing fire risk, and all respond positively to the effects of fire (Cable 1971; Brown and Smith 2000; Esque and Schwalbe 2000; Burquez-Montijo et al. 2002; AZ-WIPWG 2005a, 2005b). Persistence of these species has the potential to significantly alter the lower-elevation frontcountry landscape at Tonto NM, where repeated fires would likely have adverse impacts to native vegetation, including the characteristic cactus species.

4.4 Biological soil crusts

The biological soil crust community of Tonto NM is dominated by bryophytes (mosses and liverworts), which is unusual for the Sonoran Desert (Rosentreter and Belnap 2003). Cyanobacteria typically dominate biological soil crusts in the Sonoran Desert, with gelatinous lichens, squamulose lichens, and short mosses as important subdominants. Bryophyte occurrence and cover is generally more associated with mid- and higher elevations, where lower temperatures and higher effective moisture favor these lifeforms (Rostentreter and Belnap 2003). Additionally, Arizona spikemoss provides substantial ground cover and can help stabilize the soil surface in a manner similar to biological soil crusts (J. Belnap, personal communication).

In addition to bryophytes and cyanobacteria, field crews identified all five types of lichen growth forms at Tonto NM, suggesting a high degree of lichen diversity for such a small unit. High crust cover and diversity generally support enhanced ecosystem resilience (Gunderson 2000), as morphological groups and growth forms offer different relative contributions to erosion resistance and nitrogen fixation, and recover from disturbance at different rates (Table 4-1). The prevalence of bryophytes suggests that the soil surface is relatively moist and well-protected from water and wind erosion.

4.5 Site and soil stability

Our erosion data suggest that terrestrial locations within Tonto NM are generally stable. Overall, surface soil aggregate stability is fairly high; only one plot had an average stability value of less than 3. Total soil cover is also high, with little exposed bare soil (total bare soil averages less than 13%). Taken collectively, these results indicate a high degree of inherent resistance to raindrop and surface-flow erosion—important insurance against both natural and cultural resource loss within the monument.

However, plant litter comprised nearly one-third of soil cover, suggesting that site susceptibility to wind and water erosion could increase if fire or drought diminished litter cover. Although we did not observe any obvious signs of disturbance, six plots (102_V03, 202_V08, 202_V09, 202_V013, V202_V017, 302_V04) had rills or gullies (Figure 4-7). These features—generally small and limited within a given site—are likely the natural consequences of sporadic, extreme precipitation events in a semi-arid ecosystem, as well as the legacy of twentieth-century livestock grazing within the monument.

4.6 Implications for terrestrial vegetation and soils monitoring

Because this effort entailed some of the first terrestrial vegetation and soils monitoring in the Sonoran Desert Network, much of our focus was on evaluating the efficacy of the sampling and response designs to support improvement of the protocol. We found the plot sampling design to be efficient. Most plots were sampled within 2–4 hours, including tasks that will not need to be repeated in successive visits (i.e., initial plot layout, permanent marking and mapping, and collection of in situ soil and landscape parameters).

One major logistical limitation at Tonto NM is the challenging terrain, which added greatly to travel time to and from plots despite the relatively short distances travelled. Choosing routes that minimized tripping and falling hazards within the steep, rocky landscape at Tonto NM further increased data collection time. Overall field effort at Tonto NM was therefore higher than at the other small SODN parks—an important factor when planning and conducting repeat sampling.

Our first round of sampling at Tonto NM provided some key "lessons learned" that enhanced the SODN terrestrial vegetation and soils monitoring protocol (Hubbard et al. 2012) and efforts through the Southwest Network Collaboration

Table 4-1. Ecological function of biological soil crust morphological groups and lichen growth forms.

Morphological group/ Growth form	Description	Ecological function: Water erosion protection	Wind erosion protection	Nitrogen fixation	Recovery from disturbance
Cyanobacteria	Filamentous or single-celled bacteria	+	+	Yes	Fast
Bryophytes	Non-vascular plants, including mosses and liverworts	+++++	+++++	No	Typically slow but depends on species
Lichen					
Crustose	Lichens forming a crust-like growth that is tightly attached to the substrate	+++	++	Some	Moderate
Foliose	Three-dimensional lichens. Foliose lichens tend to be flattened, lichens with a definite upper and lower surface.	+++	+++	Some	Slow
Fruticose	Three-dimensional lichens. Fruticose lichens tend to be ropy or shrub-like, and are sometimes branched.	+++	+++	Some	Slow
Gelatinous	Lichens with an unlayered thallus becoming jelly-like when wetted. They tend to be blackish in color and turn blue-green when wet. Algal partner is a cyanobacterium.	++	++	Yes	Fast
Squamulose	Lichens with thalli occurring as discrete scales, warts or flakes that can be ear-shaped, convex or concave	++++	+++	Some	Moderate

After Eldridge and Rosentreter (1999) and Belnap and others (2001).
The + to +++++ range is a general relative scale that describes how well a particular growth form protects the soil from water or wind erosion. +++++ provides the most protection.

(see Section 3.5). The most pressing was the importance of adequate sample size for species detectability, composition, and statistical power to detect trends. Following the 2009 sampling period, our initial analyses strongly suggested that our sample size for high-elevation sites (>3,701', 302 stratum) was insufficient. The addition of two plots to this stratum in 2010 resulted in a robust dataset, improved power, and added clear insights into an unusual, interesting, and important high-elevation vegetation type, mountain mahogany/crucifixion thorn chaparral. Following this experience, we now set five plots per stratum as the minimum sample size for all units covered by this protocol.

4.7 Are terrestrial vegetation and soils within the range of natural variability?

Our data reflect an intact and functioning terrestrial ecosystem with species abundances and diversity within expected ranges. Vegetation composition and abundance are consistent with published data from elsewhere in the Sonoran Desert ecoregion, as well as network monitoring data from other SODN parks. Our results further suggest that our sites well represent the upland communities found at the monument through the detailed vegetation classification and mapping effort (Studd 2011).

As this was only the first comprehensive terrestrial vegetation and soils monitoring effort at Tonto NM, we are unable to conduct trend analyses. However, somewhat limited historical and anecdotal data from Tonto NM may provide some insights into possible trends in vegetation during the last half of the twentieth century.

Jenkins and others (1995) and Phillips (1997) used repeat photographs, historic park records, and plot data (from the 1990s) to conclude that vegetation changes had occurred between the 1950s and 1990s. Specifically, both cited (1) increased shrub density in both terrestrial upland and xeroriparian habitats throughout the

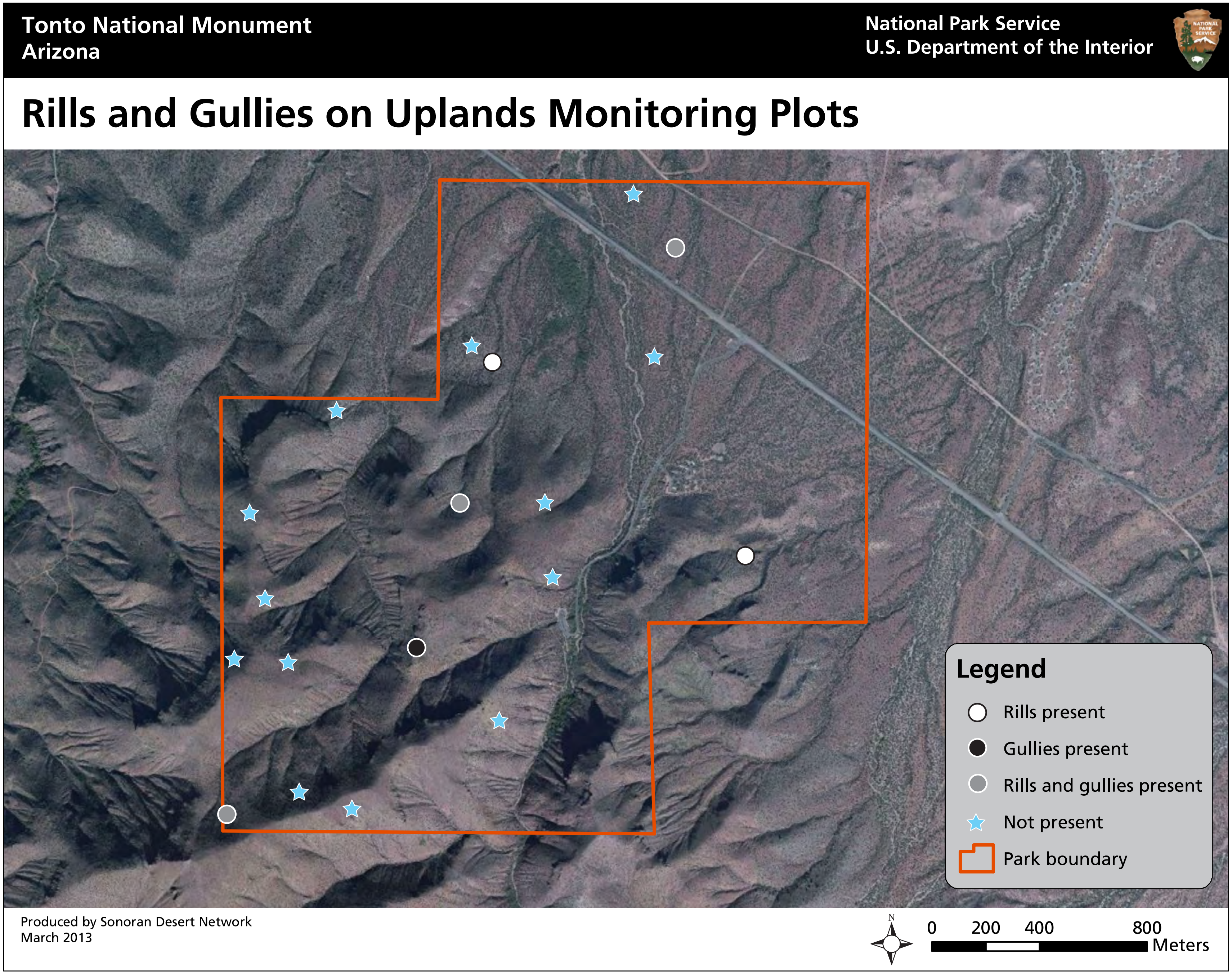

Figure 4-7. Presence and absence of rills and gullies on monitoring plots, Tonto National Monument.

monument, and (2) a decrease in succulents and other characteristic desert scrub plants in upper Cave Canyon and adjacent areas along the southern boundary. They linked the former to the restriction and eventual removal of livestock grazing during the same period, whereas the latter (more localized reduction in desert scrub) was attributed to a period of unusually high fire frequency.

While compelling, the base datasets for both studies are relatively limited both in spatial and temporal extent and relatively little field data were actually collected in these focused assessments. Continued terrestrial vegetation and soils monitoring will permit us to better assess the accuracy of their conclusions, and detect any directional changes going forward.

Within the context of the network's vital signs for species composition, community structure, and dynamic soil function, we conclude that terrestrial vegetation and soils at Tonto NM are within the range of natural variability, and current conditions suggest a degree of resistance to exotic-plant encroachment and resilience to altered wildfire regimes and enhanced erosion.

5 Literature Cited

Aber, J., and J. Melillo. 1991. Terrestrial ecosystems. Philadelphia, Pa.: Saunders College Publishing.

Albrecht, E. W., B. F. Powell, W. L. Halvorson, and C. A. Schmidt. 2007. Vascular plant and vertebrate inventory of Tonto National Monument. U.S. Geological Survey Open-File Report 2007-1295. [http://pubs.usgs.gov/of/2007/1295/].

Anable, M. E., M. P. McClaran, and G. B. Ruyle. 1992. Spread of introduced Lehmann lovegrass *Eragrostis lehmanniana* Nees. in southern Arizona, USA. Biological Conservation 6:181–188.

Anderson, M. J., R. N. Gorley, and K.R. Clarke. 2008. PERMANOVA+ for PRIMER: Guide to software and statistical methods. PRIMER-E, Plymouth, U.K.

Arizona Game and Fish Department (AGFD). 1988. Threatened native wildlife in Arizona.

——. In prep. Wildlife of special concern in Arizona. Arizona Game and Fish Department, Phoenix, Arizona.

Arizona Wildland Invasive Plant Working Group. 2005a. *Avena fatua* plant assessment form, version 1. http://www.usgs.nau.edu/swepic/swvma/plantpdf/Avena_fatua_AZ_PAF.pdf. Accessed December 23, 2005.

——. 2005b. *Eragrostis lehmanniana* plant assessment form, version 1. http://www.usgs.nau.edu/swepic/swvma/plantpdf/Eragrostis_lehmanniana_AZ_PAF.pdf. Accessed December 23, 2005.

Bailey, R. G. 1998. Ecoregions: The ecosystem geography of the oceans and continents. New York: Springer-Verlag Inc.

Belnap, J. 2003. Factors influencing nitrogen fixation and nitrogen release in biological soil crusts. Pages 241–261 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.

Belnap, J., B. Büdel, and O. L. Lange. 2003. Biological soil crusts: Characteristics and distribution. Pages 3–30 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.

Belnap J., and D. Eldridge. 2003. Disturbance and recovery of biological soil crusts. Pages 363–383 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.

Belnap, J., J. H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard, and D. Eldridge. 2001. Biological soil crusts: Ecology and management. BLM Technical Reference 1730-2. Bureau of Land Management, Denver, Colorado.

Belnap, J., S. L. Phillips, J. E. Herrick, and J. R. Johansen. 2007. Wind erodibility of soils at Fort Irwin, California (Mojave Desert), USA, before and after trampling disturbance: Implications for land management. Earth Surface Processes and Landforms 32:75–84.

Bennetts, R. E., J. E. Gross, K. Cahill, C. L. McIntyre, B. B. Bingham, J. A. Hubbard, L. Cameron, and S. L. Carter. 2007. Linking monitoring to management and planning: Assessments points as a generalized approach. The George Wright Forum 24(2):59–77.

Bingham, B. B., R. E. Bennetts, and J. A. Hubbard. 2007. Integrating science and management: the road to Rico-Chico. The George Wright Forum 24(2):21–25.

Bock, C. E., J. H. Bock, K. L. Jepson, and J. C. Ortega. 1986. Ecological effects of planting African lovegrasses in Arizona. National Geographic Research 2:456–463.

Bock, C. E., J. H. Bock, L. Kennedy, and Z. F. Jones. 2007. Spread of non-native grasses into grazed versus ungrazed desert grasslands. Journal of Arid Environments 71:229–235.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. New York: Wiley-Interscience.

Brian, N. J. 1991. Resurvey of 1961 line intercept transects at Tonto National Monument, Arizona. Technical Report No. 38. Tucson: University of Arizona Press.

Brooks, M. L., and J. C. Chambers. 2011. Resistance to invasion and resilience to fire in desert shrublands of North America. Rangeland Ecology and Management 64(5):431–438.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677–688.

Brooks, M. L., T. C. Esque, and T. Duck. 2003. Fuels and fire regimes in creosotebush, blackbrush, and interior chaparral shrublands. Report for the Southern Utah Demonstration Fuels Project, U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado.

Brooks, M. L., and G. R. McPherson. 2008. Ecological role of fire and causes and ecological effects of altered fire regimes in the southwest. Proceedings from the Southwest Region Threatened, Endangered, and At-Risk Species Workshop; October 22–25, 2007; Tucson, Arizona. Reston, Va.: HydroGeoLogic 8–1 through 8–3.

Brown, D. E. 1982. Biotic communities of the American Southwest United States and Mexico. Desert Plants 4:1–341.

Brown, J., and S. Archer. 1999. Shrub invasion of grassland: Recruitment is continuous and not regulated by herbaceous biomass or density. Ecology 80(7):2385–2396.

Brown, J. K., and J. K. Smith, eds. 2000. Wildland fire in ecosystems: Effects of fire on flora. Gen. Tech. Rep. RMRS-GRT-42, vol. 2. U.S. Forest Service Rocky Mountain Research Station, Ogden, Utah.

Burgess, R. L. 1965. A checklist of the vascular flora of Tonto National Monument, Arizona. Journal of the Arizona Academy of Science 3(4):213–223.

Burquez-Montijo, A., M. E. Miller, and A. Martinez-Yrizar. 2002. Mexican grasslands, thornscrub, and the transformation of the Sonoran Desert by invasive exotic buffelgrass (*Pennisetum ciliare*). Pages 126–146 *in* B. Tellman, ed., Invasive exotic species in the Sonoran region. Tucson: University of Arizona Press and the Arizona-Sonora Desert Museum.

Cable, D. R. 1971. Lehmann lovegrass on the Santa Rita Experimental Range, 1937–1968. Journal of Range Management 24:17–21.

Clarke, K. R., and R. M. Warwick. 2001. Change in marine communities: An approach to statistical analysis and interpretation, 2nd edition. Plymouth, U.K.: Primer-E, Ltd.

Croxen, F. W. 1926. History of grazing on Tonto. Paper presented at the Tonto Grazing Conference, Phoenix, Arizona.

D'Antonio, C., and P. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63–87.

Dallett, N. L. 2008. A confluence of change: A history of Tonto National Monument. Western National Parks Association, Tucson, Arizona.

Davenport, D. W., D. D. Breshears, B. P. Wilcox, and C. D. Allen. 1998. Viewpoint: Sustainability of pinyon-juniper ecosystems—a unifying perspective of soil erosion thresholds. Journal of Range Management 51(2):231–232.

Eldridge, D. J., and R. Rosentreter. 1999. Morphological groups: A framework for monitoring microphytic crusts in arid landscapes. Journal of Arid Environments 41:11–25.

Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management, Denver, Colorado. BLM Technical Reference 1730-1.

Esque, T. C., and C. Schwalbe. 2000. Nonnative grasses and fire create double jeopardy. People, Land, and Water, July/August. http://www.usgs.gov/invasive_species/plw/grassfire.html. Accessed June 21, 2004.

Gori, D. F., and C. A. F. Enquist. 2003. An assessment of the spatial extent and condition of grasslands in central and southern Arizona, southwestern New Mexico and northern Mexico. Prepared by The Nature Conservancy, Arizona Chapter.

Gray, S. T. 2008. Framework for linking climate, resource inventories and ecosystem monitoring. Natural Resource Technical Report NPS/GRYN/NRTR—2008/110. National Park Service, Fort Collins, Colorado.

Gunderson, L. H. 2000. Ecological resilience–in theory and application. Annual Review of Ecology and Systematics 31:425–439.

Halvorson, W. L., and P. Guertin. 2003. USGS Weeds in the West: Status of introduced plants in southern Arizona parks. http://sdfsnet.srnr.arizona.edu/index.php?page=datamenu&lib=2&sublib=13. Accessed September 30, 2011.

Herrick, J. E., J. W. Van Zee, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005a. Monitoring manual for grassland, shrubland and savanna ecosystems. Volume 1: Quick start. U.S. Department of Agriculture Agricultural Research Service, Jornada Experimental Range, Las Cruces, New Mexico.

——. 2005b. Monitoring manual for grassland, shrubland, and savanna ecosystems. Volume II: Design, supplementary methods, and interpretation. Tucson:University of Arizona Press.

Hiett, K. L., and W. L. Halvorson. 1999. Inventory and assessment of avifauna and a monitoring protocol proposal for Tonto National Monument, Arizona. Technical Report No. 62. USGS Cooperative Park Studies Unit, School of Renewable Natural Resources, University of Arizona, Tucson.

Hubbard, J. A., C. L. McIntyre, S. E. Studd, T. W. Nauman, D. Angell, M. K. Connor, and K. Beaupré. 2012. Terrestrial vegetation and soils monitoring protocol and standard operating procedures for the Sonoran Desert Network. Natural Resource Report NPS/SODN/NRR—2012/509. National Park Service, Fort Collins, Colorado.

Hubbard, J. A., S. Studd, and C. McIntyre. 2010. Terrestrial vegetation and soils monitoring at Fort Bowie National Historic Site: 2008 status report. Natural Resource Technical Report NPS/SODN/NRTR—2010/368. National Park Service, Fort Collins, Colorado.

Ingram, M., 2000. Desert storms. Pages 41–50 *in* S. J. Phillips and P. W. Comus, eds., A natural history of the Sonoran Desert. Tucson: Arizona-Sonora Desert Museum Press.

Jenkins, P. D., F. W. Reichenbacher, K. Johnson, and A. Condor. 1995. Vegetation inventory, classification, and monitoring for Tonto National Monument, Arizona. National Biological Service, Cooperative Park Studies Unit, University of Arizona. Technical report No. 50.

Keeley, J. E., and F. W. Davis. 2000. Chaparral. Pages 203–253 *in* M. G. Barbour and W. D. Billings, eds., North American terrestrial vegetation. Second edition. Cambridge, U.K.: Cambridge University Press.

Lange, O. L. 2003. Photosynthesis of soil-crust biota as dependent on environmental factors. Pages 217–240 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management. Ecological Studies Series 150, second edition. Berlin, Germany.

Lindsay, B. A., D. G. Robinett, and F. R. Toupal. 1994. Soil survey of Tonto National Monument. U.S. Department of Agriculture, Soil Conservation Service, Tucson, Arizona.

Martin, L. 2001. Hydrogeology and potable water supply, Tonto National Monument. Arizona. National Park Service, Water Resources Division.

McAuliffe, J. R. 1999. The Sonoran Desert: Landscape complexity and ecological diversity. Pages 68–114 *in* R. H. Robichaux, ed., Ecology of Sonoran Desert plants and plant communities. Tucson: University of Arizona Press.

McIntyre, C. 2008. Erosion assessment of cultural resource sites using an index method for Tonto National Monument. Unpublished report to the National Park Service. Sonoran Institute, Tucson, Arizona.

McPherson, G. R. 1995. The role of fire in desert grasslands. Pages 130–151 *in* M. P. McClaran and T. Van Devender, eds., The desert grassland. Tucson: University of Arizona Press.

National Climatic Data Center (NCDC). 2012. 1981–2010 climate normals for Roosevelt, Arizona. http://www.ncdc.noaa.gov/cdo-web. Accessed October 4, 2011.

National Park Service (NPS). 2005. Sonoran Desert Network monitoring plan. National Park Service, Sonoran Desert Network, Tucson, Arizona.

——. 2006. Geologic resource evaluation scoping summary: Tonto National Monument, Arizona. National Park Service, Geologic Resources Division, Denver, Colorado.

——. 2009. Strategic plan for natural resource inventories: FY 2008–FY 2012. Natural Resource Report NPS/NRPC/NRR—2009/094. National Park Service, Fort Collins, Colorado.

——. 2011. Public use statistics office, annual park visitation report for Tonto NM. http://www.nature.nps.gov/stats. Last accessed 9/29/2011.

Nations, D., and E. Stump. 1996. Geology of Arizona. Second edition. Dubuque, Ia.: Kendall/Hunt.

Nauman, T. 2007. Water erosion prediction project (WEPP) use for assessment of cultural site water erosion risk at Tonto National Monument, Arizona. Unpublished report to the National Park Service. Sonoran Institute, Tucson, Arizona.

Nauman, T., and C. McIntyre. 2008. Erosion assessment of cultural resource sites at Tonto National Monument: Water erosion prediction project (WEPP) simulations. Unpublished report to the National Park Service. Sonoran Institute, Tucson, Arizona.

Phillips, B. 1992. Status of non-native plant species, Tonto National Monument, Arizona. Technical report NPS/WRUA/NRTR-92/46. http://sdrsnet.srnr.arizona.edu/index.php?page=reports.

——. 1997. History of fire and fire impacts at Tonto National Monument, Arizona. Technical report No. 59. http://sdrsnet.srnr.arizona.edu/index.php?page=reports.

Rogers, G. F. 1986. Comparison of fire occurrence in desert and nondesert vegetation in the Tonto National Forest, Arizona. Madrono 33:278–283.

Rosentreter, R., and J. Belnap. 2003. Biological soil crusts of North America. Pages 31–50 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.

Scarborough, R. 2000. The geologic origin of the Sonoran Desert. Pages 71–85 *in* S. J. Phillips and P. W. Comus, eds., A natural history of the Sonoran Desert. Tucson, Az.: Arizona-Sonora Desert Museum Press.

Schmid, M. K., and G. F. Rogers. 1988. Trends in fire occurrence in the Arizona upland subdivision of the Sonoran Desert, 1955 to 1983. The Southwestern Naturalist 33:437–444.

Scholes, R. J., and S. R. Archer. 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics 28:517–544.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the U.S. Southwest. Climate Research 21:219–238.

Shinneman, D. J., and W. L.Baker. 2009. Environmental and climatic variables as potential drivers of post-fire cover of cheatgrass (*Bromus tectorum*) in seeded and unseeded semi-arid ecosystems. International Journal of Wildland Fire 18:191–202.

Shreve, F. 1951. Vegetation of the Sonoran Desert. Washington, D.C.: Carnegie Institution of Washington Publication no. 591.

Skagen, S. K., C. P. Melcher, W. H. Howe, and F. L. Knopf. 1998. Comparative use of riparian corridors and oases by migrating birds in southeast Arizona. Conservation Biology 12:896–909.

Sprouse, T., R. Emanuel, and B. Tellman. 2002. Surface Water quality monitoring overview and assessment: National Park Service, Sonoran Desert Network. Water Resources Research Center, University of Arizona, Tucson.

Stehman, S. V. 1999. Basic probabilistic sampling for thematic mapper accuracy assessment. International Journal of Remote Sensing 20:2347–2366.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Studd, S. E. Classification of intuitively mapped vegetation communities. 2011. Master's thesis, University of Arizona, Tucson.

Studd, S. E., T. M. Mau-Crimmins, and J. Welborn. 2011. Invasive plant mapping inventory for Tonto National Monument, 2005. Natural Resource Technical

Report NPS/SODN/NRTR—2011/478. National Park Service, Fort Collins, Colorado.

Theobald, D. M., D. L. Stevens, Jr., D. White, N. S. Urquart, A. R. Olsen, and J. B. Norman. 2007. Using GIS to generate spatially balanced designs for natural resource applications. Environmental Management 40:134–146.

U.S. Census Bureau, American FactFinder (USCB). 2011. 2010 Census Summary File 1. http://factfinder2.census.gov/. Last accessed October 4, 2011.

U.S. Fish and Wildlife Service (USFWS). 2011. Yellow-billed cuckoo (*Coccyzus americanus*) species profile. http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=B06R. Last accessed November 4, 2011.

Warren, S. D. 2003. Synopsis: Influence of biological soil crusts on arid land hydrology and soil stability. Pages 349–360 *in* J. Belnap and O. L. Lange, eds., Biological soil crusts: Structure, function, and management (2nd ed.). Ecological studies series 150. Berlin: Springer-Verlag.

Whittaker, R. H. 1975. Communities and ecosystems. Indianapolis, In.: MacMillan.

Wright, L.N., and A.K. Dobrenz. 1973. Efficiency of water use and associated characteristics of Lehmann lovegrass. Journal of Range Management 26(3):210–212.

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