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Status of Terrestrial Vegetation and Soils at Montezuma Castle National Monument, 2010–2011

Natural Resource Technical Report NPS/SODN/NRTR—2014/870

ON THE COVER

Upland vegetation in the Verde limestone sampling group. NPS photo.

Status of Terrestrial Vegetation and Soils at Montezuma Castle National Monument, 2010–2011

Natural Resource Technical Report NPS/SODN/NRTR—2014/870

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Species Named in this Document

broom snakeweed	*Gutierrezia sarothrae*
broom milkwort	*Polygala scoparioides*
bush muhly	*Muhlenbergia porteri*
catclaw acacia	*Acacia greggii*
cockspur grass	*Echinochloa*
Coves' cassia	*Senna covesii*
creosote bush	*Larrea tridentata*
crucifixion thorn	*Canotia holacantha*
desertpeony	*Acourtia* sp.
ephedra	*Ephedra viridis*
featherplume	*Dalea formosa*
globemallow	*Sphaeralcea* sp.
graythorn	*Ziziphus obtusa*
horehound	*Marrubium vulgare*
Lehmann lovegrass	*Eragrostis lehmanniana*
littleleaf ratany	*Krameria erecta*
mariola	*Parthenium incanum*
oneseed juniper	*Juniperus monosperma*
pinkflower hedgehog cactus	*Echinocereus fasciculatus*
plains blackfoot	*Melampodium leucanthum*
purple threeawn	*Aristida purpurea*
red barberry	*Berberis haematocarpa*
red brome	*Bromus rubens*
redberry mahonia	*Mahonia haematocarpa*
redstem storksbill	*Erodium cicutarium*
rushpea	*Hoffmannseggia* sp.
velvet mesquite	*Prosopis velutina*

Executive Summary

This report summarizes results of the Sonoran Desert Network (SODN)'s first season of terrestrial vegetation and soils monitoring in upland areas of Montezuma Castle National Monument (NM), in central Arizona. Our objectives were to determine the status of and detect trends, over five-year intervals, in vegetation cover and frequency, soil cover, biological soil crust cover and frequency, and surface soil stability. Twelve permanent field-monitoring sites were established and sampled in 2010–2011.

Unfortunately, our initial sampling frame did not adequately account for the riparian area surrounding Beaver Creek. Two plots were revealed to contain obligate riparian plant species and evidence of past flooding—characteristics that place those areas outside the scope of SODN uplands monitoring. We subsequently excluded areas within a 20-m buffer of the 100-year floodplain and/or the Riverwash soil map unit to correct the sampling frame. However, this still did not remove all areas influenced by Beaver Creek. After constructing a relative elevation surface in a geographic information system and consulting with the SODN aquatic ecologist, we removed two additional plots from our sample because they were not true terrestrial plots.

Stratifying the eight remaining sampling plots by rock-fragment content in the surface soils proved insufficient for partitioning the variance in vegetation at Montezuma Castle NM. We re-combined the plots into two revised strata based on a plot's proximity to Beaver Creek and underlying geology. Here we present results from the remaining eight plots and revised strata.

Our data indicated two general classes of thornscrub vegetation in the upland areas of Montezuma Castle NM. The plots within the Verde limestone stratum occur on the highest and steepest slopes of the monument. These exposed rocky and calcareous plots support the shrub-scrub communities that are typical of this region, where crucifixion thorn (*Canotia holacantha*) and creosote bush (*Larrea tridentata*) co-mingle, and perennial bunchgrasses and thorny shrubs are occasional. In contrast, plots in the terrace stratum occur on low-gradient areas composed of old alluvium and are adjacent to the Beaver Creek floodplain. Terrace plots encompass transitional spaces between the active floodplain terraces (which support mesquite bosques) and the steep, scrubby uplands, and include species common to both. The vegetation communities of the terrace plots show greater floristic affinity to the northern Sonoran Desert.

Five exotic plant species were observed in the monitoring plots: red brome (*Bromus rubens*), redstem storksbill (*Erodium cicutarium*), horehound (*Marrubium vulgare*), Lehmann lovegrass (*Eragrostis lehmanniana*), and an annual grass in the genus *Echinochloa*. Red brome was one of the most widespread plants found in the park (recorded on 7 of 8 plots). Given the low cover of red brome, it appears that native species in upland areas can effectively compete with red brome under current conditions. However, red brome can promote fires and subsequently outcompete native species that are less fire-tolerant.

Upland areas of the park, as a whole, appeared to be moderately protected from soil erosion. Only 7.2 ± 1.9% of the soil surface consisted of exposed, bare mineral soil. However, 20% of soil cover was composed of leaf litter, which could be rapidly lost following wildfire or prolonged drought. In addition, the stability of surface soil aggregates (an indicator of soil structure) was below our proposed management assessment point for the terrace stratum and several individual plots, indicating the potential for soil erosion. Although biological soil crust cover was fairly low, the occurrence of biological soil crusts was fairly high across our monitoring plots.

We conclude that the terrestrial vegetation and soils in uplands of Montezuma Castle NM are within the historic range of natural variability. Our data reflect the influence of Beaver

Creek on vegetation that extends well beyond the 100-year floodplain. The Sonoran Desert Network will continue to monitor terrestrial vegetation and soils at Montezuma Castle NM, and will revisit the eight plots in 2015. We will add one plot to each stratum to try to increase species detectability and statistical power for detecting change in mesquite cover and soil aggregate stability. Continued monitoring will permit us to detect any directional changes in the terrestrial vegetation and soils going forward.

Acknowledgements

We thank Superintendent Dorothy FireCloud, Chief of Resources Matt Guebard, and the staff and volunteers of Montezuma Castle National Monument (NM) for their on-site support of the field effort and the overall Sonoran Desert Network (SODN) Inventory and Monitoring Program. Steve Buckley, Jeff Galvin, Shannon Henke, Megan Kimball, Kate Connor, Betsy Vance, Laura Tennant, Zachary Ahrens, and Kristina Young conducted the field data collection. Betsy Vance processed the soil samples at SODN. Subsequent soil chemical and physical parameter assessments were completed by The University of Arizona's Environmental Research Laboratory. Expert data processing and management were completed by SODN Data Manager Kristen Beaupré, and Steve Buckley updated the master plant list. Finally, we would be remiss if we did not recognize former superintendent Kathy Davis, former chief of resources Sharon Kim, and biologist Dennis Casper for their critical insights and key contributions to this protocol and other research and monitoring at Montezuma Castle NM.

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 defined conditions based on community structure or lifeform composition.

NPS/S. STUDD

Figure 1-1. Montezuma Castle, Montezuma Castle National Monument.

In the Sonoran Desert and Apache Highlands ecoregions (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:

"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" (Shreve 1951).

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 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 Montezuma Castle National Monument (NM; Figures 1-1, 1-2). 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 biological soil crusts, and the stability of surface soil aggregates.

NPS/S. STUDD

Figure 1-2. Upland vegetation, Montezuma Castle, Montezuma Castle 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, and 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 Montezuma Castle 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. Biological soil crust cover and frequency by lichen growth form and generalized morphological group (bryophyte, light cyanobacteria, dark cyanobacteria).

1.3 Scope of this report

This document reports and interprets the results of the first round of terrestrial vegetation and soils monitoring at Montezuma Castle NM. SODN does not monitor terrestrial vegetation and soils at the Well unit, as that unit contains relatively little upland habitat. This report focuses on current status, with trend evaluations to commence after the next sampling period in 2015. 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.

The thematic scope is limited to terrestrial ecosystems. Aquatic resources, including riparian and xeroriparian vegetation, are addressed in the SODN streams and washes protocols. The temporal scope of this document is 2010–2011.

1.4 Overview of terrestrial ecosystems at Montezuma Castle NM

1.4.1 Park establishment and purpose

Established in 1906, Montezuma Castle NM protects and interprets a complex of imposing cliff dwellings, pueblos, and other associated prehistoric sites, and the unique and diverse natural environment that attracted and supported these early civilizations (Protas 2002).

Using the new executive authority granted by the Antiquities Act (passed only a few weeks prior), President Theodore Roosevelt established a 65-hectare (160-acre) monument to protect " . . . the prehistoric structure known as Montezuma's Castle" because it was deemed to be " . . . of the greatest ethnological value and scientific interest" (34 Stat. 3265). Subsequent expansions in 1937, 1943, 1978, and 2003 increased park area to the current total of 334 hectares (826 acres), and included a new, detached unit: the unique sinkhole and riparian ecosystems and prehistoric pueblos of nearby Montezuma Well (Protas 2002).

Although the Antiquities Act provided legal protection for natural and cultural resources, funds, guidance, and infrastructure for the park were largely absent until the appointment of site custodian Martin Jackson in 1921, and the 1923 addition of the park to the Southwest National Monuments group led by famed Superintendent Frank "Boss" Pinkley (Protas 2002). Under the effective leadership of Jackson and Pinkley, and with slowly increasing resources and guidance from the relatively new National Park Ser-

vice, preservation and protection efforts began to counteract years of vandalism and negligence at the impressive cliff dwellings and other prehistoric 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 and associated rich natural resources of Beaver Creek, and the unique aquatic ecosystems of the sinkhole at Montezuma Well.

1.4.2 Biogeographic and physiographic context

Montezuma Castle NM lies along Beaver Creek near the town of Camp Verde, in central Arizona (Figure 1-3). Although the monument spans only about 300 feet in elevation (~3,200–3,500 ft, or 975–1,066 m), this small unit encompasses both lush aquatic and riparian ecosystems and relatively dry and sparse upland thornscrub separated by imposing, steep limestone cliffs. Neighboring lands are managed by the Coconino National Forest, the Arizona State Land Department, the Yavapai Apache Nation, and private landowners (USGS 2011).

Montezuma Castle NM is within the Central Highlands physiographic province of Arizona, which is a transition zone between the Plateau Uplands (Colorado Plateau) province to the north and the Basin and Range province to the south (USGS 1969, as cited in Konieczki and Leake 1997). Rugged mountains composed of igneous, metamorphic, and sedimentary rocks characterize the Central Highlands transition zone (ADWR 2009). Valleys, mesas, canyons, plateaus, and peaks contribute to the area's topographical diversity.

Although part of the Sonoran Desert Network, Montezuma Castle NM actually lies within the Apache Highlands Ecoregion (Figure 1-4). This ecoregion spans 30 million acres in Arizona, New Mexico, and Sonora and Chihuahua, Mexico, and is characterized by mountain "sky islands" separated by grassland and desert scrub "seas" (Marshall et al. 2004). Other U.S. national parks in the Apache Highlands include nearby Tuzigoot NM, as well as Chiricahua NM, Coronado

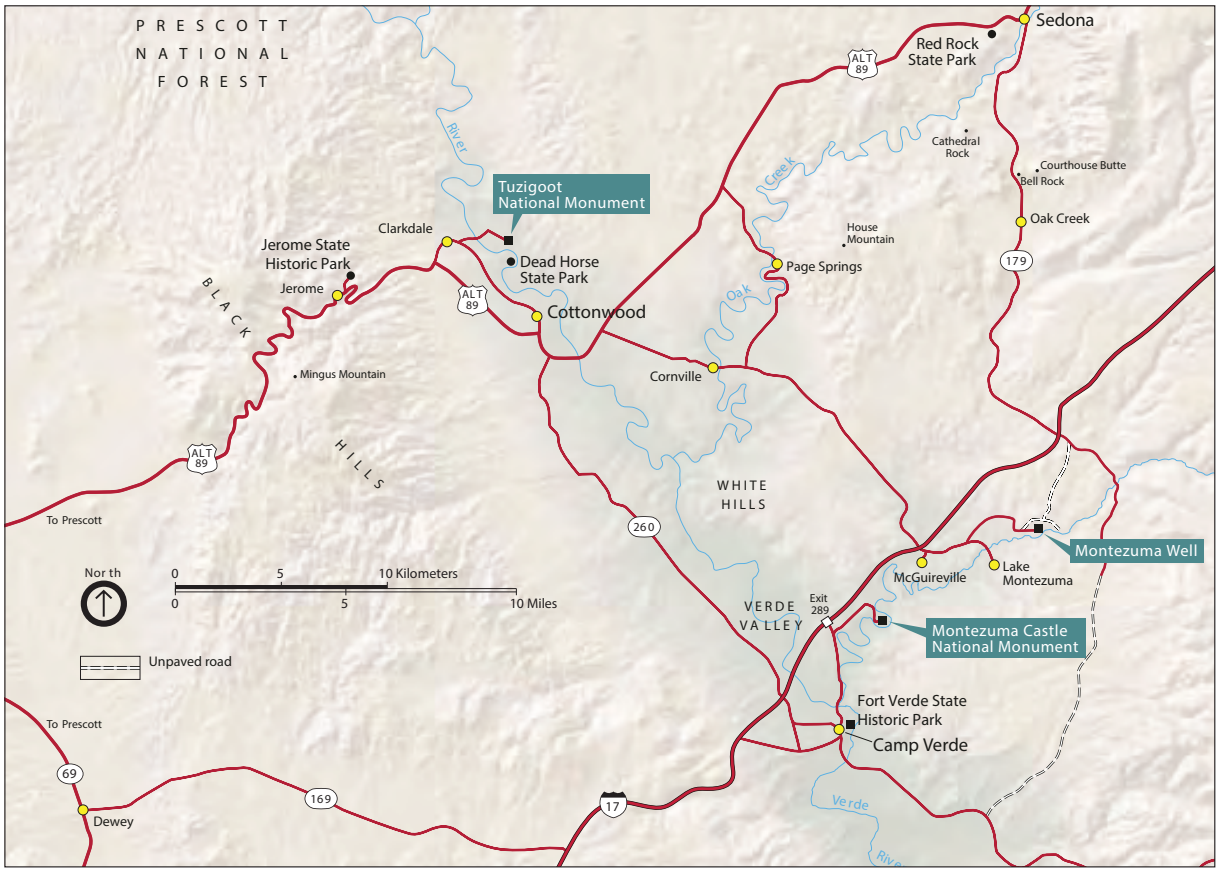

Figure 1-3. Location of Montezuma Castle National Monument.

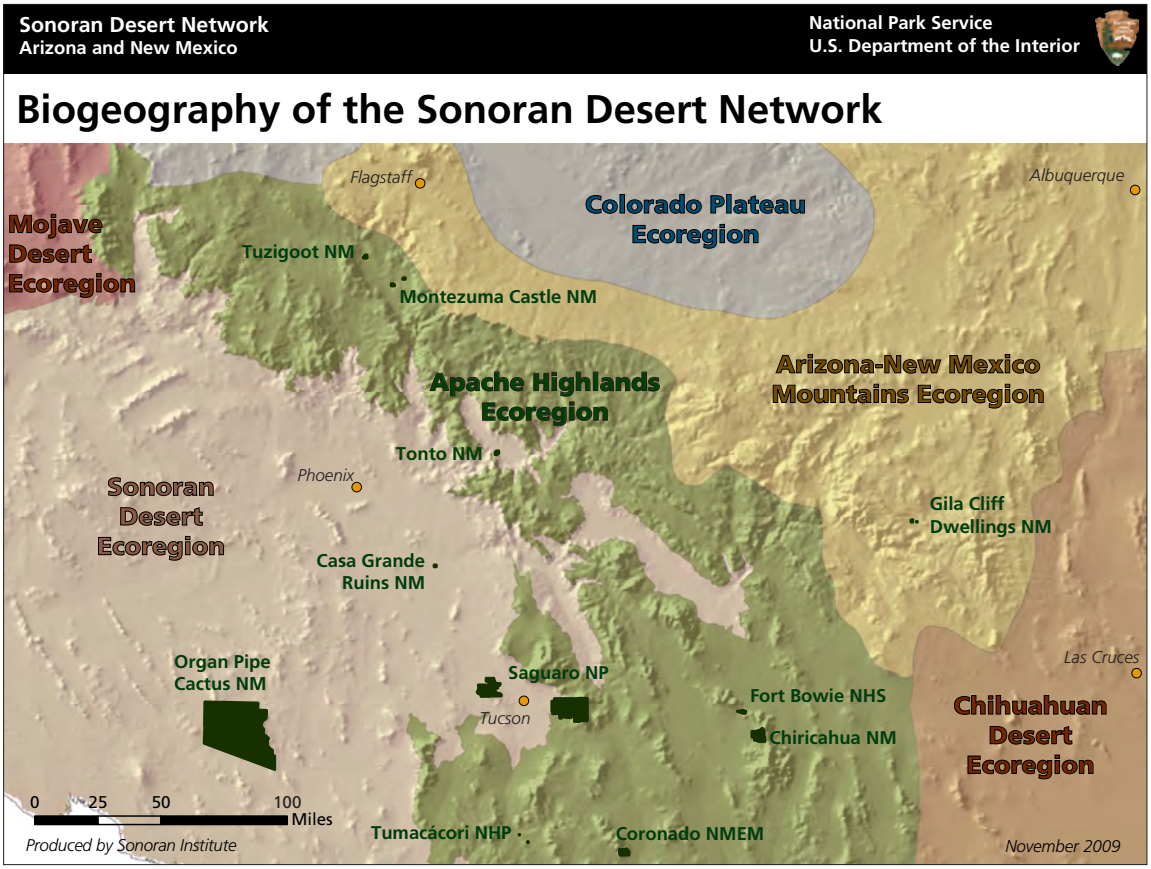

Figure 1-4. Biogeography of Sonoran Desert Network.

National Memorial, Fort Bowie National Historic Site, and much of the Rincon Mountain District of Saguaro National Park (NPS 2005).

The Apache Highlands have been subdivided into north and south subregions for purposes of resource conservation (AGFD 2006). The North Subregion covers 9.4 million acres in Arizona, and is characterized by highly dissected mesas and mountains ranging from approximately 2,100 to 8,800 feet (~640–2,682 m) in elevation (Marshall et al. 2004). The northern extent of the eastern part of this ecoregion is defined by the Mogollon Rim, where the primary landforms are steep canyons and broad, flat valleys, separated by small mountain ranges, ridges, and plateaus. The higher elevations in the northwestern part of this ecoregion are dominated by more expansive, level-topped plateaus. Toward the south, the plateau country breaks into similarly highly dissected drainages and small mountain ranges (AGFD 2006).

1.4.3 Local geology and soils

Montezuma Castle is located in the Verde River Valley, a down-faulted Cenozoic sedimentary basin dominated by Verde Formation sediment, and young lacustrine sediment with classic, evaporitic, and limestone facies (Lindsay 2000). Deposits of lacustrine and fluvial origin dominate the area surrounding the monuments. Fluvial deposits from the Verde River are further separated into terraced (moderately sorted and lightly cemented) and alluvial (unsorted and uncemented) deposits (Woodward-Clyde 1997, cited in NPS 2005).

According to the NPS Geologic Resources Inventory, four geologic units occur within the monument. Holocene-age alluvium occurs along Beaver Creek. Adjacent to the alluvium is the terrace gravels geologic unit. The Verde Formation–limestone unit covers much of the uplands area of Montezuma Castle NM, with the exception of the southwest corner, which is Verde Formation–lacustrine rock (NPS 2010b).

Two broad types of soils predominate at Montezuma Castle NM: (1) riverine bottomland soils composed of alluvium and (2) upland, rocky calcareous soils (Figure 1-5). The

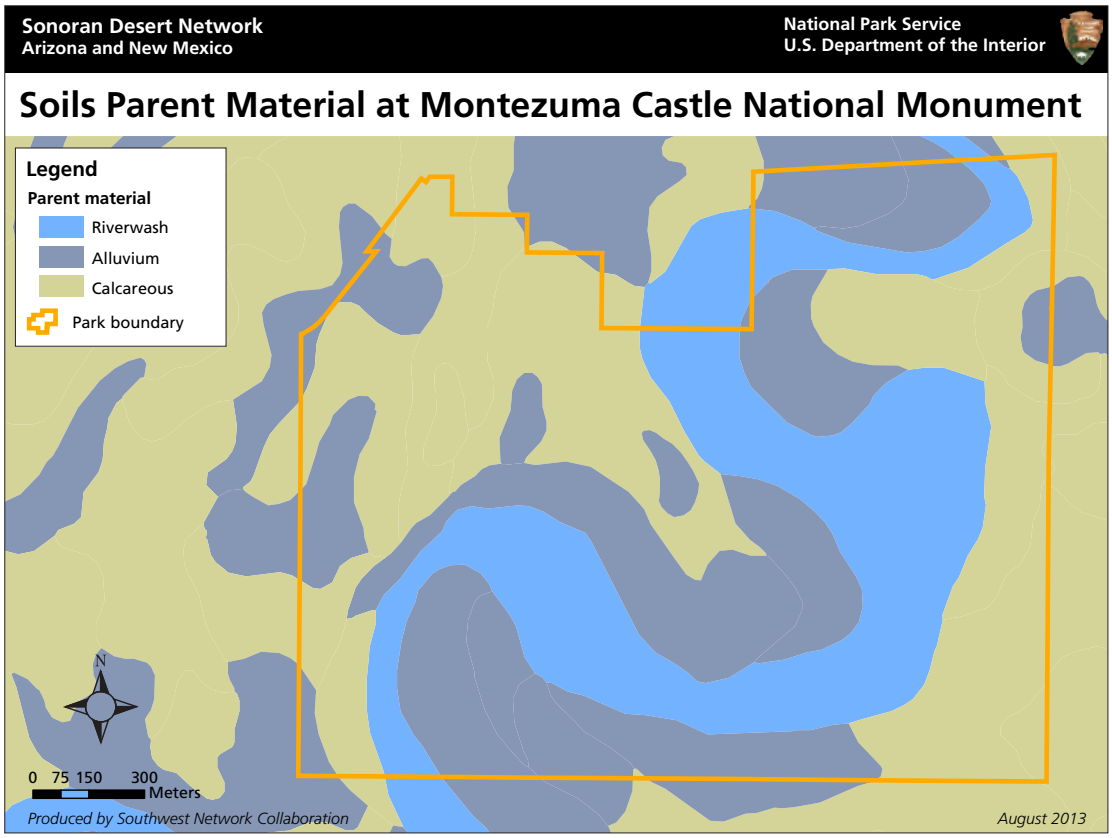

Figure 1-5. Soils at Montezuma Castle National Monument.

Retriever soil series, which consists of limestone outcrops and soils derived from limestone and is found on upland mesas, ridges, and side-slopes, dominates the soils derived from calcareous parent materials at the Castle unit. Riverwash soils along Beaver Creek consist of stratified sand, silt, and clay, with scattered deposits of gravel, cobbles, stones, and boulders. The remainder of the Castle unit is characterized by several series of finer calcareous soils (Figure 1-6) consisting of fine sandy loams, gravelly sandy loams, and clays (Rowlands 1999). However, soil properties can vary greatly over relatively small spatial scales—scales that are often not adequately captured by traditional soil surveys. Soil properties have important consequences for vegetation composition, persistence, and productivity (McAuliffe 1999).

1.4.4 Biological soil crusts

Biological soil crusts—a community of cyanobacteria, algae, lichens, and bryophytes—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, secreting polysaccharides and binding soil particles together. In addition to reducing water erosion, the polysaccharides also contribute to soil aggregate structure, which is directly correlated with soil erosion resistance (Belnap et al. 2003; Herrick et al. 2005a). Mosses

Figure 1-6. Bright white calcareous surface soils stand in sharp contrast to vegetation at Montezuma Castle National Monument.

and lichens have small, anchoring structures that help them protect the soil surface (Belnap et al. 2003).

At Montezuma Castle NM, cyanobacteria (*Nostoc commune*) dominate the crust community on non-rocky soils derived from limestone (Bowker and Belnap 2008). Lichens, a composite, symbiotic organism comprising a fungus and either a cyanobacterium or a green alga, occur on the soil surface. The rocky soils derived from limestone at the park support a rich lichen community. Nine lichens have been observed on the soil. Mosses also occur on the soil surface; five species have been observed at Montezuma Castle NM. According to a recent predictive modeling effort, the uplands areas in the western portion of the monument (limestone-derived soils) have the greatest potential for biological soil crust abundance but crust cover is highly variable (Bowker and Belnap 2008).

1.4.5 Climate and hydrology

Montezuma Castle NM experiences climate typical of the Apache Highlands Ecoregion: highly variable, bimodal precipitation with a considerable range in daily and seasonal air temperature, and relatively high potential evapotranspiration rates (TNC 1999). Approximately half of the annual precipitation falls during summer, when maximum air temperatures often exceed 30°C and lead to violent (and often localized) rainstorms. The bulk of the remaining annual precipitation falls in relatively gentle events of broad extent, occasionally as snow.

Park staff has operated a U.S. National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) station at Montezuma Castle NM since 1938. Recent (1981–2010) historic, or "normal" average annual precipitation is 14.35 inches. Average maximum temperature is 81.2°F, and average minimum temperature is 43.6°F (Figure 1-7; NCDC 2013).

Annual precipitation during the five years preceding and including vegetation and soil sampling (2007–2011) was 88% of the 30-year normal (12.65" vs. 14.35", respectively), with drier than normal periods during both winter and summer seasons (Figure 1-7). Maximum and minimum air temperatures were also consistently warmer during 2007–2011 compared to the 30-year normal (Figure 1-7).

Montezuma Castle NM lies within the middle Verde River watershed, which coincides with the 2,500-mi^2 Verde Valley subbasin of the Verde River groundwater basin. Beaver Creek, a tributary of the Verde River, runs through Montezuma Castle NM and is char-

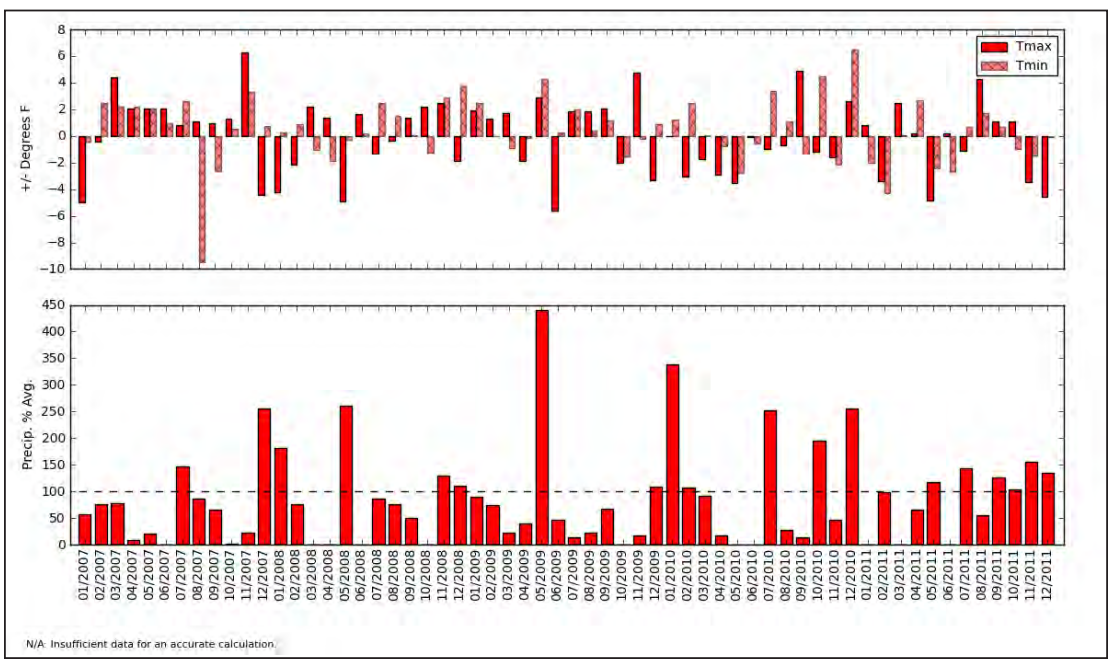

Figure 1-7. Climate data from 2007 to 2011 in the context of 30-year normals (1981–2010) for Montezuma Castle National Monument. Tmax: average daily maximum air temperature. Tmin: average daily minimum air temperature.

acterized by intermittent water flow (Schmidt et al. 2006), with perennial segments within portions of the monument. The Verde Valley subbasin extends along the Verde River between Paulden and Camp Verde, and includes Sycamore Creek, Oak Creek, Wet and Dry Beaver creeks, and West Clear Creek (Blasch et al. 2006).

1.4.6 Human habitation of the Montezuma Castle NM landscape

Archeological evidence suggests a sequence of settlement by the Hohokam, Hakataya, and Sinagua peoples in the lush valleys and hills along the Verde River beginning around 900 AD (Protas 2002). The Montezuma Castle cliff-house complex was constructed and occupied by the Sinagua people from around 1200 AD until their departure from the Verde Valley more than 200 years later (Protas 2002).

During the periods of exploration and settlement of the Verde Valley, Spanish explorers, fur trappers, surveyors, military officers, settlers, and tourists noted the impressive prehistoric structures and speculated on their origins (Protas 2002).

Portions of a large area of fertile flat land along the creeks have been farmed intermittently, beginning with the Sinagua around AD 600–800. Farming ceased after the Sinagua left the area, but European settlers resumed cultivation in the 1800s (NPS 1994).

Today, the Southwest is one of the fastest-growing regions in the United States. Population in the Verde River watershed (on the upper Verde River and part of the middle watershed upstream of Camp Verde) increased from approximately 82,000 in 1990 to an average population of over 148,000 from 2005 to 2009 (ESRI 2011). The number of housing units and households also increased, with more than 63,000 households and 75,000 housing units estimated in 2005–2009.

Table 1-1. Status of natural resource inventories for Montezuma Castle National Monument, August 2013.

Inventory	Description	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: https://irma.nps.gov/App/Reference/Profile/2170560 https://irma.nps.gov/App/Reference/Profile/2168592	Complete
Base Cartographic Data	A compilation of basic electronic cartographic materials. Products: https://irma.nps.gov/App/Reference/Profile/2164781	Complete
Baseline Water Quality	Assessment of water chemistry in Middle and West Forks of Gila River. Products: https://irma.nps.gov/App/Reference/Profile/2173766	Complete
Climate	A basic assessment of nearby climate stations and instrumentation. Products: https://irma.nps.gov/App/Reference/Profile/2170162	Complete
Geologic Resources	A synthesis of existing geologic data, resulting in a report and electronic map. Products: https://irma.nps.gov/App/Reference/Profile/2171392	Map complete, report in progress
Natural Resource Bibliography	An electronic catalog of natural resource-related information. Products: https://irma.nps.gov	Complete
Soil Resources	Electronic geospatial data regarding basic soil properties. Products: https://irma.nps.gov/App/Reference/Profile/1048933	Complete
Species Lists	Documentation of the occurrence and distributions of >90% of the vertebrates & vascular plant species, based on prior research and fieldwork. Products: Schmidt and others (2006)	Complete
Species Occurrence and Distribution		
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. Products: https://irma.nps.gov/App/Reference/Profile/2176257	Complete

1.4.7 Brief overview of natural resource inventories

Twelve basic natural resource inventories were authorized and funded through the National Park Service for all 270 parks deemed to have "significant" natural resources, including Montezuma Castle NM (NPS 2009). At time of writing, ten of these inventories had been completed and two others were in progress (Table 1-1). Coordinated at the national level, most of these inventories rely on existing information and deliver products ranging from electronic data sets to short reports. However, three inventories (species lists/species occurrence and distribution and vegetation characterization) involved extensive fieldwork culminating in detailed reports. See National Park Service (2009) for additional information on the National Park Service Natural Resource Inventory Program.

1.4.8 Other long-term monitoring and related ecological research at Montezuma Castle NM

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, and aquatic and riparian resources associated with streams (Beaver Creek and Wet Beaver Creek). Details on these efforts are provided in NPS (2005) and on the Sonoran Desert Network website, http://go.nps.gov/sodn.

Vegetation research at the monument has historically focused on the unique habitats around the sinkhole at Montezuma Well (e.g., Spangle and Sutton 1949, Clark 1963, Clark and Burgess 1966). For the Castle unit, riparian plants received a similar (albeit much reduced) emphasis, with particular interest on large riparian trees.

The first detailed research on terrestrial vegetation was conducted by Ruffner and Johnson (1990) and Rowlands (1999), each of whom developed a vegetation map and used field data to assess the vegetation composition and condition of the monument.

1.5 Natural resource management issues

1.5.1 Invasive exotic species

Long-term anthropogenic disturbance in the Verde Valley has contributed to the introduction and spread of non-native flora and fauna, a significant challenge to natural resource managers (Rowlands 1999) at Montezuma Castle NM. Non-native grasses, such as red brome (*Bromus rubens*) and ripgut brome (*Bromus diandrus*) are well-established. Exotic plant inventories of Montezuma Castle NM in the late 1990s and early 2000s found 43 exotic plant species within the Castle unit (Table 1-2; Halvorson and Guertin 2003; Mau-Crimmins et al. 2009).

Non-native fauna include feral dogs and cats, cattle, European starlings, house sparrows, and bullfrogs (Schmidt et al. 2006). Declines in abundance and the extirpation of native fish, amphibians, and some aquatic reptiles may be caused by non-native fish, crayfish, and the American bullfrog (Bonar et al. 2004). A study by Montgomery and others (1995) reported five non-native fish species in Wet Beaver Creek.

1.5.2 Visitation

Montezuma Castle NM has become an increasingly well-known and popular park unit. This notoriety, along with the state's efforts to promote tourism in Arizona, has resulted in significant increases in visitation. The close proximity to Interstate 17 and the popularity of the Phoenix and Flagstaff metropolitan areas as year-round and winter retirement residences have also contributed to the upward trend. In addition, commercial tours frequently stop at the Castle unit as people travel from the major nearby destination/departure points of Phoenix and the Grand Canyon (NPS 1994).

Prior to 1951, visitors were permitted to directly access the dwellings via a series of ladders. However, the combination of high visitation and fragile cultural resources resulted in extensive resource damage. Consequently, visitor access is currently limited to a rela-

Table 1-2. Non-native invasive plants detected at Montezuma Castle National Monument (Castle unit), 1999–2001 and 2003–2004.

Scientific name	Common name	Lifeform	Status during survey	
			1999–2001[a]	2003–2004[b]
Ailanthus altissima	tree of heaven	Tree	non-target	present
Avena fatua	wild oat	Graminoid	present	present
Avena sativa	common oat	Graminoid	present	absent
Boerhavia coccinea	scarlet spiderling	Forb/Herb	present	present
Brassica tournefortii	Asian mustard	Forb/Herb	absent	present
Bromus berteroanus	Chilean chess	Graminoid	non-target	present
Bromus diandrus	ripgut brome	Graminoid	present	present
Bromus rubens	red brome	Graminoid	present	present
Bromus tectorum	cheatgrass	Graminoid	present	present
Centaurea melitensis	Maltese star-thistle	Forb/Herb	present	present
Chloris virgata	feather fingergrass	Graminoid	present	absent
Conyza spp.	horseweed	Forb/Herb	present	absent
Cynodon dactylon	Bermudagrass	Graminoid	present	present
Cyperus esculentus	chufa flatsedge	Graminoid	present	present
Descurainia sophia	herb sophia	Forb/Herb	present	absent
Digitaria sanguinalis	hairy crabgrass	Graminoid	absent	present
Echinochloa crus-galli	barnyardgrass	Graminoid	present	present
Eragrostis cilianensis	stinkgrass	Graminoid	present	absent
Eragrostis curvula	weeping lovegrass	Graminoid	present	absent
Eragrostis lehmanniana	Lehmann lovegrass	Graminoid	present	present
Erodium cicutarium	redstem storksbill	Forb/Herb	present	present
Helianthus annuus	common sunflower	Forb/Herb	absent	present
Heterotheca subaxillaris	camphorweed	Forb/Herb	present	present
Hordeum murinum	mouse barley	Graminoid	present	absent
Lactuca serriola	prickly lettuce	Forb/Herb	present	present
Linaria dalmatica	Dalmatian toadflax	Forb/Herb	non-target	present
Lolium perenne	perennial ryegrass	Graminoid	non-target	present
Marrubium vulgare	horehound	Subshrub	present	present
Melilotus indicus	annual yellow sweetclover	Forb/Herb	absent	present
Melilotus officinalis	yellow sweetclover	Forb/Herb	present	present
Polygonum aviculare	prostrate knotweed	Forb/Herb	present	present
Polypogon monspeliensis	annual rabbitsfoot grass	Graminoid	present	present
Rumex crispus	curly dock	Forb/Herb	absent	present
Salsola spp.	Russian thistle	Forb/Herb	present	present
Schismus barbatus	common Mediterranean grass	Graminoid	absent	present
Setaria viridis	green bristlegrass	Graminoid	genus present	present
Sisymbrium irio	London rocket	Forb/Herb	present	present
Sonchus spp.	sowthistle	Forb/Herb	present	absent
Sorghum halepense	Johnsongrass	Graminoid	present	present
Tamarix spp.	tamarisk	Tree	present	present
Verbascum spp.	mullein	Forb/Herb	present	present
Verbascum thapsus	common mullein	Forb/Herb	present	present
Xanthium strumarium	rough cockleburr	Forb/Herb	present	present

[a] Halvorson and Guertin (2003)

[b] Mau-Crimmins and others (2009)

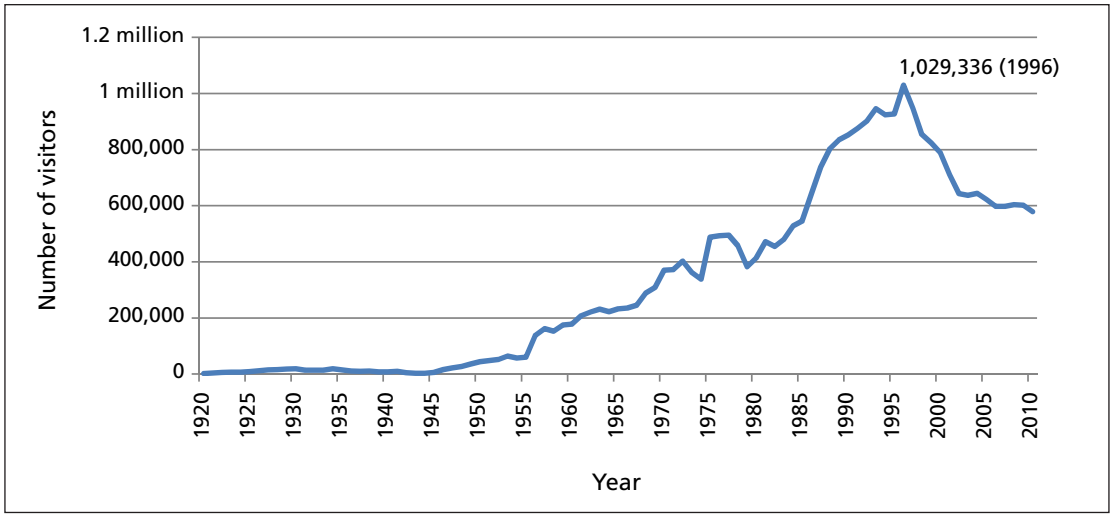

Figure 1-8. Visitation at Montezuma Castle National Monument. Data are from National Park Service park statistics (NPS 2011).

tively small, highly managed area of the park.

Based on monthly visitation from 2002 to 2007, March is the busiest month for visitors to Montezuma Castle NM, with a second, smaller peak in October. Visitation drops off during mid-summer and winter, perhaps reflecting the climate preferences of many visitors. Regional use is more evident on weekends and holidays. Heaviest use occurs from mid-morning to early afternoon, coinciding with tour-bus schedules and the travel time from Phoenix and the Grand Canyon (NPS 2010a).

Following a pattern observed throughout the National Park Service, visitation at Montezuma Castle NM increased sharply following World War II, as increased mobility and visitor services combined with strong public interest to drive visitation numbers up to a peak of 1,029,336 in 1996—50 times the number seen in 1930 (Figure 1-8). After that, visitation declined to around 600,000 per annum, and has remained fairly stable since 2002 (NPS 2011). Despite its small size and limited area of access, Montezuma Castle NM is among the most-visited national park units in the Southwest, and based on the region's growing population and the increased development of tourism services, park managers are predicting increased visitation over the next 15–20 years (NPS 2010a).

1.5.3 Adjacent land use, development, and water use

Yavapai County, which extends beyond the upper Verde River watershed, was the fastest-growing rural county in the U.S. as of 1999, and its population (132,000 in the year 2000) is expected to more than double over the next 50 years (Smith and Ledbetter 2011). Even by Yavapai County standards, the pace of growth in the Verde Valley is impressive, as demonstrated by the dramatic recent increase in housing development in the vicinity of Montezuma Castle NM (Schmidt et al. 2006). The increased development on lands adjacent to and surrounding the monument results in direct and indirect impacts, such as the introduction of non-native species (e.g., landscaping plants and feral domestic animals; Figure 1-9), increased groundwater withdrawal, surface water-quality problems and pollution, and visual intrusions to the natural landscape (NPS 1994; Schmidt et al. 2006).

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Figure 1-9. American bullfrog (*Lithobates catesbeiana*).

Groundwater and spring discharges contribute to the perennial flow in Beaver Creek, and adjacent land uses can interrupt the natural flow regimes. An increase in the number of water-supply wells drilled, due to the rapid urbanization of the area (NPS 1994), has lowered groundwater levels—a trend that could threaten the flow upper Verde River (Smith and Ledbetter 2011). Most of the flow for Beaver Creek is diverted upstream for irrigation during the summer months, which affects the amount of creek water flowing through both the Montezuma Castle and Well units (NPS 1994). Potential threats to surface-water quality include nonpoint source pollution from urban development, agricultural and livestock runoff, and discharge from septic wastewater systems (Sprouse et al. 2002).

1.5.4 Management priorities and vegetation management

Historically, resource management efforts in the Castle unit have focused almost solely on the monument's spectacular cultural resources. The 1994 Resources Management Plan (NPS 1994) clarified the importance of natural resources at the monument and highlighted key issues with native vegetation, particularly (1) grazing impacts on terrestrial vegetation, (2) issues with exotic plants and animals, and (3) the consequences of modified river hydrology on riparian vegetation. The management plan identified the lack of consistent funding and staffing for natural resource management and research, and proposed professional positions to address these needs. Funding for such a position was secured in the late 1990s (pers. comm., Kathleen Davis), but such as position was not recruited or filled until the mid-2000s.

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 plant species or lifeform not observed on the adjacent transects. See Hubbard and others (2012) for details on plot configuration and collecting the measures.

2.1.1 Vegetation and soil cover: Line-point intercept

Line-point intercept is a common and efficient technique for measuring 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 are field (<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 life form, with the exception of a suite of annual non-native plants that were recorded to the species level. Soil cover (see Hubbard et al. 2012, SOP #5) was recorded by substrate class (e.g., rock, gravel, litter), with biological soil crust cover recorded to morphological group (light cyanobacteria, dark cyanobacteria, lichen, moss).

Table 2-1. Height categories for vegetation measurement.

Layer	Height
Field	<0.5 m
Subcanopy	0.5–2.0 m
Canopy	>2.0 m

2.1.2 Vegetation frequency: Subplots

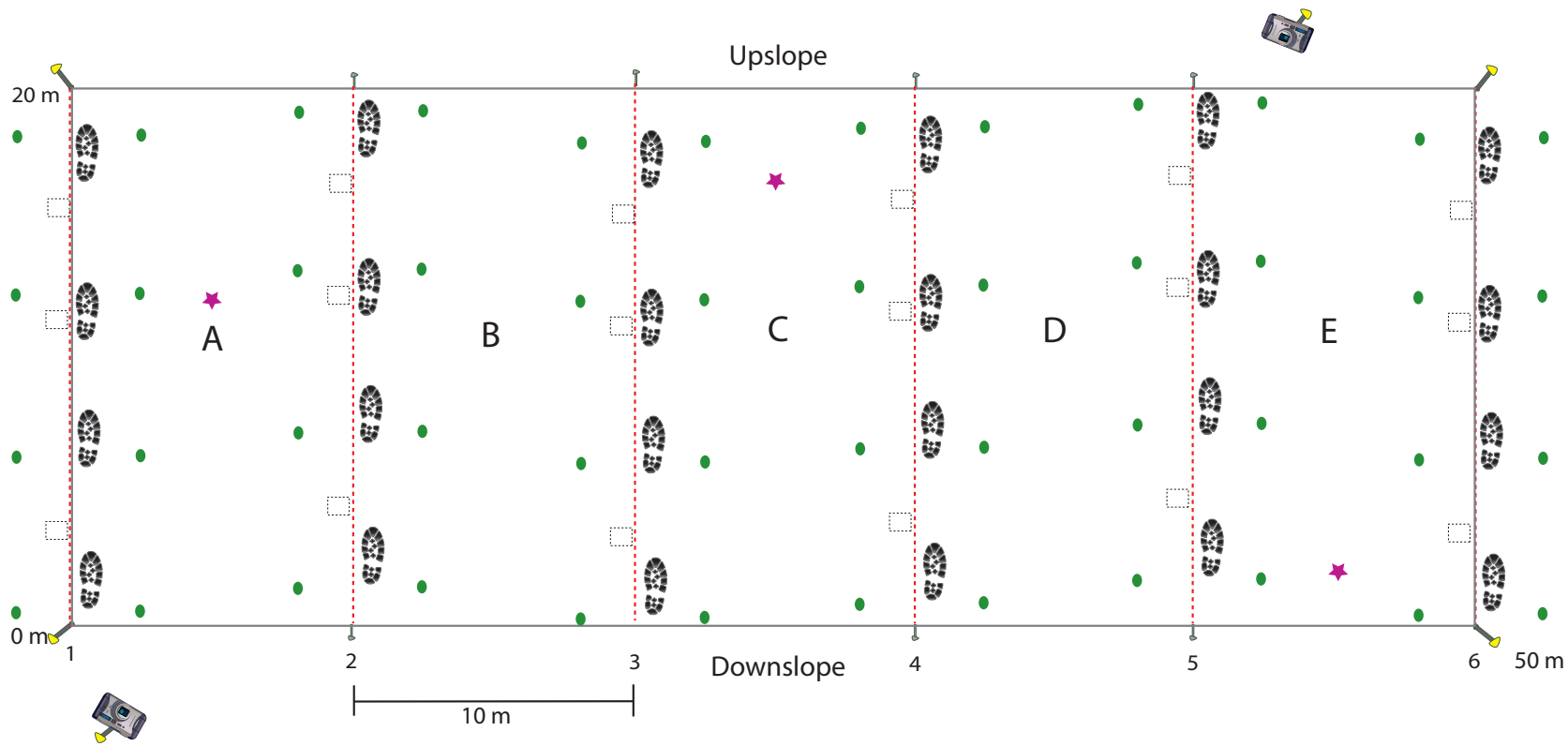
The area between any two adjacent transects formed the boundary of 10 × 20-m subplots that were used to estimate within-plot frequency of perennial plant species, exotic plants, and all lifeforms. The occurrence of any species/lifeform that was not measured on the adjacent line-point transect was recorded to determine a within-plot frequency of 0–5. Figure 2-1 explains 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. 2005b). Within each plot, samples were collected at pre-determined points on either side of the six line-point intercept transects. A total of 48 uniformly sized (2–3 mm thick and 6–8 mm on each side) samples were tested per plot, in groups of 16. Each sample was placed on a screen and soaked in water for five minutes. After five minutes, the samples were dipped slowly 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), or lichens by growth form. The observer then visually surveyed the quadrat for any lichen growth form or morphological group that was present. Soil-crust frequency by lichen growth form and morphological group was determined by the number of quadrats occupied relative to the total number of quadrats (n=18). The SODN terrestrial vegetation and soils monitoring protocol (Hubbard et al. 2012, SOP #6) provides a detailed description of the point-quadrat methodology.



Plot Layout

- Plots are 20 x 50 m, with 20-m transects running parallel to the dominant slope.
- Corners of the plots are marked with rebar or nails.
- Ends of transects are marked with nails.
- Photo points are marked with rebar or nails and direction recorded to allow for repeat photography.

Vital Signs Monitoring

- Vegetation in three height classes and substrate are measured every 0.5 m along six 20-m line-point intercept transects. Presence/absence of perennial species and a subset of invasive annual species is recorded in five subplots (A–E).
- Biological soil crust cover is measured using three 0.5 x 0.5-m point-quadrats (288 points total) along each transect.
- Surface soil aggregate stability is measured ~2.5m from both sides of a transect at four random locations per transect.
- Surface soil bulk density samples are collected at three random locations, one each within subplots A, C, and E.

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

2.1.5 Soil and site characterization

Proximate soil and landform factors 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. 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

For a variety of reasons to be described below, our sampling design underwent a number of iterations between the first year of data collection and the analysis that led to the results reported in this document.

2.2.1 Initial stratification

Initially, terrestrial vegetation and soils plots were proportionately allocated to two strata based on elevation and soil type. Stratification (see Hubbard et al. 2012) was employed to reduce spatial variability and increase sampling efficiency. Both strata had elevations between 2,501' and 3,700'. The "non-rocky" stratum ("201" plots) included areas where surface rock fragment content averaged less than 35%, according to the Natural Resource Conservation Service (NRCS) soil survey (NRCS 2011). The "rocky" stratum ("202" plots) included areas where surface rock-fragment content averaged between 35% and 90%, according to the NRCS soil survey (NRCS 2011).

2.2.2 Initial sampling frame and adjustments

The sampling frame for Montezuma Castle NM includes all terrestrial areas within park boundaries, except for the following:

- Slopes of ≥45° (for crew safety)
- Roads and buildings (including 100-m buffer)
- Trails washes, and streams (including 100-m buffer)
- Selected fragile cultural features (such as the cliff dwellings)

The total area initially excluded under these criteria was 333 acres (~135 ha), or 46% of the park area.

Initially, we allocated a total of eight permanent monitoring plots in a spatially balanced arrangement (see Section 2.2.5), based on a priori expectations of required sample size to meet our criteria for statistical power and detectability (see Sections 2.2.8–2.2.9). After analyzing the 2010 data, however, we determined that our initial sampling frame did not adequately account for the riparian area surrounding Beaver Creek, or for the influence of the river beyond the riparian area. Field observations suggested that the 100-m buffer around Beaver Creek was insufficient, as some of the potential "terrestrial" vegetation plots contained obligate riparian plant species and evidence of past flooding.

To correct the sampling frame, we applied Federal Emergency Management Agency floodplain maps (FEMA 2011) and NRCS soil maps (NRCS 2011) to determine if a plot was in the riparian area (i.e., within a 20-m buffer of the 100-year floodplain and/or the Riverwash soil map unit; Figure 2-2). Riverwash soils occur around Beaver Creek and are frequently flooded (NRCS 2011). Two plots that fell within the riparian area were subsequently excluded (Figure 2-2). Data initially collected from those plots were excluded from the results presented here (and from subsequent sampling).

To maintain our sampling intensity, we added two plots in the 201 stratum from our original ordered list (see Section 2.2.5). We also added two plots to the 202 stratum to improve our statistical power to detect trends in vegetation cover. The four new plots were sampled during the 2011 field season, and will be hereafter included as part of the long-term terrestrial vegetation and soil monitoring design for Montezuma Castle NM.

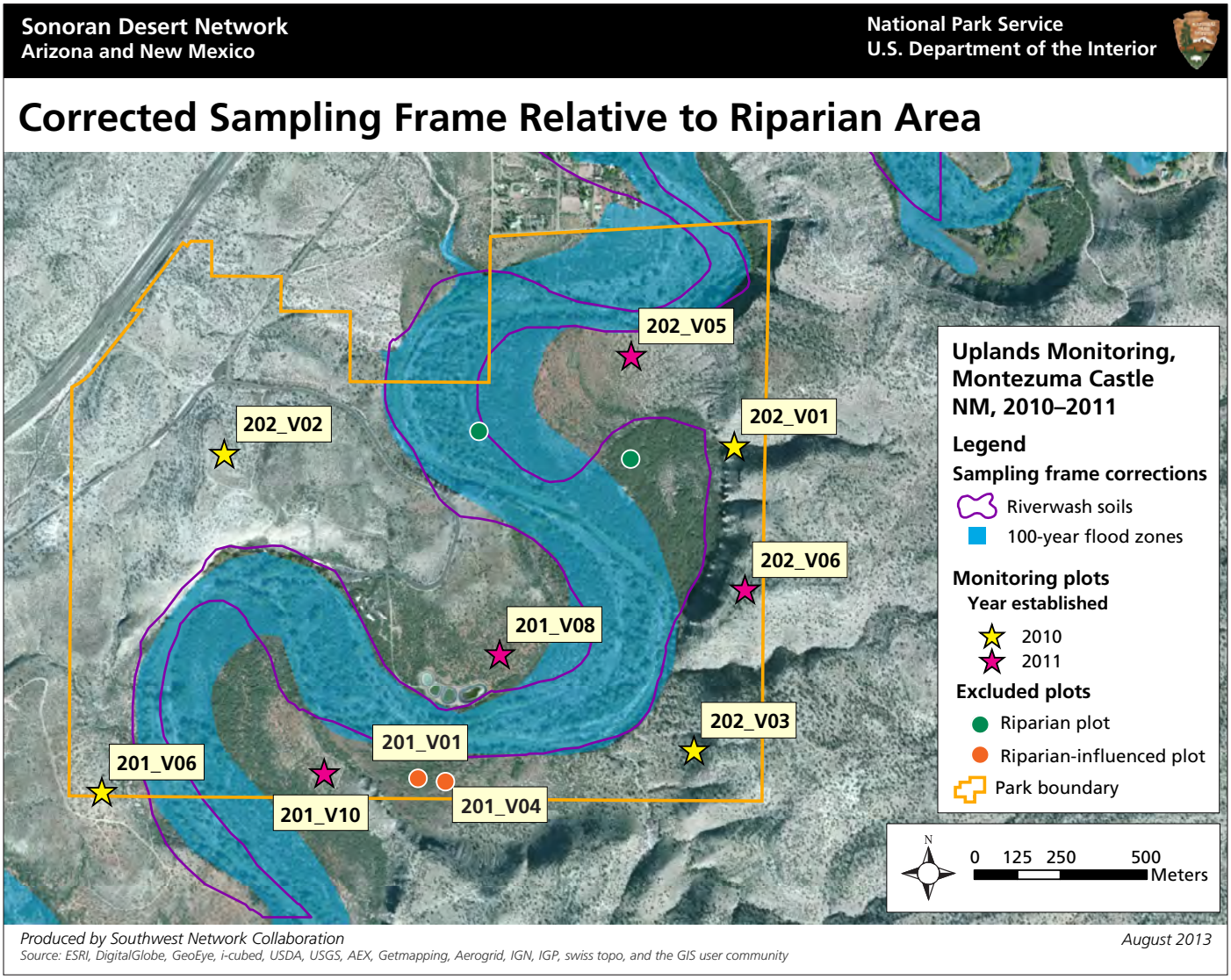


Figure 2-2. Vegetation and soils monitoring plots that fell in upland vs. riparian areas following the initial allocation of plots. Riparian-indluenced plots 201_V01 and 201_V04 were subsequently removed from monitoring (see Section 2.2.3.1).

Correcting the sampling frame resulted in exclusion of approximately 100 acres from the 201 stratum and two acres from the 202 stratum. Overall, 60% of the Castle unit was excluded from terrestrial vegetation and soils monitoring. Each stratum covered 20% of the Castle unit and half of the sampling frame.

2.2.3 Reconsideration of plots and strata

Subsequent to the changes described in Section 2.2.2, we found that cluster analysis, non-metric multidimensional scaling, and PERMANOVA+ (Clarke and Warwick 2001; Anderson et al. 2008) results suggested that our initial strata, which were based on elevation and soil rock-fragment content, did not adequately explain the variance in vegetation composition and abundance. Based on this result, we began to suspect that two factors were driving the vegetation composition of plots, rather than rock-fragment content: proximity to Beaver Creek and underlying geology. In response, we further evaluated the adequacy of our definition for excluding areas influenced by Beaver Creek.

2.2.3.1 Proximity to Beaver Creek

To establish proximity to Beaver Creek, we used a 5-m digital surface model generated by Western Mapping Company to estimate each plot's elevation above and distance from the creek. Plots 201_V01 and 201_V04 were less than five meters above and 200 m from Beaver Creek (see Figure 2-2), suggesting that the vegetation there may have ac-

cess to shallow groundwater. Plots 201_V08, 201_V10, and 202_V05 were 10–15 m above the river. Plot 201_V06 was approximately 25 m above Beaver Creek. Plots 202_V01, 202_V02, 202_V03, and 202_V06 were 40–100 m above the river's elevation.

We then consulted with the SODN aquatic ecologist regarding plots 201_V01 and 201_V04. Although the plots are outside FEMA's 100-year floodplain and the Riverwash soil map unit, the geomorphology of the area suggests that Beaver Creek influences the plots, meaning they do not represent terrestrial vegetation and soils. In response, we removed plots 201_V01 and 201_V04 from our sample (see Figure 2-2). Results from those plots are not reported here and the plots will not be included in future uplands sampling. Chapter 3 summarizes results from the remaining eight plots.

2.2.3.2 Underlying geology

According to the NPS Geologic Resources Inventory, four geologic units occur within the monument. Holocene-age alluvium occurs along Beaver Creek. Adjacent to the alluvium is the Terrace Gravel geologic unit. The Verde Formation, limestone unit covers much of the uplands area of Montezuma Castle NM with the exception of the southwest corner, which is Verde Formation, lacustrine rocks (NPS 2010b). Monitoring plots 201_V08, 201_V10, and 202_V05 are on the Terrace Gravel. Plot 201_V06 is on the Verde formation, lacustrine geologic unit. Plots 202_V01, 202_V02, 202_V03, and 202_V06 are on the Verde Formation, limestone unit.

2.2.4 Revised strata

Based on a plot's proximity to Beaver Creek and underlying geology, we utilized cluster analysis to identify potential new groupings. Cluster analysis of the vegetation composition and abundance in the remaining eight plots partitioned them into two groups (with >40% similarity). These groups became our new strata (Table 2-2).

The new terrace stratum includes four plots <25 m above the elevation of Beaver Creek, three of which occur on the Terrace Gravel geologic unit (plot 202_V06 is on the Verde Formation, lacustrine geologic unit) (Table 3-1, Figure 2-3). The new Verde limestone stratum includes four plots at least 40 m above Beaver Creek and occurring on the Verde Formation, limestone geologic unit (Table 3-1, Figure 2-3).

Table 2-2. Revised plots and strata by elevation above Beaver Creek.

Plot	Stratum	Elevation (m) above Beaver Creek			
		>5	10–15	25	40–100
201_V01	Excluded	X			
201_V04	Excluded	X			
201_V08	Terrace		X		
201_V10	Terrace		X		
202_V05	Terrace		X		
201_V06	Terrace			X	
202_V01	Verde limestone				X
202_V02	Verde limestone				X
202_V03	Verde limestone				X
202_V06	Verde limestone				X

Inference from the plots at Montezuma Castle NM is to all terrestrial areas of the park by stratum, excepting the areas discussed in Section 2.2.2.

2.2.5 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

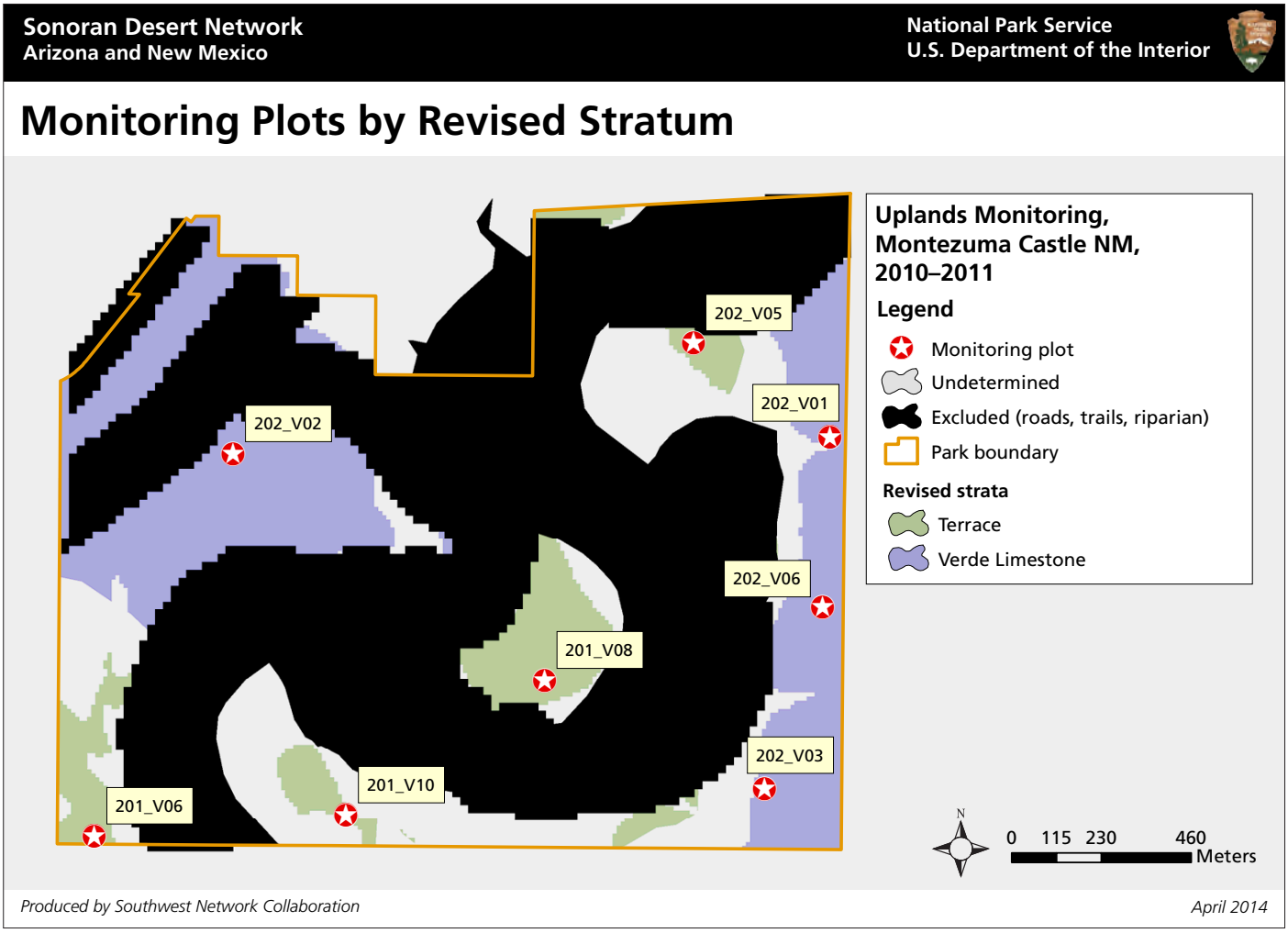


Figure 2-3. Final distribution of terrestrial vegetation and soils monitoring plots and strata at Montezuma Castle National Monument.

(Stehman 1999) and ensure spatial balance regardless of overall sample size. RRQRR designs facilitate adding or removing plots in a spatially balanced manner if statistical power, financial considerations, or additional monitoring objectives warrant adjusting the sample size. This scaling ability is an important advantage, as (1) the number of plots per park cannot always be adequately estimated a priori (see Hubbard et al. 2012) and (2) future changes in technology, objectives, and budgets may necessitate increasing or decreasing sample sizes.

2.2.6 Timing

All plots are sampled in the same year, then revisited at five-year intervals. If a major disturbance (e.g., fire, extended periods of temperature extremes, mass soil movement) occurs in the intervening years, we may collect additional plot data to characterize and account for the potential effects of these important stochastic events.

2.2.7 Management assessment points

To achieve the National Park Service's 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 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).

Management assessment points provide context and aid interpretation of ecological information in 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 advising 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.

While no management assessment points have been formally established for Montezuma Castle NM, we propose some below, based on the ecological literature and our knowledge of these ecosystems and park management goals. We intend these to (1) initiate a discussion of potential indicators and assessment points (a conversation that will expand as the park commences additional planning and as additional research and monitoring are completed) 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 detail in Chapter 4.

2.2.8 Statistical power to distinguish status from management assessment points

Estimating our statistical power to distinguish current conditions (status) from management assessment points (see Section 2.2.4) 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 (2005a) as:

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

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 from the assessment point (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.

2.2.9 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 there is only one round of data for this report, we estimate "S_{diff}" using the following equation:

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

Where:

S_1 = Sample standard deviation among sampling units at first time period and

$coor_{diff}$ = 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.

2.2.10 Evaluation of strata

The terrestrial vegetation monitoring design apportions long-term monitoring plots to strata to improve the efficiency of parkwide estimation of monitoring parameters of interest. The assumption is that vegetation and dynamic soil functional attributes respond differently to environmental factors that can

Table 2-3. Proposed management assessment points for terrestrial vegetation and soils monitoring at Montezuma Castle National Monument.

Issue	Management assessment point	Strata	Information source
Erosion hazard	Exposed bare ground cover is >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) is <Class 3	All	Value is based on professional judgment of authors; issue is described in Herrick and others 2005
	Mature biological soil crust cover is <10% of available habitat	Verde limestone	Value is based on Bowker and Belnap (2008)
Site resilience	Foliar cover of dead perennial plants is >15% (field)	All	Value is based on professional judgment of authors
	Foliar cover of dead perennial plants is >15% (subcanopy)	All	Value is based on professional judgment of authors
Exotic plant dispersal	Extent of invasive exotic plants is >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 is >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 is >1:4 (0.25) (field)	All	Professional judgment of authors; see SODN Monitoring Plan (NPS 2005) for an overview of the issue
Fire hazard	Grasses + forbs is >30% (field)	All	Value is based on professional judgment of authors
	Annual plant cover: total plant cover is >1:4 (0.25) (field)	All	Value is based on professional judgment of authors

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 analysis of variance (PERMANOVA+), non-metric multidimensional scaling (MDS), and SIMPER, a permutation procedure that reveals which species contribute the most to any between- and within-group dissimilarities. These non-parametric multivariate community analysis techniques make few assumptions about the data, yielding a simple yet powerful analysis tool (Clarke and Warwick 2001).

3 Results

3.1 Evaluation of strata

The revised strata (see Section 2.2.4) proved much more effective at partitioning variance in the vegetation results. Permutational analysis of variance indicated significant differences between the composition and abundance of the adjusted strata (Pseudo-F = 5.27, P = 0.034), as illustrated by non-metric multidimensional scaling (Figure 3-1).

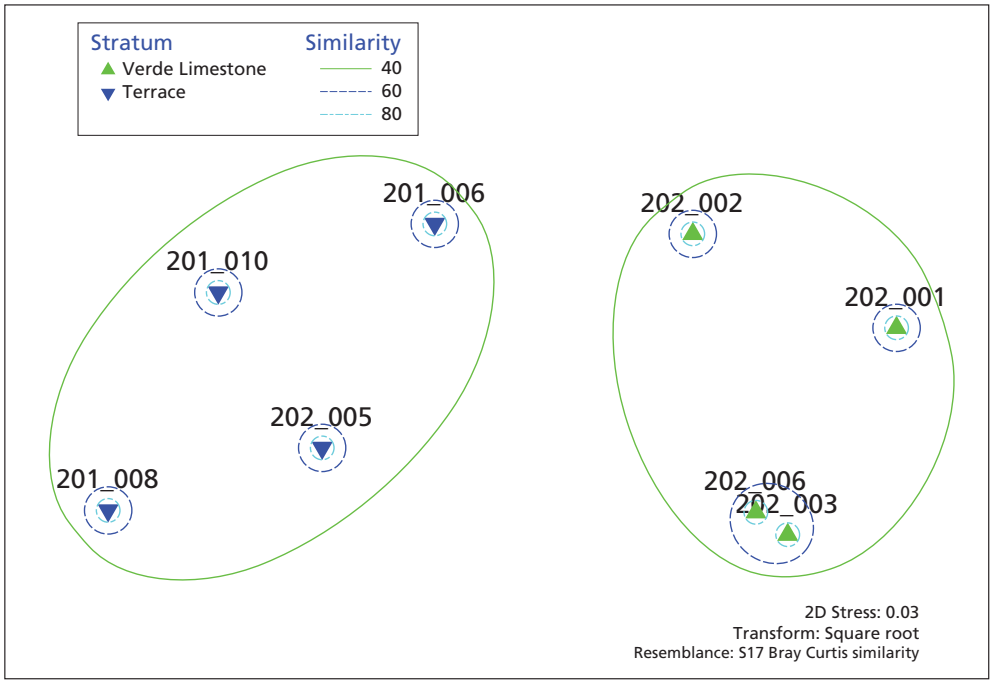


Figure 3-1. Non-metric multidimensional scaling indicates similarity of vegetation cover. The distance between any two points increases as their composition and structure differ. Each stratum had at least 40% within-group similarity but less than 20% between-group similarity, suggesting that the two strata are well differentiated by vegetation composition.

SIMPER (Clarke and Warwick 2001) analysis revealed that the trees, velvet mesquite (*Prosopis velutina*), crucifixion thorn (*Canotia holacantha*), oneseed juniper (*Juniperus monosperma*), and catclaw acacia (*Acacia greggii*), were strongly partitioned by the adjusted strata. Velvet mesquite and catclaw acacia dominated the canopy and subcanopy on terrace plots, whereas crucifixion thorn and oneseed juniper dominated the subcanopy on Verde limestone plots. The shrub, mariola (*Parthenium incanum*), also strongly differentiated the two strata, being present only on Verde limestone plots. The difference in abundance of creosote bush (*Larrea tridentata*) between the adjusted terrace plots (greater abundance) and Verde limestone plots also contributed to the dissimilarity between the groups (Table 3-1).

Based on the lack of significant differences between the two initial strata and the apparent significant difference between the adjusted strata, we conducted analyses and present results below based on the adjusted strata (terrace and Verde limestone).

3.2 Parkwide vegetation patterns

3.2.1 Exotic species

Five exotic plant species were observed in the monitoring plots, but only two were detected on the line-point intercept transects. The annual grass, red brome (*Bromus rubens*), and the annual forb, redstem storksbill (*Erodium cicutarium*), were encountered on line-point transects (Table 3-2) on both terrace and Verde limestone plots. Red brome was a co-dominant grass on terrace plots but had relatively low cover (4.0% ± 1.0%; Table 3-1). Red brome was found on all four terrace plots (Figure 3-2).

Although red brome was ubiquitous (3 of 4 monitoring plots) on Verde limestone plots (Figure 3-2), it occurred at approximately one-half the cover as it did on terrace plots (1.7 ± 1.2%; Table 3-2). A two-tailed t-test (assuming unequal variance) failed to detect a statistical difference (P = 0.19) between groups, likely due to the high variability in cover across plots within the Verde limestone stratum.

Redstem storksbill cover also did not differ significantly (P = 0.68) between terrace and Verde limestone plots, with a parkwide cover of only 1.6 ± 0.8%. Redstem storksbill occurred in three of the four terrace plots but only one of four Verde limestone plots (landscape frequency of 50%; Table 3-2, Figure 3-2).

Less common exotics were the subshrub, horehound (*Marrubium vulgare*), the perennial grass, Lehmann lovegrass (*Eragrostis*

Table 3-1. Results of SIMPER analysis of vegetation communities indicating which species contributed most to the dissimilarity between strata.

		Average abundance		Dissimilarity		Percentage	
Scientific name	**Common name**	**Terrace**	**Verde limestone**	**Average**	**Average/SD**	**Contributing**	**Cumulative**
Prosopis velutina	velvet mesquite	3.5	0	6.83	1.37	9.73	9.73
Parthenium incanum	mariola	0	3.3	6.78	5.75	9.66	19.39
Canotia holacantha	crucifixion thorn	0.23	3.12	5.89	1.57	8.39	27.78
Acacia greggii	catclaw acacia	2.86	0.28	5.26	2.15	7.5	35.27
Juniperus monosperma	oneseed juniper	0.54	2.11	4.15	1.07	5.91	41.18
Larrea tridentata	creosote bush	2.99	2.03	4.02	3.34	5.73	46.91
Muhlenbergia porteri	bush muhly	1.65	0	3.25	1.93	4.63	51.55
Krameria erecta	littleleaf ratany	0.32	1.73	2.84	1.95	4.05	55.59
Aristida purpurea	purple threeawn	1.02	1.98	2.68	1.18	3.82	59.42
Gutierrezia sarothrae	broom snakeweed	2	0.72	2.68	1.52	3.82	63.24
Snag	dead perennial plant	1.71	2.47	2.53	1.26	3.61	66.85
Erodium cicutarium	redstem storksbill	1.33	0.23	2.46	1.27	3.5	70.35
Bromus rubens	red brome	1.93	0.88	2.43	1.55	3.46	73.81
Berberis haematocarpa	red barberry	1.21	0	2.37	1.16	3.38	77.19

SD = standard deviation

Table 3-2. Cover and frequency of non-native plant species sampled at Montezuma Castle National Monument, 2010–2011.

			Cover			Frequency		
Scientific name	**Common name**	**Lifeform**	**Terrace stratum**	**Verde limestone stratum**	**Parkwide**	**Within-plot (mean ± SE)**	**Parkwide (extent)**	**Plots with species present**
Bromus rubens	red brome	Graminoid	4.0 ± 1.0%	1.7 ± 1.2%	3.0 ± 0.9%	75 ± 17%	88%	All but 202_V01
Erodium cicutarium	redstem filaree	Forb/Herb	2.6 ± 1.4%	0.2 ± 0.2%	1.6 ± 0.8%	40 ± 17%	50%	201_V08, 201_V10, 202_V05, 202_V06
Marrubium vulgare	horehound	Forb/Herb	n/a	n/a	n/a	3 ± 3%	13%	202_V01
Echinochloa sp.	barnyardgrass	Graminoid	n/a	n/a	n/a	3 ± 3%	13%	202_V03
Eragrostis lehmanniana	Lehmann lovegrass	Graminoid	n/a	n/a	n/a	3 ± 3%	13%	202_V03

Marrubium vulgare and *Echinochloa* sp. were not detected on the line-point intercept transects but were found in the subplots.

n/a = species not detected on line-point intercept transects.

A Student's t-test (2-tailed, assuming unequal variance) failed to detect statistical differences between groups for either red brome or redstem filaree (P = 0.19 and P = 0.68, respectively).

lehmanniana), and cockspur grass, an annual grass in the genus, *Echinochloa*. Horehound and Lehmann lovegrass were found on plot 202_V03. The *Echinochloa* species was found on plot 202_V01 (Table 3-2, Figure 3-2).

3.2.2 Ubiquitous species

Several plant species were ubiquitous (widespread) throughout the park (Table 3-3). The subshrub, broom snakeweed (*Gutierrezia sarothrae*), and the grass, purple threeawn (*Aristida purpurea*), were observed on all plots. As described in Section 3.2.1, the non-native, red brome, was found on seven of eight plots. Although velvet mesquite was observed on all plots in the terrace stratum, mesquite was not found on plots in the Verde limestone stratum.

3.3 Terrace stratum

3.3.1 Vegetation formations and lifeforms

Vegetation formation types were determined using a key (Appendix C), and based on the relative abundances of different plant lifeforms within each monitoring plot. Tree savanna was the most common vegetation formation within the terrace monitoring plots. Plots 201_V10 and 202_V05 were tree savannas. Plot 201_V06 was a shrub savanna and plot 201_V08 was woodland (Figure 3-3; figures begin on page 26).

Terrace plots were dominated by grasses, forbs, shrubs, and small trees (generally less than 2 m height). All major lifeforms except vines were encountered on the monitoring

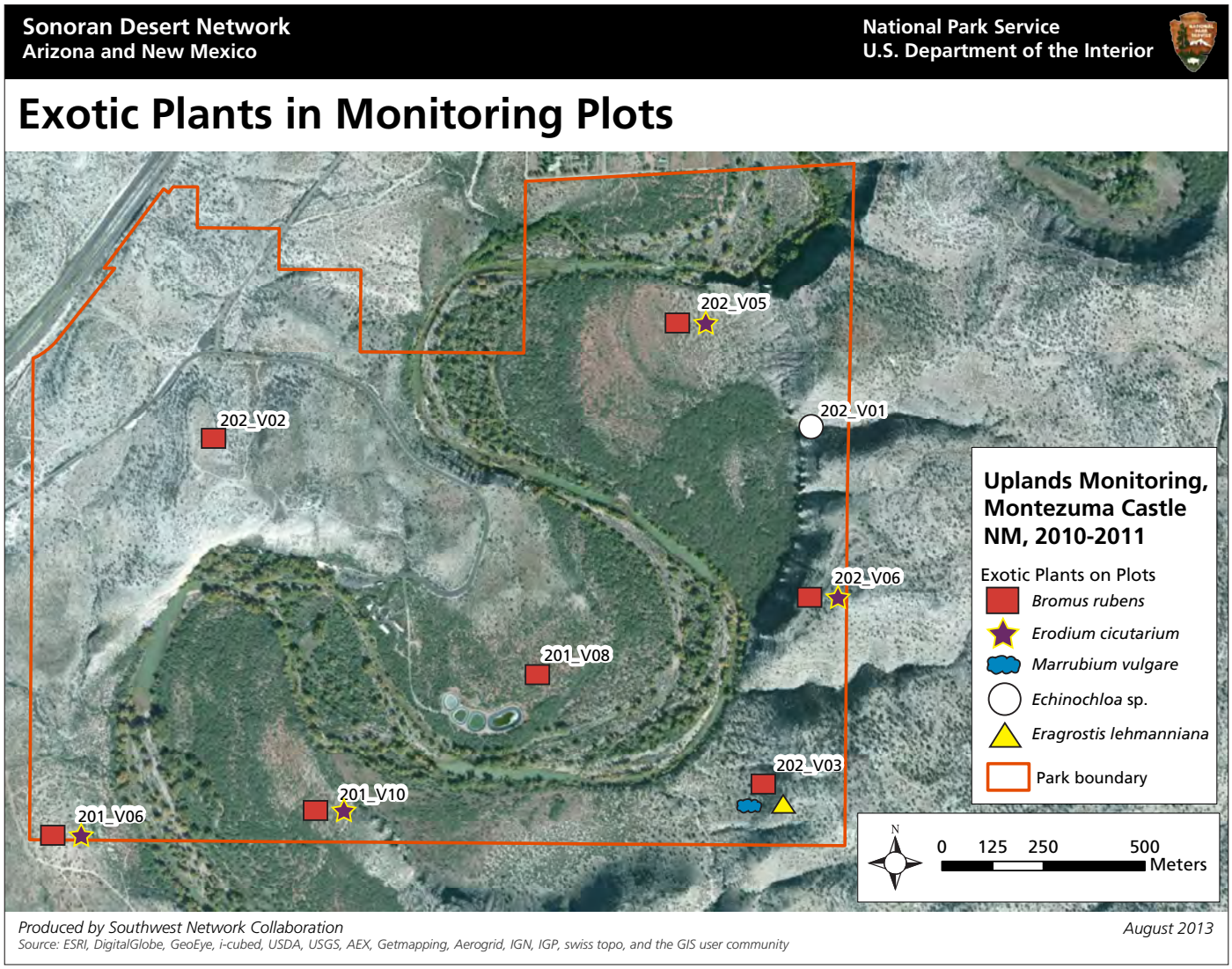


Figure 3-2. Exotic plants in long-term monitoring plots across Montezuma Castle National Monument.

Table 3-3. Ubiquitous species observed on monitoring plots at Montezuma Castle National Monument, 2010–2011.

Scientific name	Common name	Lifeform	Frequency (%)		
			Terrace stratum	Verde limestone stratum	Parkwide
Aristida purpurea	purple threeawn	Graminoid	100%	100%	100%
Gutierrezia sarothrae	broom snakeweed	Subshrub	100%	100%	100%
Bromus rubens	**red brome**	**Graminoid**	100%	75%	88%
Krameria erecta	littleleaf ratany	Subshrub	75%	100%	88%
Berberis haematocarpa	red barberry	Shrub	100%	75%	88%
Larrea tridentata	creosote bush	Shrub	75%	100%	88%
Muhlenbergia porteri	bush muhly	Graminoid	100%	50%	75%
Acacia greggii	catclaw acacia	Tree	100%	50%	75%
Yucca elata	soaptree yucca	Tree	100%	50%	75%
Cylindropuntia leptocaulis	Christmas cactus	Succulent	75%	50%	63%
Juniperus monosperma	oneseed juniper	Tree	50%	75%	63%
Erodium cicutarium	**redstem filaree**	**Forb/Herb**	75%	25%	50%
Canotia holacantha	crucifixion thorn	Tree	25%	75%	50%

Non-native plants are bolded.

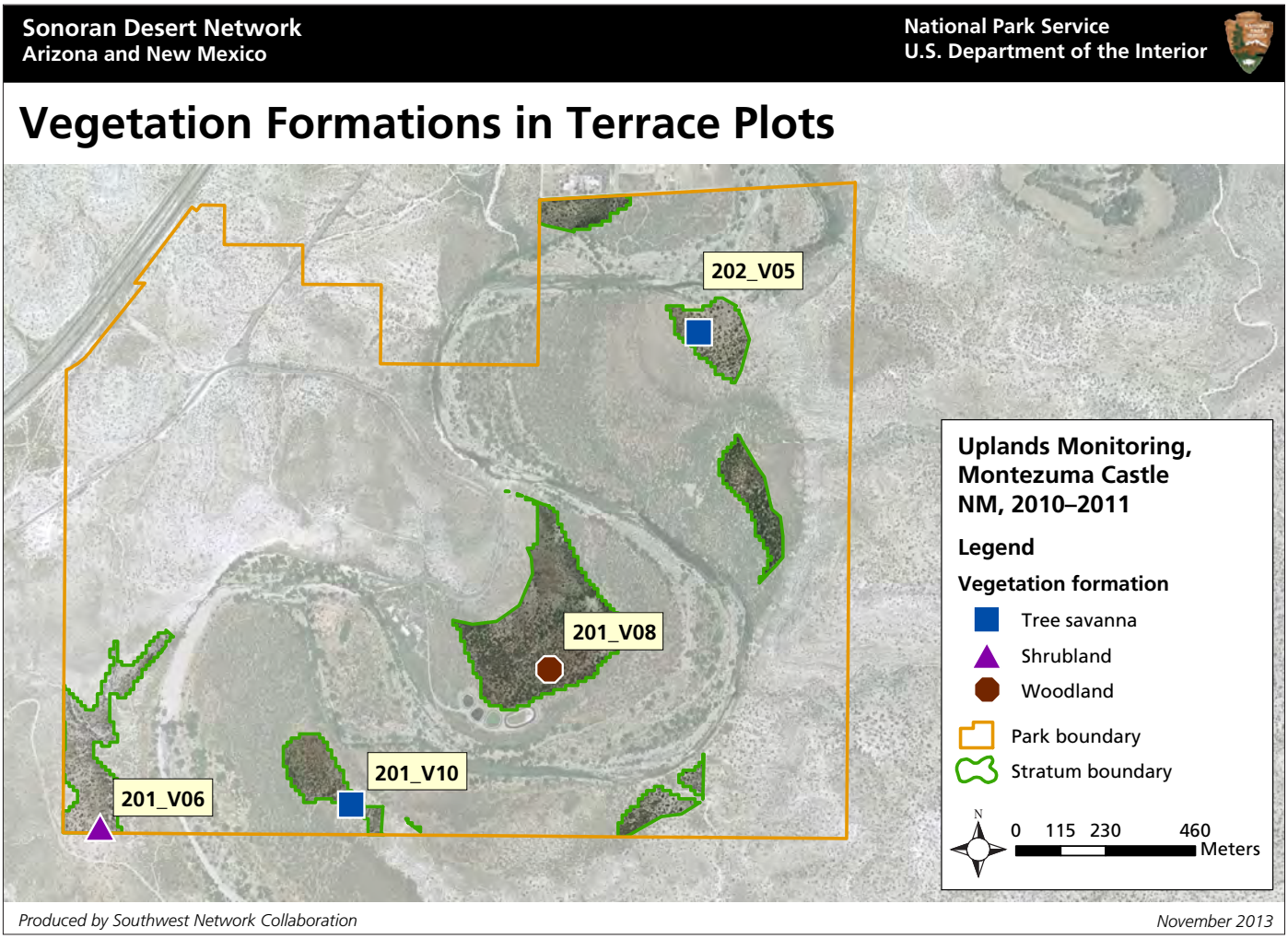


Figure 3-3. Location of monitoring plots, vegetation formations, and approximate boundary of the terrace stratum, Montezuma Castle National Monument, 2010–2011.

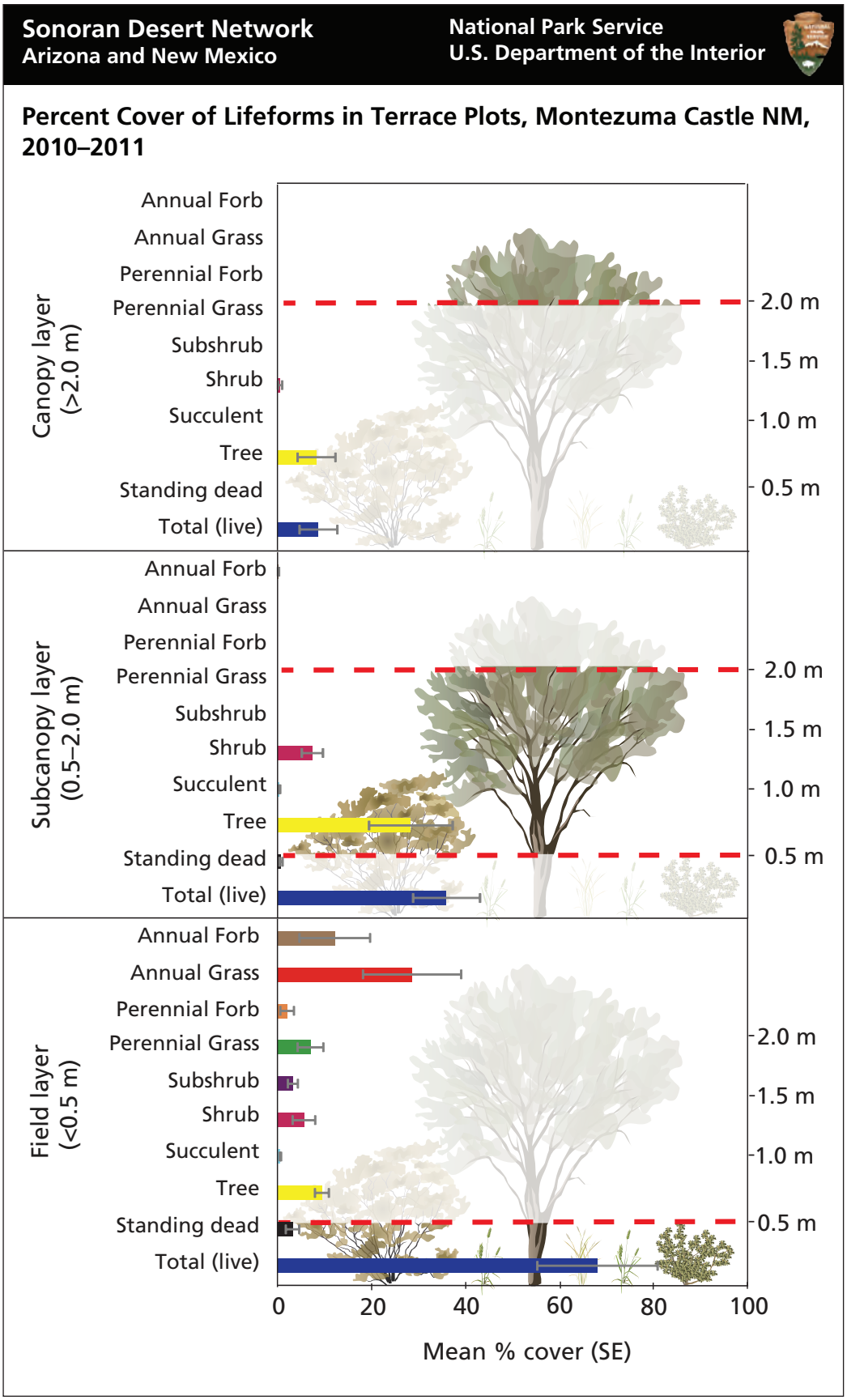


Figure 3-4. Lifeform cover in terrestrial vegetation monitoring plots, terrace stratum, Montezuma Castle National Monument, 2010–2011.

plots, although succulents were found in only trace amounts (Figure 3-4).

3.3.2 Cover and extent of perennial plant species

Monitoring plots in the terrace stratum were dominated by a subcanopy (0.5–2 m) of short-statured velvet mesquite and catclaw acacia trees and creosote bush, with an understory (<0.5 m) of a matrix of the exotic annual grass, red brome; the exotic annual forb, redstem storksbill; native perennial grasses; and subshrubs, such as *Gutierrezia sarothrae* (broom snakeweed; Table 3-4; tables begin on page 28). Velvet mesquite and catclaw acacia seedlings were also common on these plots. The greatest vegetative cover occurred in the field layer (<0.5 m; Table 3-4). See Appendix A (available with the digital version of this report), Table A1 for plot-specific information.

3.3.3 Frequency and extent of uncommon plant species

An additional nine species and four genera were detected in the frequency subplots of terrace plots (Table 3-5). Five of the uncommon species (found only on subplots) had within-plot frequencies above 10%: rushpea (*Hoffmannseggia* sp.); globemallow (*Sphaeralcea* sp.); the subshrubs, plains blackfoot (*Melampodium leucanthum*) and Coves' cassia (*Senna covesii*); and the cactus, pinkflower hedgehog cactus (*Echinocereus fasciculatus*), Table 3-5. The globemallow genus was the only uncommon species found at more than two of the terrace monitoring plots (Table 3-5). See Appendix A, Table A3 for plot-specific information.

3.3.4 Soil cover and biological soil crusts

Litter and gravel dominated the soil surface (Figure 3-5). Approximately 10% was bare soil without vegetative cover. An additional 8% was bare soil with vegetative cover. Plot-specific information is provided in Appendix A, Table A4.

Light cyanobacteria crusts were ubiquitous and dominated the biological soil crust community, accounting for nearly 10% of the soil cover as measured on the transects. In contrast, dark cyanobacteria crusts, lichens, and mosses each accounted for less than 1% soil cover. Although lichen cover was low, crews observed crustose and squamulose lichens in two terrace plots and gelatinous lichens in one plot. Moss was observed in two terrace plots. Plot-specific information is provided in Appendix A, Tables A4–6.

3.3.5 Soil stability

The average surface aggregate stability rating for plots in the terrace stratum was 3.0 ± 0.5 ("somewhat stable"), with high variability between plots. Overall, samples located under vegetation had higher stability ratings (3.3 ± 0.5) than samples without vegetative cover (2.7 ± 0.6). However, in one plot, samples without vegetative cover were somewhat more stable than samples under vegetative cover. All plots in the terrace stratum had an average stability rating of at least 2 ("somewhat unstable"). Plots 201_V10 and 202_V05 had average stability ratings of less than 3 for samples without vegetative cover. Plot-specific information is provided in Appendix A, Table A7.

3.3.6 Site and soil characterization

Surface soils in the terrace stratum were sandy loams, with the exception of plot 202_V05, which was a loam. Rock-fragment content (fraction of soil sample >2 mm in diameter by mass) ranged from 2% to 42% in the terrace stratum. Plot 201_V08 had 2% rock fragments, whereas the other plots had at least 37% rock fragments. The plots tended to have low organic contents (<2% total organic carbon). Bulk density ranged from 0.8 to 1.6 grams/cm^3. Plot-specific information for the soil characterization is provided in Appendix A, Table A8.

Half of the plots showed evidence of erosion. Plot 202_V05 had a rill that affected less than 5% of the plot. Plot 201_V08 had modest amounts (<5%) of pedestalling. Plot-specific information for the site characterization is provided in Appendix A, Table A8.

3.3.7 Management assessment points

Two parameters crossed an assessment point threshold: exotic plant dispersal and soil aggregate stability. Exotic plants occurred on all terrace monitoring plots, although at relatively modest cover (6.6% ± 2.2, Table 3-6).

Table 3-4. Average cover values for species measured in the field, subcanopy, and canopy height categories, terrace monitoring plots, Montezuma Castle National Monument, 2010–2011.

Species	Common Name	Lifeform	Field (<0.5 m)				Subcanopy (0.5–2.0 m)				Canopy (>2.0 m)				Extent (of 4)
			AVG	SE	MDC	n=	AVG	SE	MDC	n=	AVG	SE	MDC	n=	
Astragalus calycosus	Torrey's milkvetch	Forb/Herb	0.2%	0.2%	5%	1	---	---	---	---	---	---	---	---	1
Astragalus tephrodes	ashen milkvetch	Forb/Herb	0.3%	0.2%	5%	2	---	---	---	---	---	---	---	---	2
Erodium cicutarium	**redstem storksbill**	Forb/Herb	2.6%	1.4%	5%	3	---	---	---	---	---	---	---	---	3
Aristida purpurea	purple threeawn	Graminoid	1.7%	1.0%	5%	3	---	---	---	---	---	---	---	---	4
Bromus rubens	**red brome**	Graminoid	4.0%	1.0%	5%	4	---	---	---	---	---	---	---	---	4
Dasyochloa pulchella	low woollygrass	Graminoid	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	1
Elymus elymoides	squirreltail	Graminoid	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	2
Muhlenbergia porteri	bush muhly	Graminoid	3.6%	2.3%	5%	4	---	---	---	---	---	---	---	---	4
Chaetopappa ericoides	rose heath	Subshrub	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	2
Gutierrezia sarothrae	broom snakeweed	Subshrub	4.3%	1.2%	5%	4	---	---	---	---	---	---	---	---	4
Krameria erecta	littleleaf ratany	Subshrub	0.4%	0.4%	5%	1	---	---	---	---	---	---	---	---	3
Atriplex canescens	fourwing saltbush	Shrub	2.1%	2.1%	5%	1	1.3%	1.3%	5%	2	---	---	---	---	1
Berberis haematocarpa	red barberry	Shrub	0.3%	0.3%	5%	1	1.8%	1.1%	5%	1	0.5%	0.5%	5%	1	4
Ephedra sp.	jointfir	Shrub	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	1
Ephedra viridis	Mormon tea	Shrub	0.9%	0.9%	5%	1	---	---	---	---	---	---	---	---	2
Larrea tridentata	creosote bush	Shrub	4.6%	1.5%	5%	3	7.4%	2.6%	6%	4	---	---	---	---	3
Cylindropuntia leptocaulis	Christmas cactus	Succulent	0.6%	0.6%	5%	1	---	---	---	---	---	---	---	---	3
Yucca elata	soaptree yucca	Succulent	0.4%	0.2%	5%	2	---	---	---	---	---	---	---	---	4
Acacia greggii	catclaw acacia	Tree	4.5%	1.6%	5%	4	4.2%	1.1%	5%	1	0.5%	0.5%	5%	1	4
Canotia holacantha	crucifixion thorn	Tree	---	---	---	---	0.2%	0.2%	5%	1	---	---	---	---	1
Juniperus monosperma	oneseed juniper	Tree	---	---	---	---	0.4%	0.4%	5%	1	0.7%	0.7%	5%	1	2
Prosopis velutina	velvet mesquite	Tree	5.8%	2.8%	6%	3	10.6%	5.7%	12%	4	1.8%	1.6%	5%	2	4

"MDC" = minimum detectable change (% cover)

"n" = required number of plots for power criteria

"Extent" = number of plots in which species was detected on transects or in subplots (out of 4). Exotic species are bold, and annuals are shaded.

Highlighted species failed to meet our statistical power criteria.

Table 3-5. Within-plot frequency and extent of uncommon species encountered only on subplots of terrace monitoring plots at Montezuma Castle National Monument, 2010–2011.

Scientific name	Common name	Lifeform	Within-plot frequency (n=5 subplots)		Extent (of 4)
			Mean	SE	
Astragalus allochrous var. *playanus*	halfmoon milkvetch	Forb/Herb	5%	5.0%	1
Astragalus sp.	milkvetch	Forb/Herb	5%	5.0%	1
Leptochloa dubia	green sprangletop	Graminoid	5%	5.0%	1
Echinocereus fasciculatus	pinkflower hedgehog cactus	Shrub	25%	18.9%	2
Rhus virens	evergreen sumac	Shrub	5%	5.0%	1
Ziziphus obtusifolia	lotebush	Shrub	5%	5.0%	1
Abutilon parvulum	dwarf Indian mallow	Subshrub	5%	5.0%	1
Melampodium leucanthum	plains blackfoot	Subshrub	25%	25.0%	1
Senna covesii	Coves' cassia	Subshrub	20%	20.0%	1
Sphaeralcea sp.	globemallow	Subshrub	25%	12.6%	3
Opuntia phaeacantha	tulip pricklypear	Succulent	5%	5.0%	1
Hoffmannseggia sp.	rushpea	N/A	25%	25.0%	1
Tiquilia sp.	crinklemat	N/A	10%	10.0%	1

"Extent" = number of plots in which species was detected on transects or in subplots (of 4).
Variables with an asterisk do not meet our statistical power criteria.

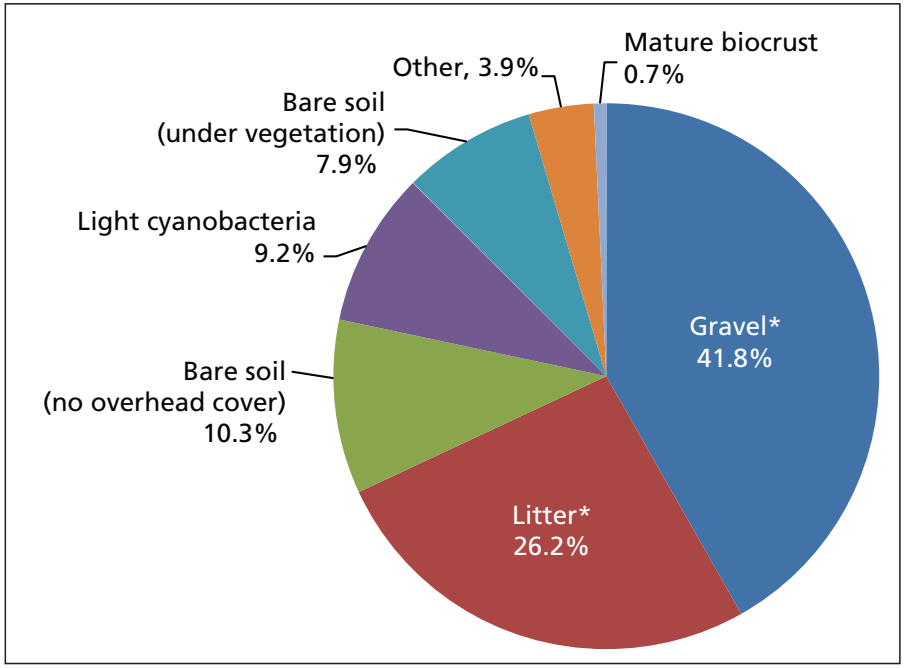


Figure 3-5. Average soil cover (% by class) in the terrace stratum, Montezuma Castle National Monument, 2010–2011. Variables with an asterisk did not meet our statistical power criteria. Mature biocrust = dark cyanobacteria + lichen + moss.

Table 3-6. Terrestrial vegetation and soils monitoring data in the context of proposed management assessment points, terrace stratum, Montezuma Castle National Monument, 2010–2011.

Issue	Management assessment point	Mean ± SE	Point met?	Recommendation
Erosion hazard	Exposed bare ground cover is >20%	10.3% ± 3.2	no	Continue monitoring
	Surface soil aggregate stability (with no overhead vegetation) is <Class 3	2.7 ± 0.6	YES	Continue monitoring
Site resilience	Foliar cover of dead perennial plants is >15% (field)	3.1% ± 1.4	no	Continue monitoring
	Foliar cover of dead perennial plants is >15% (subcanopy)	0.4% ± 0.2	no	Continue monitoring
Exotic plant dispersal	Extent of invasive exotic plants is >50%	100%	YES	Meet and consider
Exotic plant invasion	Total cover of exotic plants is >10% (field)	6.6% ± 2.2	no	Continue monitoring
	Exotic plant cover: total plant cover is >1:4 (0.25) (field)	0.16	no	Continue monitoring
Fire hazard	Grasses + forbs is >30% (field)	13.1% ± 3.0	no	Continue monitoring
	Annual plant cover: total plant cover is >1:4 (0.25) (field)	0.18	no	Meet and consider

The exceedance of the assessment point for exotic plant dispersal was largely driven by one species: red brome.

The stability of surface soil aggregates was below our proposed management assessment point (MAP; Table 3-6), indicating the potential for significant soil erosion. Individually, two plots (201_V10 and 202_V06) failed to meet the MAP for soil aggregate stability, and plot 202_V06 had stability values of less than 2 for samples not located under vegetation cover.

Individually, plot 201_V10 failed to meet the MAPs for exotic plants and fire hazard, due to the relatively high cover of the annual grass, red brome. Appendix A, Table A9 for plot-specific results in the context of management assessment points.

3.4 Verde limestone stratum

3.4.1 Vegetation formations and lifeforms

Vegetation formation types were determined using a key (Appendix C), and based on the relative abundances of different plant lifeforms within each monitoring plot. Vegetation formations varied greatly across Verde limestone plots (Figure 3-6). Plot 202_V03 was a tree savanna, plot 202_V02 was a shrub savanna, plot 202_V01 was a shrubland, and plot 202_V06 was a wooded shrubland.

Small trees and shrubs dominated Verde limestone plots, although perennial grasses were also important (Figure 3-6; figures begin on page 32). Trees were generally under 2 m in stature. As on the terrace plots, the greatest

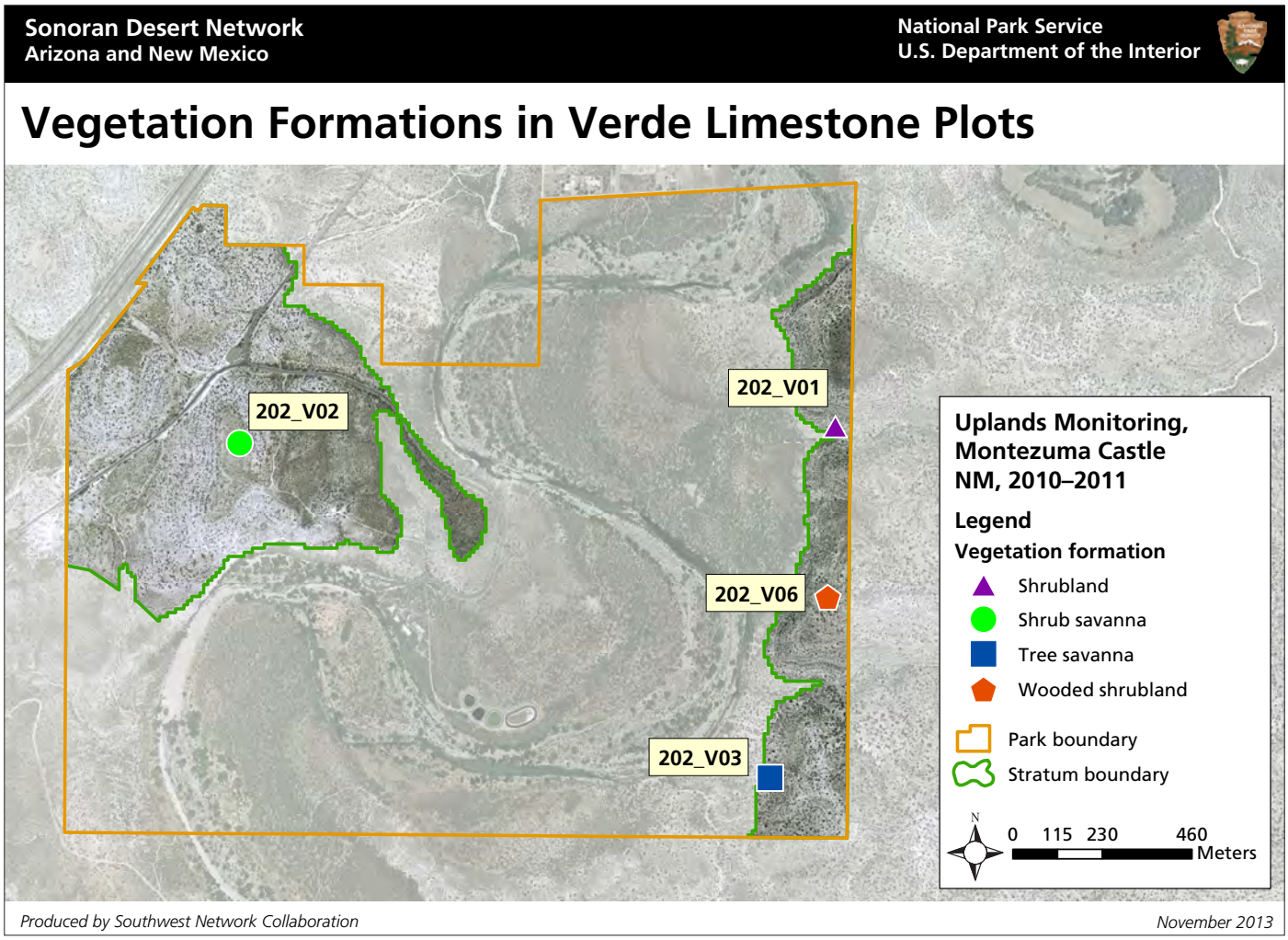


Figure 3-6. Location of monitoring plots, vegetation formations, and approximate boundary of the Verde limestone stratum, Montezuma Castle National Monument, 2010–2011.

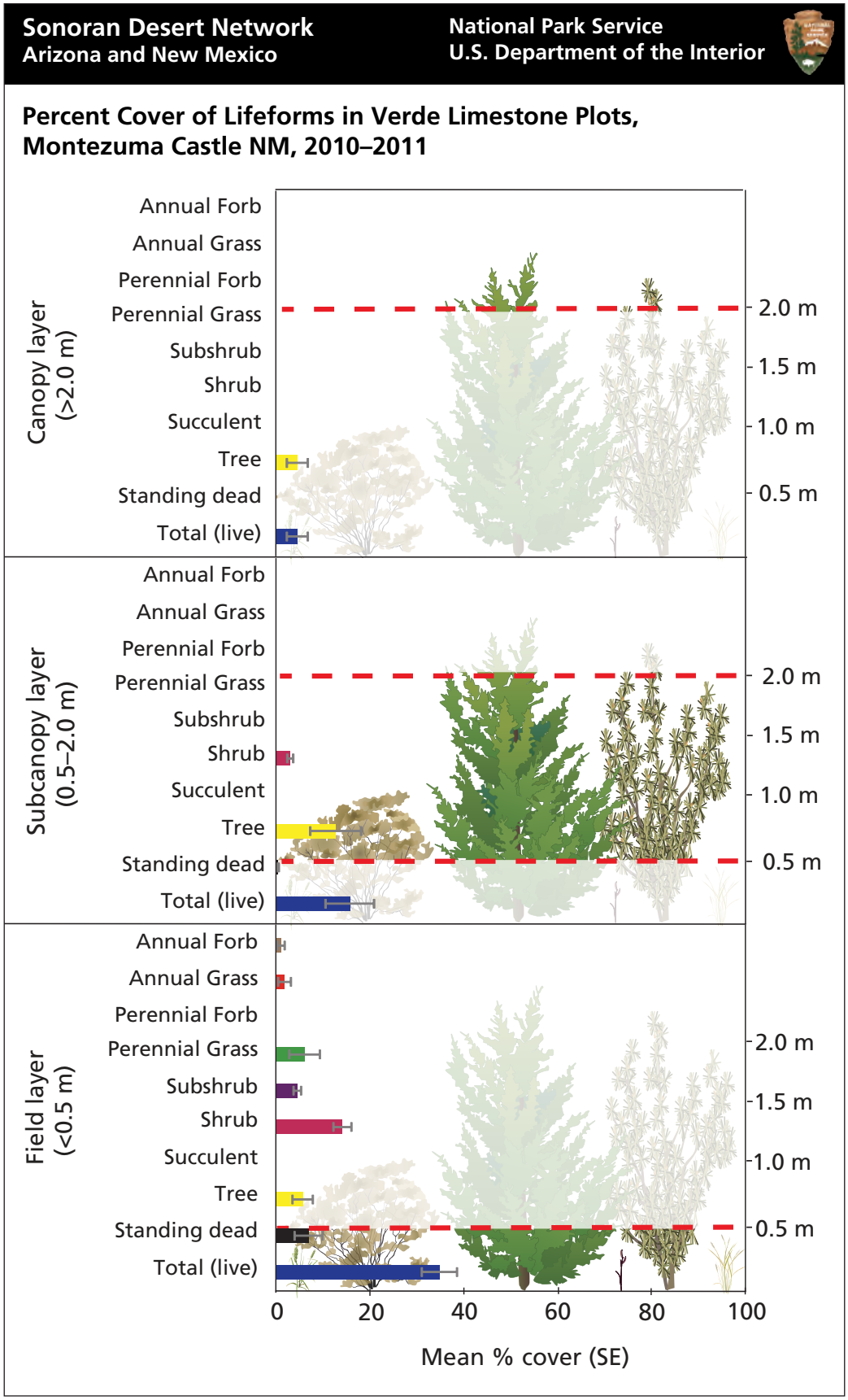


Figure 3-7. Lifeform cover in terrestrial vegetation monitoring plots, Verde limestone stratum, Montezuma Castle National Monument, 2010–2011.

plant cover was in the field layer (<0.5 m). All major lifeforms except vines were encountered on the monitoring plots, although perennial forbs and succulents were found in only trace amounts (Figure 3-7).

3.4.2 Cover and extent of perennial plant species

Verde limestone plots contained a sparse canopy and subcanopy of crucifixion thorn, an emblematic species of the higher latitudes of the Sonoran Desert, and oneseed juniper (Table 3-7; tables begin on page 34). The understory was dominated by the native annual grass, purple threeawn; the shrub, mariola; and the subshrub, littleleaf ratany (*Krameria erecta*; Table 3-7). Plot-level results are given in Appendix A, Table A2.

3.4.3 Frequency and extent of uncommon plant species

An additional 29 species and 4 genera were detected in the frequency subplots of Verde limestone plots, including the non-native, cockspur grass; Lehmann lovegrass; and horehound (Table 3-8). Five of the uncommon species (found only on subplots) had within-plot frequencies above 15%: desert-peony (*Acourtia* sp.); the forb, broom milkwort (*Polygala scoparioides*); the subshrub, featherplume (*Dalea formosa*); the grass, bush muhly (*Muhlenbergia porteri*); and the shrub, red barberry (*Berberis haematocarpa*) (Table 3-8). Red barberry was found at three Verde limestone monitoring plots; otherwise, none of the uncommon species was found at more than two of the plots (Table 3-5). See Appendix A, Table A3 for plot-specific information.

3.4.4 Soil cover and biological soil crusts

Gravel dominated the soil surface, covering 60% of the soil surface along the transects (Figure 3-8). Litter, rock, and bedrock also occurred frequently. Approximately 7% was bare soil, roughly half of which was without vegetative cover. Plot-specific information is provided in Appendix A, Table A4.

Biological soil crust cover was low across the Verde limestone plots. Light cyanobacteria crusts accounted for 1% of the soil cover as measured on transects, and "mature biocrusts" (dark cyanobacteria, lichen, and moss) covered 2% of the soil surface on the transects and 4% of the available habitat in the quadrats. However, the occurrence of biological soil crusts was relatively high across the monitoring plots. Crews observed squamulose lichens in three Verde limestone plots, gelatinous lichens in two plots, and crustose lichen on one plot. Plot-specific information is provided in Appendix A, Tables A4–6.

3.4.5 Soil stability

The average surface aggregate stability rating for plots in the Verde limestone stratum was 3.5 ± 0.6 ("stable"), with a high degree of between-plot variability. Plot 202_V06 had an average stability rating of less than 2, "unstable." Samples under vegetation had somewhat higher stability ratings (3.8 ± 0.5) compared to samples without vegetative cover (3.3 ± 0.6). Plot-specific information is provided in Appendix A, Table A7.

3.4.6 Site and soil characterization

All surface soil samples were loams (sandy loam, loamy sand, or loam) with at least 30% rock fragments. Rock-fragment content (fraction of soil sample >2 mm in diameter by mass) ranged from 30% to 52%. The plots tended to have low organic contents (<2% total organic carbon). Bulk density ranged from 0.9 to 1.1 grams/cm^3. Plot-specific information for the soil characterization is provided in Appendix A, Table A8.

All plots exhibited evidence of relatively minor (<5%) burrowing. Two plots (202_V01 and 202_V03) had tunneling over less than 5% of the plot. None of the plots had rills or gullies or showed evidence of sheet erosion or pedestalling. Plot-specific information for the site characterization is provided in Appendix A, Table A8.

3.4.7 Management assessment points

Exotic plants occurred on all Verde limestone monitoring plots but had relatively low cover (Table 3-9). The exceedance of the exotic-plant dispersal MAP was driven by red brome, which occurred on three of the four plots.

Table 3-7. Average cover values for species measured in the field, subcanopy, and canopy height categories, Verde limestone monitoring plots, Montezuma Castle National Monument, 2010–2011.

Scientific name	Common name	Lifeform	Field (<0.5 m)				Subcanopy (0.5–2.0 m)				Canopy (>2.0 m)				Extent (of 4)
			AVG	SE	MDC	n=	AVG	SE	MDC	n=	AVG	SE	MDC	n=	
Erodium cicutarium	**redstem storksbill**	Forb/Herb	0.2%	0.2%	5%	1	---	---	---	---	---	---	---	---	1
Aristida purpurea	purple threeawn	Graminoid	5.4%	3.4%	8%	4	---	---	---	---	---	---	---	---	4
Bouteloua curtipendula	sideoats grama	Graminoid	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	1
Bromus rubens	**red brome**	Graminoid	1.7%	1.2%	5%	2	---	---	---	---	---	---	---	---	3
Tridens muticus	slim tridens	Graminoid	0.6%	0.6%	5%	1	---	---	---	---	---	---	---	---	1
Brickellia sp.	spearleaf brickellbush	Subshrub	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	1
Brickellia atractyloides	brickellbush	Subshrub	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	2
Encelia farinosa	goldenhills	Subshrub	0.2%	0.2%	5%	1	---	---	---	---	---	---	---	---	1
Gutierrezia sarothrae	broom snakeweed	Subshrub	1.0%	0.6%	5%	2	---	---	---	---	---	---	---	---	4
Krameria erecta	littleleaf ratany	Subshrub	3.1%	0.7%	5%	4	---	---	---	---	---	---	---	---	4
Aloysia wrightii	Wright's beebrush	Shrub	0.2%	0.2%	5%	1	0.1%	0.1%	5.0%	1	---	---	---	---	1
Ephedra sp.	jointfir	Shrub	0.2%	0.2%	5%	1	---	---	---	---	---	---	---	---	2
Ephedra viridis	mormon tea	Shrub	0.8%	0.8%	5%	1	0.4%	0.4%	5.0%	1	---	---	---	---	1
Larrea tridentata	creosote bush	Shrub	2.3%	0.5%	5.0%	4	2.1%	0.9%	5%	1	---	---	---	---	4
Parthenium incanum	mariola	Shrub	10.6%	1.6%	5%	4	0.4%	0.2%	5%	1	---	---	---	---	4
Acacia greggii	catclaw acacia	Tree	0.3%	0.3%	5%	1	---	---	---	---	---	---	---	---	2
Canotia holacantha	crucifixion thorn	Tree	4.0%	1.6%	5%	3	7.8%	3.7%	8.0%	4	2.0%	1.1%	5.0%	1	3
Juniperus monosperma	oneseed juniper	Tree	1.5%	0.8%	5%	2	4.9%	2.9%	7%	3	2.6%	1.6%	5.0%	2	3
Eriogonum sp.	buckwheat	N/A	0.1%	0.1%	5%	1	---	---	---	---	---	---	---	---	1
Krameria sp.	ratany	N/A	0.5%	0.5%	5%	1	---	---	---	---	---	---	---	---	1
Tiquilia sp.	crinklemat	N/A	0.3%	0.3%	5%	1	---	---	---	---	---	---	---	---	2

"MDC" = minimum detectable change (% cover)

"n" = required number of plots for power criteria (see text)

"Extent" = number of plots in which species was detected on transects or in subplots (out of 4). Exotic species are bold, and annuals are shaded.

Table 3-8. Within-plot frequency and extent of uncommon species encountered only on subplots of Verde limestone monitoring plots, Montezuma Castle National Monument, 2010–2011.

Scientific name	Common name	Lifeform	Within-plot frequency (n=5 subplots)		Extent (of 4 plots)
			Mean	SE	
Allionia incarnata	trailing windmills	Forb/Herb	5%	5.0%	1
Astragalus calycosus	Torrey's milkvetch	Forb/Herb	5%	5.0%	1
Chamaesyce sp.	sandmat	Forb/Herb	10%	10.0%	1
Delphinium scaposum	tall mountain larkspur	Forb/Herb	10%	10.0%	1
Mirabilis multiflora	Colorado four o'clock	Forb/Herb	5%	5.0%	1
Nicotiana obtusifolia	desert tobacco	Forb/Herb	15%	15.0%	1
Polygala scoparioides	broom milkwort	Forb/Herb	20%	20.0%	1
***Echinochloa* sp.**	**cockspur grass**	Graminoid	5%	5.0%	1
Eragrostis lehmanniana	Lehmann lovegrass	Graminoid	5%	5.0%	1
Muhlenbergia porteri	bush muhly	Graminoid	20%	11.5%	2
Piptochaetium fimbriatum	pinyon ricegrass	Graminoid	5%	5.0%	1
Setaria grisebachii	Grisebach's bristlegrass	Graminoid	5%	5.0%	1
Atriplex canescens	fourwing saltbush	Shrub	5%	5.0%	1
Berberis haematocarpa	red barberry	Shrub	55%	18.9%	3
Calliandra humilis	dwarf stickpea	Shrub	5%	5.0%	1
Lycium pallidum	pale desert-thorn	Shrub	5%	5.0%	1
Purshia mexicana	Mexican cliffrose	Shrub	5%	5.0%	1
Rhus aromatica	fragrant sumac	Shrub	5%	5.0%	1
Rhus trilobata	skunkbush sumac	Shrub	10%	10.0%	1
Ziziphus obtusifolia	lotebush	Shrub	15%	9.6%	2
Brickellia microphylla	brickellbush	Subshrub	15%	15.0%	1
Dalea formosa	featherplume	Subshrub	25%	15.0%	2
Eriogonum microthecum	slender buckwheat	Subshrub	5%	5.0%	1
Marrubium vulgare	**horehound**	Subshrub	5%	5.0%	1
Melampodium leucanthum	plains blackfoot	Subshrub	15%	15.0%	1
Thymophylla acerosa	pricklyleaf dogweed	Subshrub	10%	10.0%	1
Tiquilia canescens	woody crinklemat	Subshrub	10%	10.0%	1
Cylindropuntia leptocaulis	Christmas cactus	Succulent	10%	5.8%	2
Opuntia phaeacantha	tulip pricklypear	Succulent	15%	15.0%	1
Purshia stansburiana	Stansbury cliffrose	Tree	15%	15.0%	1
Yucca elata	soaptree yucca	Tree	15%	9.6%	2
Acourtia sp.	desertpeony	N/A	20%	14.1%	2
Streptanthus sp.	twistflower	N/A	5%	5.0%	1

Exotic species are bold, and annuals are shaded.

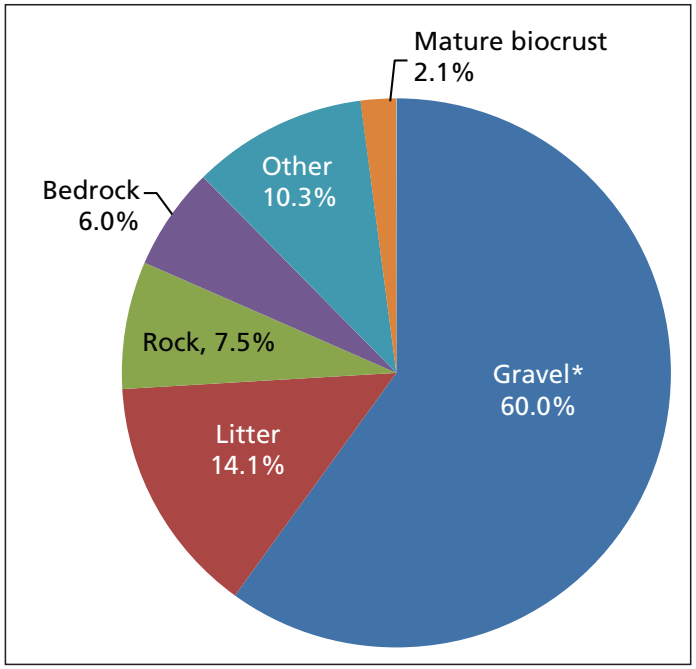


Figure 3-8. Average soil cover (% by class) in the Verde limestone stratum, Montezuma Castle National Monument, 2010–2011. Variables with an asterisk did not meet our statistical power criteria. Mature biocrust = dark cyanobacteria + lichen + moss.

Table 3-9. Terrestrial vegetation and soils monitoring data in the context of proposed management assessment points, Verde limestone stratum, Montezuma Castle National Monument, 2010–2011.

Issue	Management assessment point	Mean ± SE	Point met?	Recommendation
Erosion hazard	Exposed bare ground cover is >20%	4.1% ± 0.6	NO	Continue monitoring
	Surface soil aggregate stability (with no overhead vegetation) is <Class 3	3.3 ± 0.6	NO	Continue monitoring
	Mature biological soil crust cover is <10% of available habitat	4.3% ± 1.5	YES	Continue monitoring
Site resilience	Foliar cover of dead perennial plants is >15% (field)	7.0% ± 3.0	NO	Continue monitoring
	Foliar cover of dead perennial plants is >15% (subcanopy)	0.2% ± 0.2	NO	Continue monitoring
Exotic plant dispersal	Extent of invasive exotic plants is >50%	100%	YES	Meet and consider
Exotic plant invasion	Total cover of exotic plants is >10% (field)	1.9% ± 1.2	NO	Continue monitoring
	Exotic plant cover: total plant cover is >1:4 (0.25) (field)	0.06	NO	Continue monitoring
Fire hazard	Grasses + forbs is >30% (field)	9.2% ± 2.6	NO	Continue monitoring
	Annual plant cover: total plant cover is >1:4 (0.25) (field)	0.1	NO	Continue monitoring

Dark cyanobacteria crusts, lichens, and bryophytes (collectively known as mature biological soil crusts) covered just over 4% of the available habitat on the soil surface, which is less than the 10% cover reported by Bowker and Belnap (2008) for the park. Individually, none of the Verde limestone plots met the MAP for biological soil crusts. The variability reported by Bowker and Belnap (2008) was high and the methodologies used by SODN and Bowker and Belnap (2008) were different. Therefore, the authors' opinion is that the biological soil crust community warrants further investigation before any action is contemplated.

Individually, plot 202_V06 failed to meet the MAP for soil aggregate stability, with stability values of less than 2 for samples not under vegetation cover. Plot 202_V02, with 34% of the total plant cover from annual plants, failed to meet a fire-hazard MAP. See Appendix A, Table A10 for plot-specific results in the context of management assessment points.

3.5 Design considerations

3.5.1 Power to detect trends in common species and lifeforms

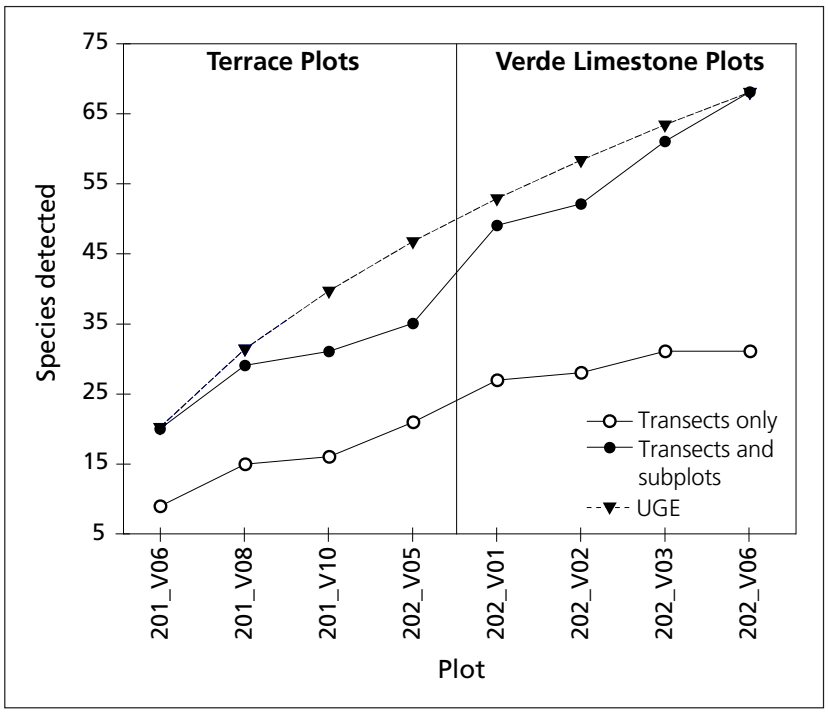


Figure 3-9. Species accumulation curves for cover and frequency data collected on uplands plots at Montezuma Castle National Monument, 2010–2011. Curves show cumulative numbers of species detected as plots are added. UGE = mean species accumulation curve with samples entered in random order (Ugland et al. 2003).

Our proposed sampling design, using the updated strata, generally exceeded our expectations for statistical power to detect trends in plant lifeforms and common perennial species based on 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). Our data indicate that we will be able to detect a parkwide and within-stratum 5% change (absolute foliar cover) for nearly all detected perennial species and lifeforms (Appendix A, Tables A1–A2).

Only one perennial species failed to meet our criteria: velvet mesquite in the subcanopies (0.5–2.0 m) of the terrace stratum (Appendix A, Table A1). We estimate that we can only detect a 12% change in this species for this height and stratum, based on the 2010–2011 data. The high between-plot variability of this species likely contributed to the failure to meet our initial design criteria for tree lifeforms, as well, as we estimate that we can only detect an 8% change in subcanopy trees parkwide and an 11% change in subcanopy trees in the terrace stratum (Appendix A, Table A1). Although no single tree species failed to meet our criteria within the Verde limestone stratum, we estimate that we can detect a 12% change in subcanopy trees in that stratum (Appendix A, Table A2).

Also of concern was our difficulty in detecting change in total cover in (1) the field layers (<0.5 m) of terrace plots and (2) the subcanopy of each stratum. We estimate that we can only detect a 13% change in total cover in the field layer of terrace plots (Appendix A, Table A1). Within the subcanopy layer, we estimate that we can detect a 12% and 11% change in the terrace and Verde limestone plots, respectively (Appendix A, Table A1–A2).

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

Line-point intercept transects on the eight monitoring plants detected 32 species; employing the frequency subplots added 41 species. Of the 73 species detected, 68% were exclusive to plots in one stratum or the other (14 exclusively in the terrace stratum, 36 in Verde limestone). Species accumulation curves (Figure 3-9) suggest that adding plots would increase species detections, particu-

larly in the Verde limestone stratum.

For the 41 species encountered only in frequency subplots, our design met or exceeded our sampling objectives for detecting trends (i.e., detect at least a 10% change in within-plot frequency with 90% power and 10% chance of false change error) in approximately 60% of these uncommon perennial species. We had less power to detect change in 17 species.

3.5.3 Power to detect trends in soil parameters

Our design met or exceeded our sampling objectives (i.e., to detect at least a 10% change, with 90% power and 10% chance of false change error) for most soil-cover types at the proposed sampling intensity. The exceptions were gravel in both strata and parkwide, and litter in the terrace stratum. We estimate that we can detect a 12% change in litter cover and a 31% change in gravel cover along the transects for the terrace stratum and a 12% change in gravel in the Verde limestone stratum.

Overall, we did not meet our criteria for average soil stability estimates (i.e., to detect at least a 1 stability class change, with 90% power and 10% chance of false change error) at the proposed sampling intensity. For the terrace stratum, we estimate that we can detect a stability-class change of 1.1 for samples under vegetation and a stability-class change of 1.2 for samples not under vegetation. For the Verde limestone stratum, we estimate that we can detect a stability-class change of 1.1 for samples under vegetation and a stability-class change of 1.3 for samples not under vegetation.

Within the point-quadrats, our power to detect change in 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 groups and parkwide, with the exception of light cyanobacteria crusts in the terrace plots, which failed to meet our criteria (i.e., to detect at least a 10% change, with 90% power and 10% chance of false change error). For light cyanobacteria crusts in the terrace plots, we estimate that we will be able to detect an 11% change.

We failed to meet our power objectives for detecting changes in the frequencies of most growth forms and morphological groups of biological soil crusts.

3.5.4 Biological soil crust cover along transects vs. in quadrats

Biological soil crust cover was measured (1) as part of the soil-substrate cover measurements on the line-point intercept transects and (2) in point-quadrats placed adjacent to the transects. 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. The different sampling approaches did not result in statistically significant different results (at the $P < 0.10$ level) for any of the morphological groups. However, the cover of light and cyanobacteria crusts and bryophytes was somewhat higher when measured in the point-quadrats.

4 Discussion

4.1 Exotic invasive 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.

4.1.1 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 Montezuma Castle NM, suggesting that it is not dispersal-limited from suitable habitats within the park. Its extent throughout the park (88% of SODN monitoring plots) exceeded the management assessment point for exotic-plant dispersal (see Tables 3-6 and 3-9). Areas that are likely to be colonized have been colonized, without regard to elevation or soil type. During the 1999–2001 (Halvorson and Guertin 2003) and the 2003–2004 (Mau-Crimmins et al. 2009) exotic-plant surveys, red brome was ubiquitous across the monument (Figure 4-1). Red brome is and likely will remain a ubiquitous species at Montezuma Castle NM for the foreseeable future.

In addition, red brome represents a significant portion of the field layer (<0.5 m) of terrace plots

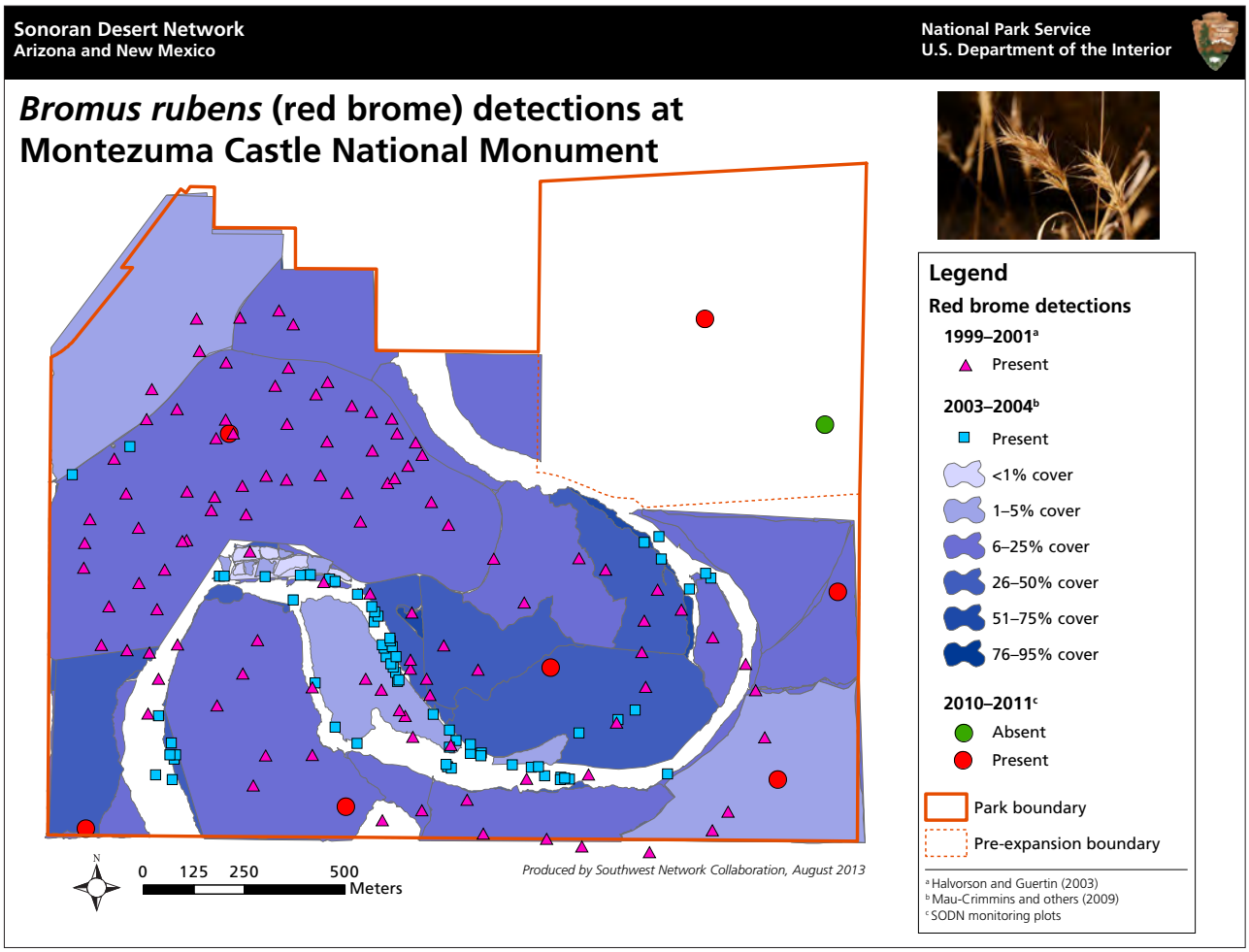


Figure 4-1. Distribution of the exotic annual grass, red brome (*Bromus rubens*), at Montezuma Castle National Monument (Castle unit), based on current and historical data.

(4.0% ± 1.0). Plots in the Verde limestone stratum had relatively low foliar cover of red brome (1.7% ± 1.2).

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 Montezuma Castle NM. Given the low cover of red brome, it appears that native species in uplands areas can effectively compete with it under current conditions.

4.1.2 Consequences of fire and red brome

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 (*B. tectorum*), red brome has a suite of traits (e.g., avoidance via long-lived seedbank, rapid germination and flower production, effective wind dispersal of seeds) that tend to make it more resilient to disturbance (particularly wildfire) than many native species (Brooks and Chambers 2011).

Prolific fine-fuel production (e.g., by red brome) 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 growth of red brome at the expense of natives that are less fire-tolerant. 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).

4.2 Vegetation communities

The vegetation of the monument can be classified into two broad types: (1) riparian woodlands and gallery forests, and (2) thornscrub communities in the rocky uplands. Within the upland scrub communities, our data showed a secondary division into two groups, generally correlating to distance from and elevation above Beaver Creek (Figure 4-2).

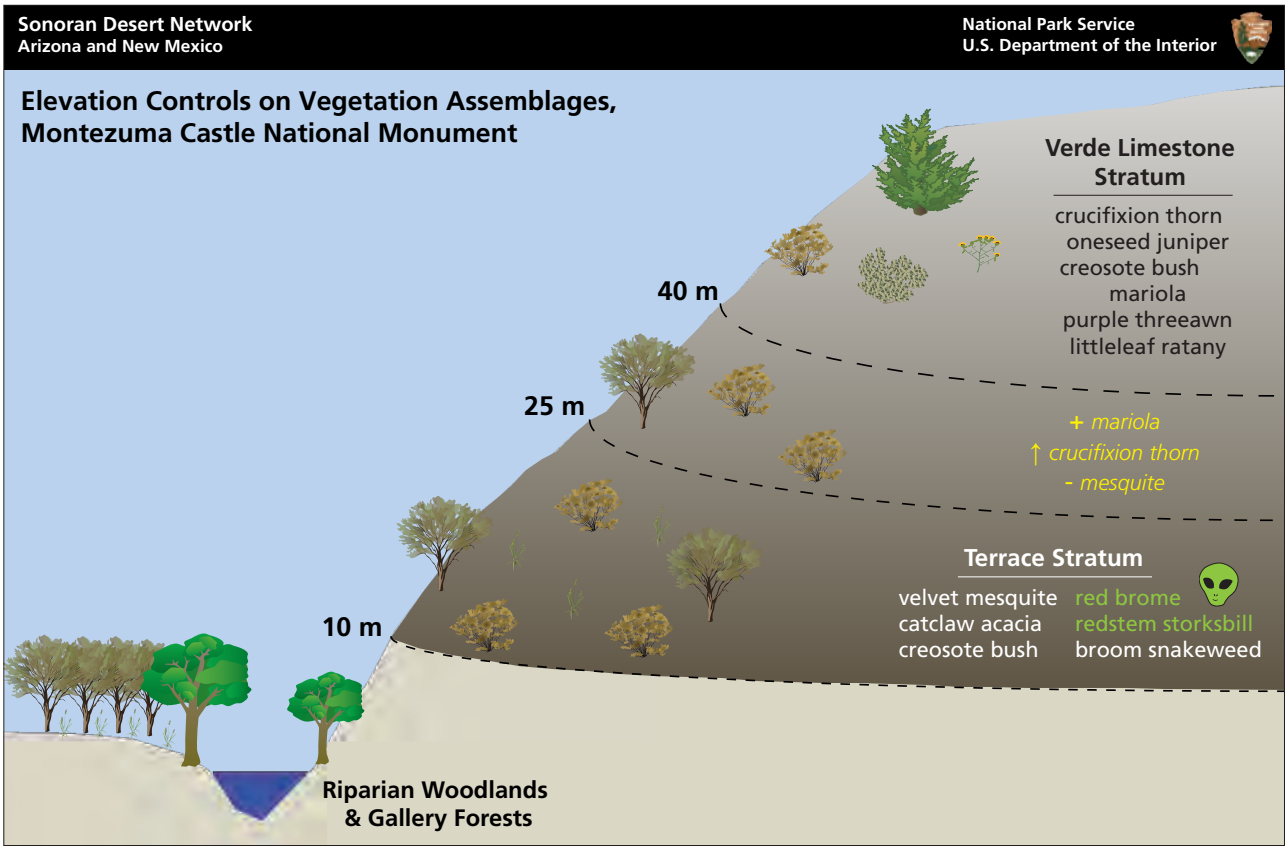


Figure 4-2. Elevation above and distance from Beaver Creek controls terrestrial vegetation assemblages at Montezuma Castle National Monument. This figure shows the characteristic species of each biome and those most responsible for the dissimilarities between types (italicized) as determined by species similarity permutation procedure (SIMPER; see Section 3.1).

The plots within the Verde limestone stratum occur on the highest and steepest slopes of the monument, often approaching the flat mesa tops or straddling the upper backslopes. These exposed rocky and calcareous plots support the shrub-scrub communities that are typical of this region, where crucifixion thorn and creosote comingle and perennial bunchgrasses and thorny shrubs are occasional. These species, along with ephedra (*Ephedra viridis*), littleleaf ratany (*Krameria erecta*), redberry mahonia (*Mahonia haematocarpa*) and graythorn (*Ziziphus obtusa*), define a scrubby landscape with widely spaced, low-growing plants and dotted with tall shrubs. The creosote bush–crucifixion thorn scrubland association is the most predominant vegetation community in the upland areas at Montezuma Castle NM.

In contrast, the terrace plots occur on low-gradient areas composed of old alluvium and are adjacent to the Beaver Creek floodplain. Terrace plots encompass transitional spaces between the active floodplain terraces (which support mesquite bosques) and the steep, scrubby uplands, and include species common to both. These two broadly described vegetation communities intergrade with one another as elevation above the floodplain increases, with only the very steepest of cliffs providing a definitive barrier.

The vegetation communities of the terrace plots show greater floristic affinity to the northern Sonoran Desert, with a greater abundance of large, shrubby mesquite and acacia, and patches of creosote dominating the sandy flats. However, as noted by Rowlands (1999), the overall park flora has a stronger affinity to the Great Basin conifer woodlands, semi-desert grasslands, and interior chaparral than it does to other ecoregions.

However, none of those Great Basin plant-community components is well developed at the monument—likely because the winter temperatures are milder and summer temperatures higher at this park, which lies nears the confluence of three ecoregions. In particular, perennial grasslands are absent, and characteristic Great Basin plants, such as *Purshia stansburiana* (Stansbury cliffrose), *Juniperus* sp. (juniper) and *Atriplex canescens* (fourwing saltbush) are common but not dominant. Other species, such as mariola, mesquite, and creosote bush, are common throughout both the Chihuahuan and Sonoran deserts, indicating that Montezuma Castle NM, like many other Arizona park units, lies at a crossroads of floral influences.

Disturbance has played a significant role in shaping the lowland areas at Montezuma Castle NM. Past agricultural practices, a legacy of livestock grazing, current trespass cattle, and recurring flooding have had major impacts on riparian forest and bosque vegetation (Rowlands 1999). These influences continue to be seen in the presence and abundance of non-native annuals. The higher-elevation Verde limestone plots, with a sparse abundance of non-natives, appear to be the least disturbed and most stable areas of the monument.

4.3 Site stability and erosion

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. 2005a). 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 Montezuma Castle NM.

Static and dynamic factors determine the vulnerability of a site to water erosion (Herrick et al. 2005a). Static factors are generally not affected by management actions and include soil texture, depth, and parent material; slope; aspect; and climate (Herrick et al. 2005a). Dynamic factors that affect water erosion include soil disturbance, soil structure, total cover, and plant basal cover. The quantity of total cover (soil cover and vegetation cover) is the most important dynamic factor affecting water erosion (Herrick et al. 2005a). Most soil loss occurs in "unprotected" areas (i.e., 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).

Our data indicate that soils at Montezuma Castle NM are currently very well protected, with only $7.2 \pm 1.9\%$ of the soil surface consisting of exposed,

bare mineral soil. However, 20% of soil cover is composed of leaf litter, which could be rapidly lost following wildfire or prolonged drought.

In addition, the stability of surface soil aggregates (an indicator of soil structure) was below our proposed management assessment point for the terrace stratum and several individual plots (see Table 3-6), indicating the potential for significant soil erosion. However, over 40% of the soil in the terrace stratum was covered by gravel, which should confer some stability on the soil.

Our data on the dynamic factors of water erosion indicate that while potential erosion is a concern, actual erosion is currently moderate on the SODN monitoring plots. Nauman (2010) surveyed roughly 340 acres of the Castle unit of Montezuma Castle NM and found that approximately 4% (~13 acres) of the surveyed area showed signs of accelerated erosion. Just under half of the features mapped were sheet erosion, one-third were rills, and under 20% were gullies. Nauman (2010) estimated that the 486 unique features represented nearly 11,000 m^3 of soil loss, with the gullies accounting for the majority of that loss.

Although current soil loss appears to be moderate and localized, the potential impacts of wildfire and prolonged drought on critical soil resources at Montezuma Castle NM are substantial due to inherent site instability.

4.4 Implications for terrestrial vegetation and soils monitoring

Although change detection of subcanopy (0.5–2.0-m) mesquite in the terrace stratum just missed our statistical power criteria, overall statistical power for status and trend detection was excellent for both of the new strata, and generally exceeded our design criteria. Despite relatively high between-plot variation, we also met or exceeded our thresholds for soil cover and surface aggregate stability.

We detected less than 20% (73 of 404) of the documented flora of the Castle unit (Schmidt et al. 2006). We believe that this is reasonable, considering that we grouped all annual grasses and forbs (except exotics) and did not sample include riparian zones or riparian-influenced areas of the park (those areas are sampled as part of the SODN streams protocol). However, species accumulation curves suggested that our sampling intensity was marginal for species detection. As a result, we will add one plot to each of the new strata with the next sampling in 2015, and re-evaluate after that field season.

After comparing these results with our monitoring objectives, we conclude that the revised strata are appropriate. We will maintain the same approach for future monitoring.

This effort entailed some of the first terrestrial vegetation and soils monitoring in the SODN. Therefore, 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 (e.g., initial plot layout, permanent marking and mapping, and collection of *in situ* soil parameters).

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

Based on the species composition, community structure, and dynamic soil function vital signs, we conclude that terrestrial vegetation and soils at Montezuma Castle NM are within the range of natural variability. Recognizing the limitations of historical data, the current park conditions compare very favorably with those described in local and regional accounts.

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Appendix A. Supplementary Data Tables

This appendix is available only with the electronic version of the document.

Appendix B. Repeat Photos and Plot Locations

Graphics begin on next page.

Montezuma Castle National Monument
Arizona

National Park Service
U.S. Department of the Interior

Uplands Plot 201_V06 in 2010

Photo point 2 (0m, 20m corner: 14 degrees

Photo point 3 (50m, 20m corner): 110 degrees

Photo point 1 (0m, 0m corner): 276 degrees

Photo point 4 (50m, 0m corner): 196 degrees

Plot location

Uplands plot
Park boundary

Meters
0 500 1,000

Plot layout

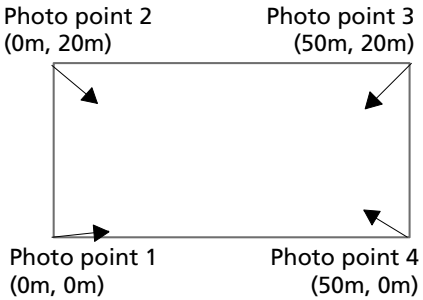


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Uplands Plot 201_V08 in 2011

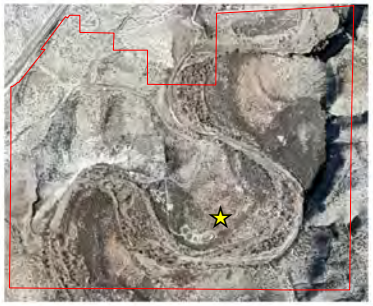
Photo point 2 (0m, 20m corner: 160 degrees

Photo point 3 (50m, 20m corner): 246 degrees

Photo point 1 (0m, 0m corner): 110 degrees

Photo point 4 (50m, 0m corner): 344 degrees

Plot location



Uplands plot

Park boundary

N

Meters

0 500 1,000

Plot layout

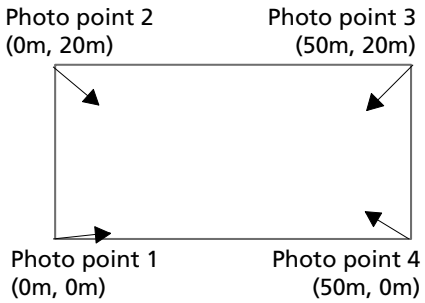


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Montezuma Castle National Monument
Arizona

National Park Service
U.S. Department of the Interior

Uplands Plot 201_V10 in 2011

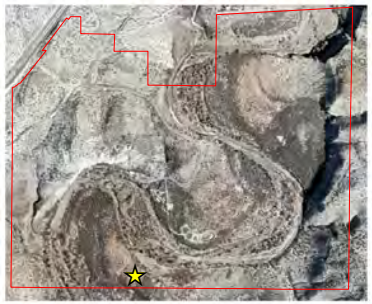
Photo point 2 (0m, 20m corner: 180 degrees

Photo point 3 (50m, 20m corner): 250 degrees

Photo point 1 (0m, 0m corner): 130 degrees

Photo point 4 (50m, 0m corner): 360 degrees

Plot location



Uplands plot
Park boundary

Meters
0 500 1,000

Plot layout

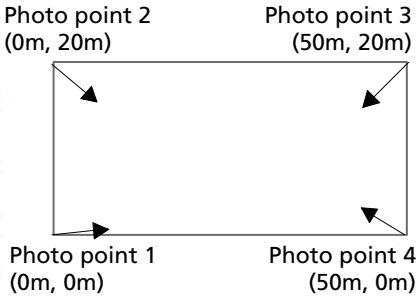


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Uplands Plot 202_V01 in 2010

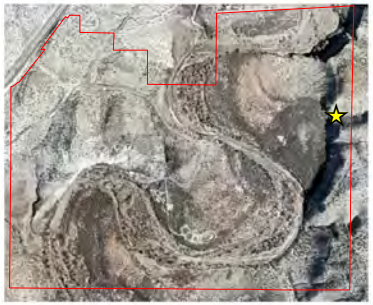
Photo point 2 (0m, 20m corner: 123 degrees

Photo point 3 (50m, 20m corner): 249 degrees

Photo point 1 (0m, 0m corner): 38 degrees

Photo point 4 (50m, 0m corner): 308 degrees

Plot location



Uplands plot
Park boundary

N

Meters
0 500 1,000

Plot layout

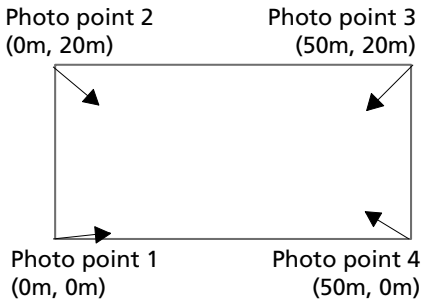


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Montezuma Castle National Monument
Arizona

National Park Service
U.S. Department of the Interior

Uplands Plot 202_V02 in 2010

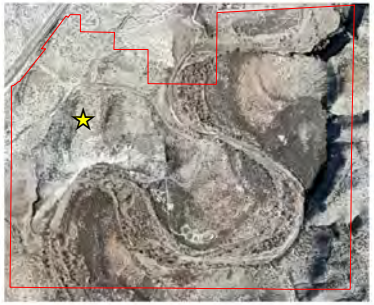
Photo point 2 (0m, 20m corner: 10 degrees

Photo point 3 (50m, 20m corner): 126 degrees

Photo point 1 (0m, 0m corner): 320 degrees

Photo point 4 (50m, 0m corner): 193 degrees

Plot location



Uplands plot
Park boundary
N
Meters
0 500 1,000

Plot layout

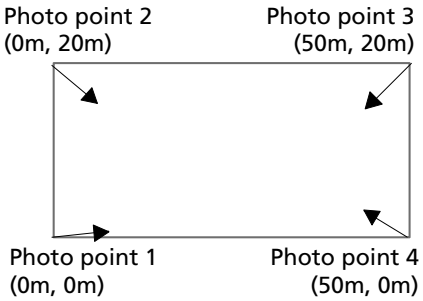


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Uplands Plot 202_V03 in 2010

Photo point 2 (0m, 20m corner: 236 degrees

Photo point 3 (50m, 20m corner): 315 degrees

Photo point 1 (0m, 0m corner): 92 degrees

Photo point 4 (50m, 0m corner): 45 degrees

Plot location

Uplands plot
Park boundary

Meters
0 500 1,000

Plot layout

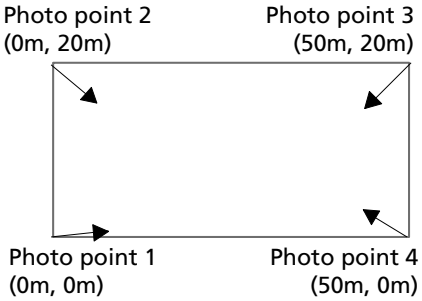


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Montezuma Castle National Monument
Arizona

National Park Service
U.S. Department of the Interior

Uplands Plot 202_V05 in 2011

Photo point 2 (0m, 20m corner: 180 degrees

Photo point 3 (50m, 20m corner): 280 degrees

Photo point 1 (0m, 0m corner): 140 degrees

Photo point 4 (50m, 0m corner): 0 degrees

Plot location

Uplands plot
Park boundary

N

Meters
0 500 1,000

Plot layout

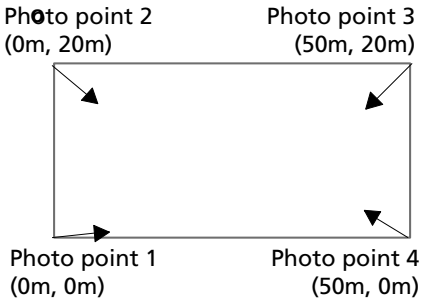


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Uplands Plot 202_V06 in 2011

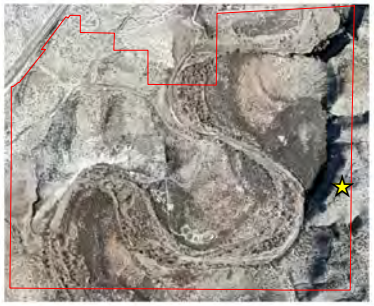
Photo point 2 (0m, 20m corner: 256 degrees

Photo point 3 (50m, 20m corner): 320 degrees

Photo point 1 (0m, 0m corner): 200 degrees

Photo point 4 (50m, 0m corner): 70 degrees

Plot location



Uplands plot
Park boundary

Meters
0 500 1,000

Plot layout

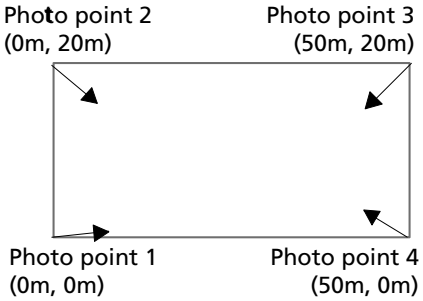


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m, 20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higer-resolution photos are available from SODN.

Produced by SODN
October 2013

Appendix C. Key to Vegetation Formations

KEY TO VEGETATION FORMATIONS:

1. What is the dominant surface cover?
Trees ..... go to 2
Shrubs ..... go to 3
Herbaceous ..... go to 4
Sparse vegetation (1–10%) or Rock/Bare Soil..... go to 5
Agriculture ..... go to 6

2. Trees:
11 Tree Cover > 60%?
21 Site is predominantly associated with an ephemeral watercourse. Intermittently Flooded Forest (IFF)
22 Site is predominantly associated with a perennial watercourse. Riparian Forest (RF)
23 Site is in an upland zone. Forest (F)

12 Tree Cover < 60%?
31 Site is predominantly associated with an ephemeral watercourse. Intermittently Flooded Woodland (IFW)
32 Site is predominantly associated with a perennial watercourse. Riparian Woodland (RW)
33 Site is in an upland zone. Woodland (W)

3. Shrubs:
11 Tree Cover > 10%. Wooded Shrubland (WS)
12 Tree Cover < 10%. Shrubland (S)

4. Herbaceous:
11 Tree cover < 10% AND Shrub cover < 10% Herbaceous (H)
12 Tree and/or Shrub cover >10%
21 Tree cover > Shrub cover Tree Savanna (TS)
22 Tree cover < Shrub cover Shrub Savanna (SS)

5. Sparse Vegetation/Rock/Bare Soil:
11 Site is predominantly bedrock or surface rock with vegetative cover less than 10%.
21 Vegetation is primarily tree cover. Wooded Rock Outcrop (WRO)
22 Vegetation is primarily shrub cover. Shrubby Rock Outcrop (SHRO)
23 Vegetation is primarily herbaceous cover. Herbaceous Rock Outcrop (HRO)
24 There is no clear dominant. Sparse Rock Outcrop (SRO)

12 Site is predominantly covered with boulders, cobble, bare soil, or gravel with vegetative cover less than 10%.
31 There is no vegetation cover. Barren (B)
32 Vegetation is primarily tree cover. Wooded Barren (WB)
33 Vegetation is primarily shrub cover. Shrubby Barren (SHB)
34 Vegetation is primarily shrub cover. Herbaceous Barren (HB)
35 There is no clear dominant. Sparse Barren (SB)

6. Agriculture:
Site is predominantly agricultural land. Agricultural (A)

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 309/124569, May 2014

National Park Service
U.S. Department of the Interior

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