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Status of Terrestrial Vegetation and Soils at San Bernardino National Wildlife Refuge

Natural Resource Report NPS/SODN/NRR—2018/1649



ON THE COVER
Vegetation sampling at San Bernardino National Wildlife Refuge
Photography by U.S. Fish & Wildlife Service

Status of Terrestrial Vegetation and Soils at San Bernardino National Wildlife Refuge

Natural Resource Report NPS/SODN/NRR—2018/1649

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Contents

Page

Figures . . . vii
Tables . . . ix
Executive Summary . . . xi
Acknowledgments . . . xiii
Acronyms . . . xiii
1 Introduction . . . 1
1.1 Background . . . 1
1.2 Goals and objectives . . . 1
1.3 How to use this report . . . 2
1.4 Overview of San Bernardino NWR . . . 2
1.4.1 Refuge establishment and purpose . . . 2
1.4.2 Biogeographic and physiographic context . . . 2
1.4.3 Local geology and soils . . . 4
1.4.4 Biological soil crusts . . . 5
1.4.5 Site and stability . . . 5
1.4.6 Climate . . . 5
1.4.7 Human habitation of San Bernardino NWR . . . 6
1.4.8 Other long-term monitoring and related ecological research at San Bernardino NWR . . . 7
1.5 Assessment points and natural resource management issues at at San Bernardino NWR . . . 8
1.5.1 Upland erosion impacts on sensitive aquatic and riparian resources . . . 9
1.5.2 Terrestrial habitat impacts on upland threatened and endangered species . . . 10
1.5.3 Woody plant encroachment of semi-desert grassland . . . 10
1.5.4 Invasive non-native species . . . 12
1.5.5 Altered fire regimes . . . 14
2 Methods . . . 15
2.1 Response design . . . 15
2.1.1 Vegetation and soil cover: line-point intercept . . . 15
2.1.2 Vegetation frequency: subplots . . . 15
2.1.3 Soil aggregate stability . . . 15
2.1.4 Biological soil crust cover and frequency: Point-quadrats . . . 15
2.2 Sampling design . . . 17
2.2.1 Overview . . . 17

Contents (continued)

Page

2.2.2 Spatial balance . . . 17
2.2.3 Sampling frame . . . 18
2.2.4 Statistical power to distinguish status from management assessment points . . . 19
2.2.5 Statistical power to detect trends . . . 20
2.2.6 Evaluation of strata . . . 20
2.2.7 Diversity of perennial plants . . . 20
3 Results . . . 21
3.1 Design considerations . . . 21
3.1.1 Evaluation of strata . . . 21
3.1.2 Power to detect trends in plant lifeforms and common perennial species . . . 21
3.1.3 Diversity of perennial plants . . . 21
3.2 Non-rocky, foothills stratum (301) . . . 24
3.3 Sandy clay loam, non-rocky, foothills substratum (301-EAST) . . . 24
3.3.1 Vegetation formations, lifeforms, and perennial plant diversity (301-EAST) . . . 24
3.3.2 Cover and extent of perennial plant species (301-EAST) . . . 24
3.3.3 Frequency and extent of uncommon plant species (301-EAST) . . . 28
3.3.4 Cover and frequency of exotic species (301-EAST) . . . 28
3.3.5 Soil cover and biological soil crusts (301-EAST) . . . 30
3.3.6 Surface aggregate soil stability (301-EAST) . . . 30
3.3.7 Site and soil characterization (301-EAST) . . . 30
3.3.8 Management assessment points (301-EAST) . . . 31
3.4 Non-rocky foothills stratum (claypan substratum 301-WEST) . . . 34
3.4.1 Vegetation formations, lifeforms, and perennial plant diversity (301-WEST) . . . 34
3.4.2 Cover and extent of perennial plant species (301-WEST) . . . 34
3.4.3 Frequency and extent of uncommon plant species (301-WEST) . . . 37
3.4.4 Cover and frequency of exotic species (301-WEST) . . . 37
3.4.5 Soil cover and biological soil crusts (301-WEST) . . . 37
3.4.6 Soil stability (301-WEST) . . . 37
3.4.7 Site and soil characterization (301-WEST) . . . 37
3.4.8 Management assessment points (301-WEST) . . . 37
4 Discussion . . . 41
4.1 Sacaton grasslands and savannas: linking riparian corridors and uplands at San Bernardino NWR . . . 41

Contents (continued)

Page

4.2 Annual grasslands: claypans or land use history? . . . 44
4.3 Substantial erosion potential throughout uplands . . . 47
4.3.1 Soil armor: some weak links . . . 47
4.3.2 Beneath the armor: unstable surface soil aggregates . . . 47
4.4 Erosion in uplands: implications for aquatic habitats at San Bernardino NWR . . . 47
4.5 Woody plant encroachment: generally low, but mesquite has invaded sacaton grasslands. . . . 49
4.6 Exotic plants: colonization but not invasion of clay loam sites . . . 49
4.7 Resistant and resilient plant communities . . . 49
4.8 Altered fire regimes . . . 50
4.9 Recommendations for additional research and monitoring . . . 50
4.10 Are terrestrial vegetation and soils within the range of natural variability? . . . 51
5 Literature Cited . . . 53
Appendix A. Permanent Plot Photos . . . 57

Figures

Page

Figure 1-1. Location of San Bernardino NWR in southeastern Arizona. . . . 3

Figure 1-2. Regional Biogeography of the Sonoran and Chihuahuan Deserts Zone (USFWS) and the Sonoran Desert Network (NPS). . . . 4

Figure 1-3. 2013 Climate data in the context of 30-year normals from the COOP station located at the Bisbee-Douglas International Airport (www.climateanalyzer.org). . . . 7

Figure 2-1. Terrestrial vegetation and soils monitoring plot design. . . . 16

Figure 2-2. Sampling frame and allocation of monitoring plots for terrestrial vegetation and soils monitoring, San Bernardino NWR. . . . 19

Figure 3-1. Non-metric multidimensional scaling (MDS) indicates similarity of vegetation communities by soil strata. . . . 21

Figure 3-2. Non-metric multidimensional scaling (MDS) of vegetation similarity at San Bernardino NWR suggests two broad vegetation types within the ***a. priori*** soil strata. . . . 22

Figure 3-3. Locations of monitoring plots across the strata (301-EAST, 301-WEST), San Bernardino NWR, 2013. . . . 22

Figure 3-4. Species accumulation curves for sandy clay loam, non-rocky, foothills sites (substratum 301-EAST) suggest diminishing returns with increased sampling intensity. . . . 23

Figure 3-5. Species accumulation curves for the claypan, non-rocky, foothills sites (substratum 301-WEST) indicates the low species richness of the site. . . . 23

Figure 3-6. Lifeform cover in terrestrial vegetation monitoring plots on sandy clay loam, foothills 3,701-4,500 ft) sites with non-rocky soils (substratum 301-EAST) at San Bernardino NWR, 2013. . . . 25

Figure 3-7. Number of exotic species detected by plot, San Bernardino NWR, 2013. . . . 29

Figure 3-8. Distribution of biological soil crusts on monitoring plots, San Bernardino NWR, 2013. . . . 31

Figure 3-9. Lifeform cover in terrestrial vegetation monitoring plots on claypan, foothills (3,701-4,500 ft) sites with non-rocky soils (Substratum 301-WEST) at San Bernardino NWR, 2013. . . . 35

Figure 4-1. Example of the big sacaton/mixed shrub savanna (301-EAST) found on non-rocky (<35% surface soil rocks) sites in central and eastern portions of San Bernardino NWR. . . . 41

Figure 4-2. Dominant species on the drier end of the 301-EAST stratum at San Bernardino NWR, 2013. . . . 42

Figure 4-3. Non-metric multidimensional scaling (MDS) of terrestrial upland vegetation, San Bernardino NWR, 2013.. . . . 42

Figure 4-4. Vegetation and soils data for sandy clay loam, non-rocky, foothills (301-EAST) monitoring sites in the context of management assessment points, San Bernardino NWR, 2013. . . . 43

Figure 4-5. Example of the annual grass/tobosagrass grasslands (301-WEST) found on non-rocky (<35% surface soil rocks) sites in western portions of San Bernardino NWR. . . . 44

Figure 4-6. Vegetation and soils data for sandy claypan, non-rocky, foothills (301-WEST) monitoring sites in the context of management assessment points, San Bernardino NWR, 2013. . . . 45

Figure 4.-7. Summary of the two primary terrestrial vegetation types at San Bernardino NWR, 2013. . . . 46

Figure 4.-8. Effect of soil cover on erosion by water. . . . 48

Tables

Page

Table 1-1. Known and hypothetical federal and state listed species that occur in or adjacent to San Bernardino and Leslie Canyon National Wildlife Refuges. 11

Table 1-2. Non-native plants detected in and around San Bernardino NWR (SEINet 2017). 13

Table 2-1. Height categories for vegetation measurement. 15

Table 2-2. Categories for aggregate stability of surface soils. 17

Table 2-3. Number, name, and characteristics of sampling strata for terrestrial vegetation and soils. 18

Table 2-4. Allocation of permanent terrestrial vegetation and soils monitoring plots by strata, San Bernardino NWR. 18

Table 3-1. Cover values (%) for perennial and non-native annual species (by lifeform) measured in the field (<0.5 m stature), subcanopy (0.5-2.0 m), and canopy (>2.0 m) layers of sandy clay loam, non-rocky, foothills (301-A substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. 26

Table 3-2. Within-plot frequency (%), standard error (SE), and extent (out of 11 plots) of uncommon plant species (found only on subplots and not on transects) sampled on sandy clay loam, non-rocky, foothills (301-EAST substratum) on San Bernardino NWR. 28

Table 3-3. Presence/absence of non-native plants detected on vegetation monitoring plots, San Bernardino NWR. 29

Table 3-4. Soil surface cover (% by category) for clay loam, non-rocky, foothills (301-EAST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. 30

Table 3-5. 2013 soil and site characterization for sandy clay loam, non-rocky, foothills (301-EAST substratum) monitoring sites (Elev. 3,701-4,500 ft), at San Bernardino NWR. 32

Table 3-6. Vegetation and soils data for sandy clay loam, non-rocky, foothills (301-EAST substratum) monitoring sites in the context of management assessment points, San Bernardino NWR. 33

Table 3-7. Cover values (%) for perennial and non-native annual species (by lifeform) measured in the field (<0.5 m stature), subcanopy (0.5-2.0 m), and canopy (>2.0 m) layers of claypan, non-rocky, foothills (301-WEST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. 36

Table 3-8. Within-plot frequency (%), standard error (SE), and extent (out of 11 plots) of uncommon plant species (found only on subplots and not on transects) sampled on sandy clay loam, non-rocky, foothills (301-EAST substratum) on San Bernardino NWR. 37

Table 3-9. Soil surface cover (% by category) for claypan, non-rocky, foothills (301-WEST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. 38

Table 3-10. 2013 soil and site characterization for claypan, non-rocky, foothills (301-WEST substratum) monitoring sites (Elev. 3,701-4,500 ft), at San Bernardino NWR. 39

Table 3-11. Vegetation and soils data for claypan, non-rocky, foothills (301-WEST substratum) monitoring sites in the context of management assessment points, San Bernardino National Wildlife Refuge. 40

Executive Summary

This report summarizes results of the initial terrestrial vegetation and soils monitoring in upland areas of San Bernardino National Wildlife Refuge (NWR) in Arizona. This project was conducted through a partnership between the U.S. National Park Service Sonoran Desert Network and the U.S. Fish and Wildlife Service Sonoran and Chihuahuan Deserts Zone. We established and sampled fifteen permanent field-monitoring sites in 2013. Our objectives were to determine the status of and detect trends in cover of vegetation, soil, and biological soil crusts; stability of surface soils; and frequency of vegetation.

Despite at least a century of varied—and at times, intensive—land uses, terrestrial vegetation at San Bernardino NWR were generally within the expected range of natural variability. Twenty-five years of succession on fallow agricultural fields led to partial recovery of native sacaton grasslands—an important and regionally scarce vegetation community that supports a variety of ecosystem functions and habitat for wildlife. More xeric upland vegetation were also well within the spatial and temporal variance of the site and ecoregion.

Upland areas on the western third of the refuge contained annual grass/tobosagrass grasslands over a shallow, dense claypan. Perennial plant diversity on these sites was very low – comparable with much more xeric low desert locations that we have sampled in the western Sonoran Desert. Although past land use may have been an important factor, we speculate that the unusually shallow claypan may dramatically reduce available soil water, limiting plant diversity and productivity beyond what would be expected based on precipitation.

Although present throughout most of the refuge, non-native plants did not appear to have effectively invaded native plant communities. Encroachment by mesquite and other native woody plants was also limited, with the important exception of the recovering sacaton grasslands. Actively reducing mesquite on these sites should help maintain their integrity within the refuge.

Unstable surface soil aggregates combined with relatively large areas of exposed soil indicated a high degree of soil erosion potential throughout the refuge. These conditions may reflect previous land uses (particularly intensive livestock grazing), although the extended period of recovery— more than 25 years—from those uses suggests that inherent soil factors may be a more important factor. Regardless, enhanced soil erosion could have tremendous direct impacts on ecosystem structure and function in upland ecosystems, as well as important consequences (through sediment and nutrient transport) for the aquatic systems that are the primary management focus and mission of San Bernardino NWR. We recommend managers focus on mitigating soil erosion from upland areas, and consider a site-specific soil inventory coupled with erosion modelling to more precisely assess soil erosion hazard and management options. We also recommend repeating this monitoring effort on 5-year cycles, beginning in 2018.

Acknowledgments

We thank Refuge Manager Bill Radke, Refuge Specialist Chris Lohrengel and the rest of the staff of San Bernardino NWR for their on-site support of the field effort conducted by the Sonoran and Chihuahuan Deserts Zone (SCDZ) Inventory and Monitoring Program. Rob Hastings, Matt Christensen, Alecio Lopez-O'Day and Emily Yurcich conducted the field data collection with Bethany DeRango. Matt Christensen and staff from the Brigham Young University Environmental Analytical Laboratory processed the soil samples. Steve Buckley provided botanical expertise for crew training and identification of unknown samples while in the field. Data processing and management support was provided by Sonoran Desert Network Data Manager, Kristen Bonebrake. Lastly, many thanks to the Tucson Audubon Society and New Mexico State University who have provided several of the field personnel throughout this and many ongoing projects. Their technical and administrative support has proved invaluable during the course of this collaboration.

Acronyms

AGFD: Arizona Game and Fish Department

GRTS: Generalized Random Tessellation Stratified

I&M: Inventory and Monitoring Program

LCNWR: Leslie Canyon National Wildlife Refuge

NF: National Forest

NPS: National Park Service

NWR: National Wildlife Refuge

RRQRR: Reversed Randomized Quadrant-Recursive Raster

SBNWR: San Bernardino National Wildlife Refuge

SCDZ: Sonoran and Chihuahuan Deserts Zone

SODN: Sonoran Desert Network

USFS: U.S. Forest Service

USFWS: U.S. Fish and Wildlife Service

1 Introduction

1.1 Background

Generating more than 99.9% of Earth's biomass (Whittaker 1975), plants are the primary producers of life on Earth. Vegetation 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 often focuses on manipulating vegetation to achieve refuge management objectives, with defined conditions based on community structure or lifeform composition.

In the deserts of the American Southwest, 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 and Chihuahuan Deserts Zone, as part of the U.S. Fish & Wildlife Service (USFWS) collaboration with the National Park Service (NPS) 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 San Bernardino National Wildlife Refuge (NWR). Indicators of terrestrial vegetation integrity include vegetation community structure, lifeform abundance, status and trends of established exotic plants, and early detection of previously undetected exotic plants. Indicators of soil dynamic function and erosion resistance include the cover of mineral soil and the stability of surface soil aggregates.

1.2 Goals and objectives

The overall goal of the Sonoran and Chihuahuan Deserts Zone and NPS Sonoran Desert Network terrestrial vegetation and soils monitoring is to ascertain broad-scale changes in vegetation and dynamic soils properties in the context of changes in other ecological drivers, stressors, ecological processes, and focal resources of interest. This integrated



Field staff recording terrestrial vegetation at San Bernardino NWR. USFWS

approach explores patterns and identifies candidate explanations to support effective management and protection of refuge natural resources in a cumulative fashion, such that the results of each successive round of monitoring builds upon the knowledge gained from previous efforts and related research and monitoring activities.

Specific, measurable objectives for terrestrial vegetation and soils monitoring at San Bernardino NWR are to determine the status of and detect trends in

1. Terrestrial vegetation cover for common perennial species, non-native plants, and all plant lifeforms.
2. Terrestrial vegetation frequency of uncommon perennial species and non-native plants.
3. Terrestrial soil cover by substrate classes (bare soil, litter, woody debris, vegetation, biological soil crust, rock fragments of several size classes) that influence resistance to erosion.
4. Terrestrial soil stability of surface aggregates by stability class (1–6).
5. Basal cover and frequency of biological soil crusts by lichen growth form and morphological group.

1.3 How to use this report

This is a large report; readers with specific interests can focus on particular sections.

Just the highlights, please:

- Executive Summary
- Chapter 4
- Figures 4-4, 4-5, 4-6 and 4-7.

Add detail on management implications:

- Sections 3.3.8, 3.4.8
- Tables 3-6, 3-11

Add detail on sampling design:

- Chapter 2
- Section 3.1
- Figure 2-1

This document reports and interprets the results of the first round of terrestrial vegetation and soils monitoring at San Bernardino NWR, thus our focus is necessarily on current status. We do, however, interpret the information in the context of management objectives and ecological considerations.

1.4 Overview of San Bernardino NWR

1.4.1 Refuge establishment and purpose

San Bernardino NWR was established on April 1, 1982, to protect the unique wetland habitats and the endangered and threatened native fish of the Rio Yaqui watershed. The grasslands, riparian areas, and surface water of the site attracted settlers to the area, bringing farming, mineral extraction, fire control, and livestock production that all impacted the once abundant ground and surface waters (Radke 2013a). These pressures led to the listing of four species of fish in the Rio Yaqui watershed under the U.S. Endangered Species Act: Yaqui chub (*Gila purpurea*; endangered), Yaqui topminnow (*Poeciliopsis sonoriensis*; endangered), Yaqui beautiful shiner (*Cyprinella formosa*; threatened), and Yaqui catfish (*Ictalurus pricei*; threatened). The protection and recovery of these species is the primary focus of San Bernardino NWR.

The approximately 959 hectares (2,369 acres) along the international border with Mexico in southeastern Arizona (Figure 1-1) that currently comprise the refuge was initially acquired by The Nature Conservancy and transferred to USFWS in 1981 (Radke 2013a). By protecting and preserving surface waters within the watershed, San Bernardino NWR and nearby Leslie Canyon NWR serve a critical role in supporting populations of native fish by restoring and maintaining aquatic and riparian habitat in the United States and Mexico.

1.4.2 Biogeographic and physiographic context

San Bernardino NWR is located on the U.S.–Mexico international border about 27 kilometers east of the city of Douglas in Cochise County, southeastern Arizona. The refuge is in an area of Chihuahuan desert and desert grassland that is considered part of the Mexican Highland section of the Basin and Range physiographic province and lies within the Apache Highlands Ecoregion (Gori and Enquist 2003; Figure 1-2). Refuge lands range in elevation from about 1,134 m–1,195 m (3,720 ft–3.920 ft), and encompass a portion of the headwaters of the Yaqui River.

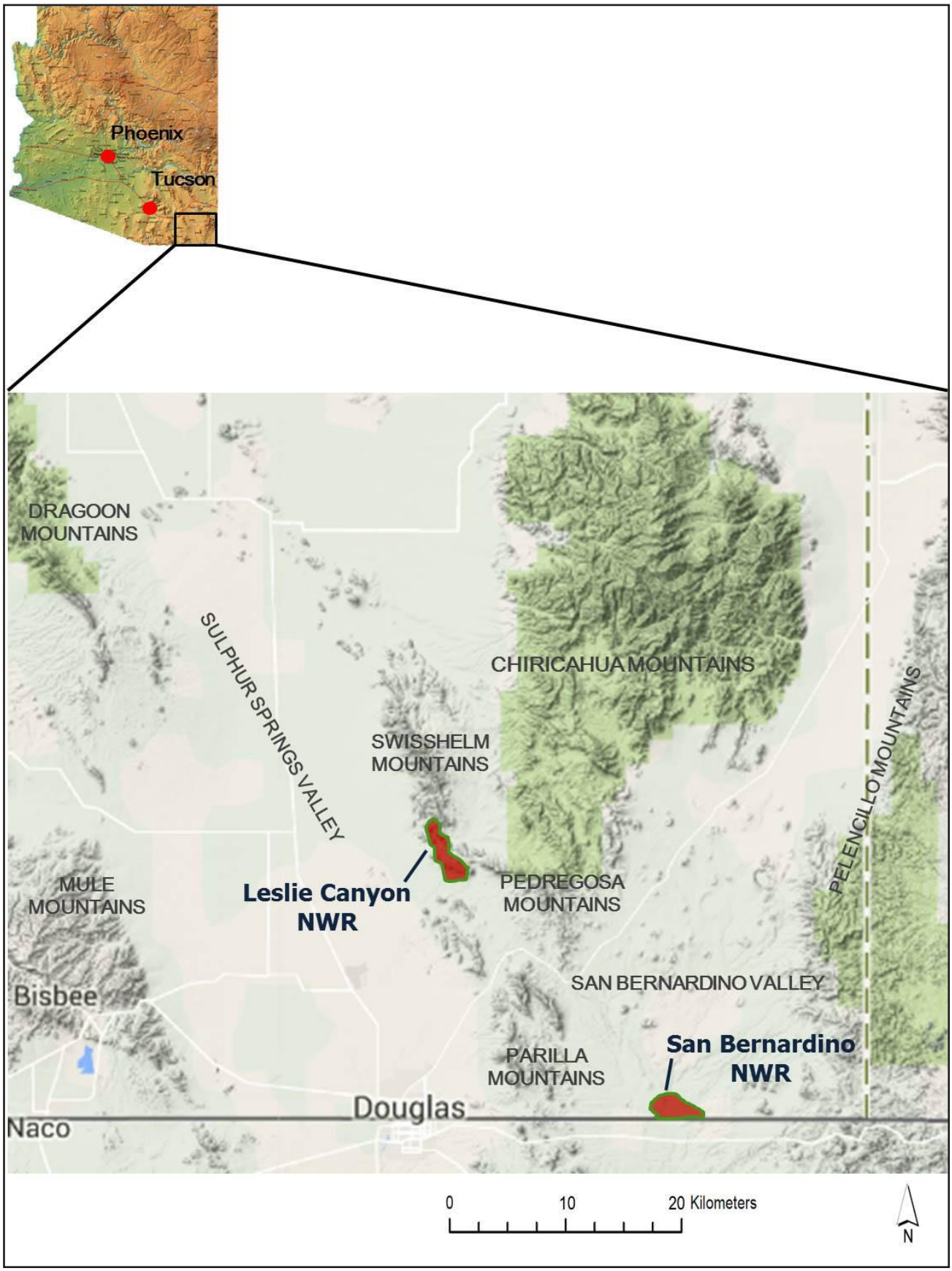


Figure 1-1. Location of San Bernardino NWR in southeastern Arizona.

San Bernardino NWR is in a basin situated between the Perilla, Pedregosa and Chiricahua Mountains to the west, and the Peloncillo Mountains to the east. The refuge is comprised of gently rolling uplands and flat bottomlands arranged north to south, parallel with the San Bernardino cienega (shallow wetland) that is the focus of management for the refuge. The uplands are composed primarily of Chihuahuan desert grassland, shrub savanna, and desert scrub. Bottomlands are composed of recovering irrigated cropland arranged around the cienega which contains a series of artesian wells, springs, and artificial ponds with associated riparian vegetation and marshland habitats. The bottomland soils also support fragmented stands of mesquite bosque.

1.4.3 Local geology and soils

San Bernardino NWR is within the basin and range geologic region, characterized by discontinuous linear mountain ranges orientated generally northwest to southeast, and separated by wide basins/alluvial plains (Scarborough 2000). The region has been impacted by volcanic activity and recent earthquakes that have altered underground water flow and created many seeps and springs. Locally, the mountains are composed of volcanic and sedimentary rock including rhyolite, andesite, quartzite, limestone, sandstone and shale.

Upland soils within San Bernardino NWR are generally deep to very deep and well-drained, although

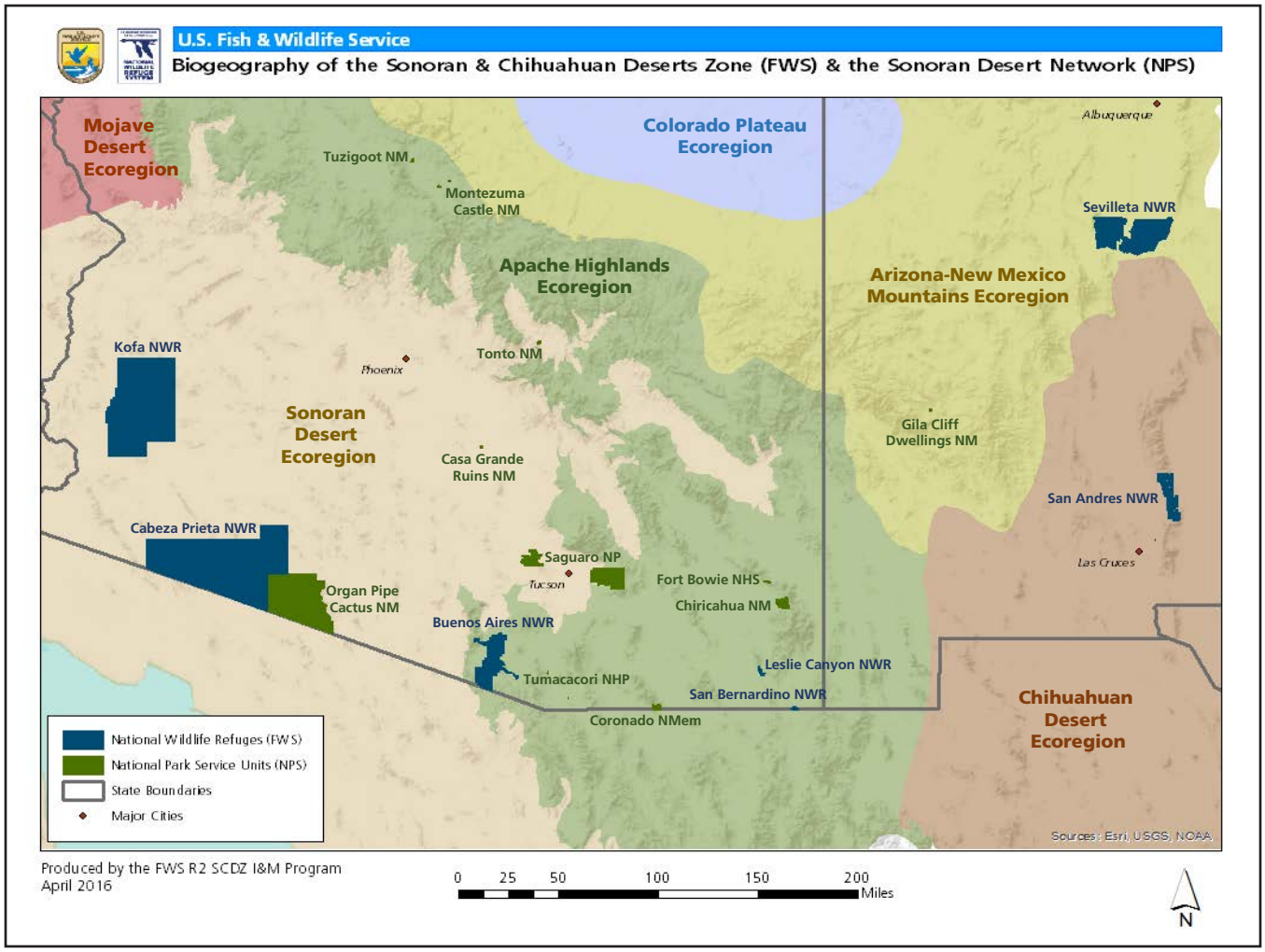


Figure 1-2. Regional Biogeography of the Sonoran and Chihuahuan Deserts Zone (USFWS) and the Sonoran Desert Network (NPS). Chihuahuan Desert Network (NPS) parks are not shown here.

the western portion of the refuge contains extensive, near-surface clay pans of 55–84 cm thickness (USDA 2002). Soils are formed from mixed, fan, or stream alluvium. Approximately three quarters of the refuge on the eastern side has sandy loam or sandy clay loam soils with mostly sandy loam and fine sandy loam surface soils (USDA 2002). A smaller area in this eastern portion has gravelly loam surface soils. The western quarter (which contains the shallow clay pans) of the refuge lies slightly higher in elevation with silty clay loam and dense clay soils (USDA 2002).

1.4.4 Biological soil crusts

Open spaces on the soils in arid and semi-arid regions are often covered by biological soil crusts, a community of cyanobacteria, algae, lichens, and bryophytes. Biological soil crusts provide key ecosystem functions, such as increasing water and wind erosion resistance, contributing organic matter, and fixing atmospheric nitrogen (Belnap 2003a). Cyanobacteria weave through the upper few millimeters of soil, binding together soil particles by secreting polysaccharides. In addition to reducing water erosion, the polysaccharides contribute to soil aggregate structure (Belnap et al. 2003), which is directly correlated with soil erosion resistance (Belnap et al. 2003; Herrick et al. 2005b). Mosses and lichens have small, anchoring structures that help them protect the soil surface (Belnap et al. 2003).

Biological soil crusts contribute fixed carbon to soil through decaying and leaching processes (Lange 2003). Some cyanobacteria and cyanolichens have the ability to fix atmospheric nitrogen. This process reduces atmospheric nitrogen (N_2) to ammonia (NH_4^+), which is usable by vascular plants. Biological soil crusts can be the dominant source of nitrogen for desert ecosystems (Belnap 2003b).

The distribution and species composition of biological soil crusts is influenced by soil chemistry and disturbance (Belnap et al. 2001). In general, lichens with the same growth form have similar ecological functions. Squamulose lichens provide the most protection of the soil from water erosion, followed by crustose, foliose, and fruticose lichens. Gelatinous lichens provide the least protection from water erosion. Having some vertical growth allows lichens to provide additional protection from wind erosion by increasing surface roughness and decreasing the erosive power of wind. Crustose and gelatinous lichens are effective at resisting detachment but do not provide as much resistance to wind erosion as other growth forms (Eldridge and Rosentreter 1999). All gelatinous lichens fix nitrogen, whereas nitrogen fixation is species-dependent for the other growth forms (Belnap et al. 2001).

1.4.5 Site and stability

Site stability is the resistance of a site to localized wind and water erosion of soils (Herrick et al. 2005b) —with tremendous consequences for ecosystems and the protection of finite aboveground and subsurface cultural resources. As recovery of disturbed soils is particularly slow in dry and seasonally dry environments (Aber and Melillo 1991), avoiding erosion is of paramount importance for effective natural resource management in the Desert Southwest.

Static and dynamic factors determine the vulnerability of a site to water erosion (Herrick et al. 2005b). Static factors are generally not affected by management actions and include soil texture and rock-fragment content, depth and parent material, slope inclination and aspect, and climate. Static factors set the range of erosion potential. Within that range, dynamic factors may be influenced by disturbance and management action to determine actual erosion (Herrick et al. 2005b). Dynamic factors affecting water erosion include soil disturbance, soil structure, total cover, and plant basal cover. The amount of total cover (soil cover and vegetation cover) is the single most-important dynamic factor affecting water erosion (Herrick et al. 2005b). Most soil loss occurs in "unprotected" areas with uncovered, bare soils (Davenport et al. 1998), whereas rock, gravel, vegetation, biological soil crusts, and even plant debris (litter and duff) can "armor" the soil, slowing the flow of water and permitting increased infiltration of water into the soil profile (Belnap et al. 2007).

1.4.6 Climate

Located within the Tropical-Subtropical Desertland climatic zone (Brown et al. 1994), San Bernardino NWR has a semi-arid climate. The refuge 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



A monsoon storm rolls across the valley bringing rainfall near San Bernardino NWR. USFW)

rates (TNC 1999). Summer rains dominate the precipitation pattern in the form of monsoon thunderstorms, which are generally localized and torrential. Winter storms are gentler and more widespread and typically longer in duration.

Annual average precipitation (1981-2010) at the nearby Bisbee-Douglas International Airport is 33.3 cm (13.10 in), with over 52% coming in July, August, and September (Western Regional Climate Center 2016). Monsoon storm cells are spatially discontinuous and high summer temperatures result in high evaporation rates. About 35% of the refuge area precipitation occurs during winter months (November–April), mostly from frontal storm systems. We provide climographs of monthly minimum and maximum average air temperature and precipitation from the Bisbee-Douglas International Airport in Figure 1-3. The airport is approximately 32 km northwest of the refuge. These data undergo all quality assurance and control checks prescribed by the NOAA Cooperative Observer Program, and provide a longer period of record. See www.climateanalyzer.org for details. We report data from refuge rain gauges as well.

2013 was relatively mild after the previous two years when record high yearly average temperatures were reached. Spring and summer had above normal temperatures through June, but not much above normal. Fall and winter had below normal temperatures. The Bisbee-Douglas airport had the wettest monsoon on record (41.3 cm [16.3 in] from June 15 to September 30). While the annual rain total at the airport was just above normal, it was largely due to the monsoon record, as most other months were well below precipitation averages. San Bernardino NWR itself had less monsoonal rain than the airport and ponds were well below normal. However, monsoon floods did occur in Black Draw. Rain gauges on the refuge reported approximately 24.1 cm (9.5 in) of rain during the monsoon and a 2013 year total of about 26.7 cm (10.5 in; Radke 2013a).

1.4.7 Human habitation of San Bernardino NWR

Indigenous hunters were the earliest inhabitants some 10,000 years ago when the area was cooler, wetter and had more vegetation. Though climatic changes over the centuries created the drier and warmer land we see today, dependable water sources have long attracted humans to the area.

As early as the 1500s, Spanish explorers visited this area followed by Jesuit priests in the 1700s and a Spanish presidio was established in the late 1770s (Radke 2013a). The Apache arrived in the 1600s and used areas throughout the region for hunting and gathering. Ranching began in 1822 with

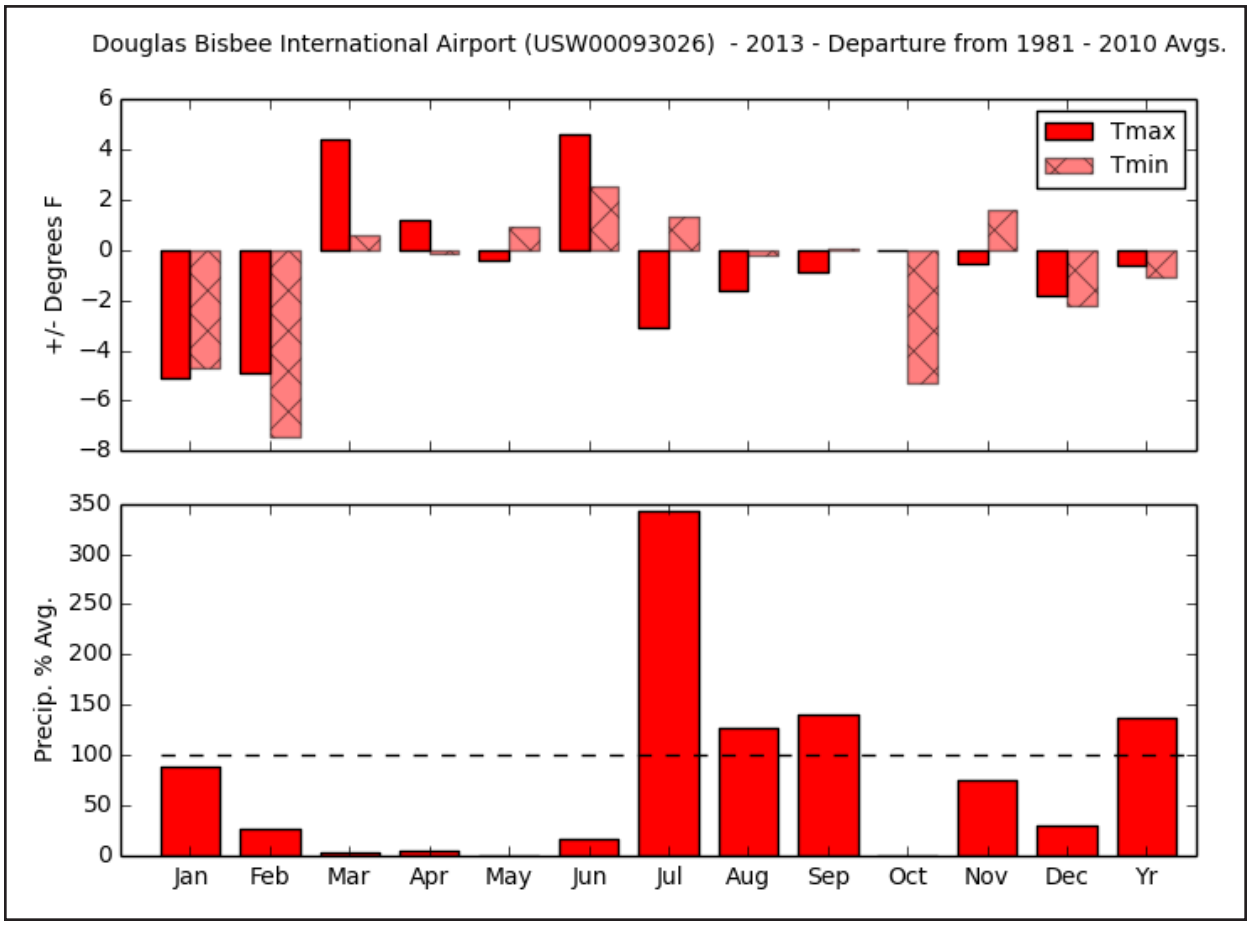


Figure 1-3. 2013 Climate data in the context of 30-year normals from the COOP station located at the Bisbee-Douglas International Airport, approximately 27 kilometers west of the refuge and similar in elevation (www.climateanalyzer.org).

the acquisition of the San Bernardino land grant and widespread cattle grazing progressed. After Apaches briefly drove out the ranchers, cattle ranching resumed on a large scale when John Slaughter established the 26,305 hectare (65,000 acre) San Bernardino Ranch in 1884 (Radke 2013a). The Mexican Revolution reached this border area in 1915 when Pancho Villa and his army fought in nearby Agua Prieta. Rock fortifications remain on San Bernardino NWR and on Slaughter Ranch nearly 100 years after they sheltered U.S. Cavalry troops stationed there to protect settlers (Radke 2013a).

The San Bernardino Valley once had permanently flowing creeks, springs, and wetlands. The farming, mineral extraction, fire control, and rise in livestock production that began in the 1800s created an increase in competition for precious water in the area. Cattle ranching and farming continued in the area until 1979 when The Nature Conservancy began to acquire the properties for resource protection, leading ultimately to establishment of these lands in the National Wildlife Refuges System (Radke 2013a).

1.4.8 Other long-term monitoring and related ecological research at San Bernardino NWR

San Bernardino NWR is one of the few refuges administered by USFWS created specifically to protect native fish, specifically the endangered Yaqui chub and Yaqui topminnow and the threatened Yaqui catfish and Yaqui beautiful shiner (USFWS 1994). Fish recovery efforts include stabilization of existing populations, establishment of self-sustaining populations, and extensive restoration of wetland habitat (Radke 2013a). From 2001–2004 sporadic fish trapping and marking occurred. In 2005, the effort was expanded; lentic environments (e.g., ponds) are monitored with traps and analyzed using mark-recapture theory, and lotic environments (e.g., streams) are monitored using electro-fishing



The endangered Yaqui chub. RADKE/ USFWS

equipment and analyzed using depletion theory. Groundwater levels are monitored to ensure that the Yaqui watershed habitat is maintained for fish species. The refuge has ongoing watershed management actions occurring in and adjacent to refuge lands and invasive, non-native species are being removed or controlled.

In addition to water resource monitoring and efforts to protect native fish populations, a vascular plant species checklist for San Bernardino and Leslie Canyon NWRs has been developed through the Flora Project, one part of a collaboration between the NPS Sonoran Desert Network and USFWS (USFWS 2016). A guide to the flora of the refuge has been completed. In addition to this guide, USFWS is capitalizing on developed methods that will communicate current information through the SEINet Biodiversity Information portal (www.swbiodiversity.org/seinet). This collaborative project provides refuge resource managers with accurate and timely baseline studies of floristic biodiversity. A refuge-specific species list can be found at http://swbiodiversity.org/seinet/projects/index.php?proj=24.

Other long-term projects at San Bernardino NWR include species-specific monitoring of the endangered Huachuca water umbel (*Lilaeopsis schaffneriana* var. *recurva*), the threatened yellow-billed cuckoo (*Coccyzus americanus*), and Gila monster (*Heloderma suspectumare*), a species of management concern. Gila monsters are protected by law and have been opportunistically monitored on the refuge since 2000. Yellow-billed cuckoo habitat has been declining due to loss of nesting habitat in its summer breeding range and loss of prey species from pesticides (TNC 1999). They are monitored annually on the refuge and in 2013, surveys indicated the refuge likely had five nesting pairs. Huachuca water umbel populations are monitored annually to identify any changes in patch size.

Since 2009, wildlife cameras have been used in riparian corridors to determine which mammal species are present and to monitor dynamics and long-term changes in the use of these corridors that lie along and/or cross the international border. Refuge staff also monitor Cochise pincushion cactus (*Coryphantha robbinsorum*), a federally listed threatened species, on ranchlands west of the refuge.

1.5 Assessment points and natural resource management issues at at San Bernardino NWR

To achieve the public lands mission of resource protection, resource management and monitoring must be explicitly linked (Bingham et al. 2007). Management assessment points can act 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



Twin Pond at San Bernardino NWR. USFWS

result in management actions, or reflect any legal or regulatory standard. They are only intended to serve as a potential early warning system, giving scientists and managers the opportunity to pause, review the available information in detail, and consider options. Bennetts and others (2007) provide a detailed explanation of this concept and its application to monitoring and management of protected areas.

Below we describe natural resource management issues at San Bernardino NWR and propose a suite of management assessment points related to those issues. The issues, measures, and assessment-point values are based on the ecological literature and our collective knowledge of these ecosystems and refuge management goals. They are not enshrined in law, policy, or formal planning. Rather, they serve to provide context for resource condition and management discussions with refuge leadership.

1.5.1 Upland erosion impacts on sensitive aquatic and riparian resources

The purpose of San Bernardino NWR is to preserve native fish species, and to serve in a larger effort designed to lead to the long-term survival of threatened and endangered fish in the Yaqui watershed. Federally listed threatened and endangered species that have high management priorities for the refuge include the four fish species the refuge was established to protect (Yaqui chub, Yaqui beautiful shiner, Yaqui catfish, and Yaqui topminnow), Huachuca water umbel, and Cochise pincushion cactus (found in habitats west of the refuge; Radke 2014). The refuge and nearby Leslie Canyon NWR provide the last sanctuaries in the United States for these intermediate elevation fish and plants.

The San Bernardino Valley once supported permanently flowing creeks, springs, and marshy wetlands or ciénegas. Expanded settlement beginning in the late 1800s brought farming, mining and livestock production, all of which competed for the same precious water. The lowering water table led to severe changes in the riparian and wetland habitat and the eventual local extinctions of many species (Radke 2014). Once vast wetlands are now reduced to small areas associated with isolated artesian wells, springs, and artificial ponds. The San Bernardino Ciénega is still the most extensive wetland in the region though and is vital for the fish species the refuge is charged with protecting as well as the wetland-dependent plants and other wildlife, including the great number of migratory birds that utilize the refuge for stopovers.

Conservation of these remaining water sources and associated habitats is the primary purpose of the refuge. Cooperative work on both sides of the border has led to decreased erosion, protection of groundwater levels, wetland restoration, reclamation and restoration of mesquite-invaded lands, and removal of invasive, non-native species. Enhanced erosion in terrestrial uplands and subsequent overland flow

and sediment transport to aquatic systems can have tremendous impacts on water quality, quantity, and habitat condition. To determine the current state of erosion hazard in upland areas of the refuge, we will examine our monitoring data in the context of two management assessment points (after site evaluation, we removed the biological soil crust assessment point):

- Exposed bare ground cover (no overhead vegetation ; >10% cover violates assessment point)
- Surface soil aggregate stability (no overhead vegetation; < Class 3 "somewhat unstable" violates assessment point).

1.5.2 Terrestrial habitat impacts on upland threatened and endangered species

San Bernardino NWR is located in a transition area between Sonoran and Chihuahuan deserts and the Rocky Mountains and Sierra Madre. The result is a great diversity in the refuge's flora and fauna. Between San Bernardino NWR and nearby Leslie Canyon NWR, at least 336 bird, 67 mammal, 43 reptile, 13 amphibian, and 8 fish species have been detected (Radke 2014). From San Bernardino NWR and the immediate vicinity, 389 plant species have been vouchered and geotagged through the SEINet data portal. Over 500 species of bees have been identified in the San Bernardino valley (Radke 2014).

There are 38 species of plants and animals detected in or near the two refuges that are listed by the Federal or State Government as threatened, endangered, or species of special concern (Table 1-1; Radke 2014). While some of these species have not been detected within refuge boundaries, San Bernardino and Leslie Canyon NWRs may provide important habitat for maintaining their populations.

Ecosystem impacts associated with intense livestock grazing and other land use activities, coupled with drought and a changing climate have had significant consequences for native semi-desert grasslands and savannas in the Apache Highlands (Gori and Enquist 2003), and terrestrial ecosystems at San Bernardino NWR are no exception to this regional pattern (Radke 2014). Terrestrial plant community *resilience*—the resistance of upland vegetation to change in the face of stressors and disturbances—is a key attribute of assessing habitat condition and overall ecosystem structure and function. To ascertain the current state of plant community resilience, we will examine our monitoring data in the context of four management assessment points:

- Change in any lifeform cover (>20%violates assessment point)
- Change in any perennial species cover (>20% violates assessment point)
- Foliar cover of native perennial grasses in the field layer (<0.5m height; <10% violates assessment point)
- Cover of dead plants in any canopy layer (>10% violates assessment point).

1.5.3 Woody plant encroachment of semi-desert grassland

Woody-plant encroachment into temperate and tropical desert grassland and savanna community types has been widely reported (Brown and Archer 1999). Invasive shrubs and trees are typically native species that have increased in abundance due to shifting biotic or abiotic conditions, such as intensive and often asymmetrical herbivory by livestock or wildlife, altered fire regimes, or shifting climate regimes (Van Auken 2000).

Intensive grazing by livestock, such as occurred in and around San Bernardino NWR in the 1890s (Bailey 1994), has been a primary culprit in woody-plant encroachment. Livestock are effective vectors for seed dispersal, supply a favorable microclimate for germination and recruitment, and reduce interspecific competition and fire occurrence through selective grazing of palatable grasses (Van Auken 2000; Kupfer and Miller 2005).

In the American Southwest, mesquite plays a pivotal role in shrub encroachment into grasslands and savannas, often converting these systems into dense shrublands and thorn woodlands, with important and potentially irreversible consequences for key structural and functional attributes of these ecosystems (Brown and Archer 1999). As a result, mesquite control has become a major management focus in the region for economic and ecological reasons.

At San Bernardino NWR, refuge staff have actively treated mature mesquite in uplands and cienega habitats using mechanical treatments and herbicide application since establishment in 1981. The goal of

Table 1-1. Known and hypothetical federal and state listed species that occur in or adjacent to San Bernardino and Leslie Canyon National Wildlife Refuges.

Status	Common Name	Scientific Name	Occurrence
FT	Cochise pincushion cactus	*Coryphantha robbinsorum*	resident
FE	Huachuca water umbel	*Lilaeopsis schaffneriana*	resident
FT	San Bernardino springsnail	*Pyrgulopsis bernardina*	resident
FE/WC1	Yaqui chub	*Gila purpurea*	resident
FT/WC1	Yaqui beautiful shiner	*Cyprinella formosa*	resident
WC1	Yaqui sucker	*Catostomus bernardini*	hypothetical
FT/WC1	Yaqui catfish	*Ictalurus pricei*	resident
FE/WC1	Yaqui topminnow	*Poeciliopsis sonoriensis*	resident
FT	Chiricahua leopard frog	*Lithobates chiricahuensis*	resident
WC1	Plains leopard frog	*Lithobates blairi*	hypothetical
WC1	Lowland leopard frog	*Lithobates yavapaiensis*	resident
FT	Northern Mexican gartersnake	*Thamnophis eques*	resident
WC1	Massasauga rattlesnake	*Sistrurus catenatus*	hypothetical
WC1	American Bittern	*Botaurus lentiginosus*	rare migrant
WC1	Least Bittern	*Ixobrychus exilis*	rare migrant
WC1	Great Egret	*Casmerodius albus*	migrant
WC1	Snowy Egret	*Egretta thula*	rare migrant
WC1	Black-bellied Whistling Duck	*Dendrocygna autumnalis*	rare migrant
WC1	Osprey	*Pandion haliaetus*	migrant
WC1	Common Black Hawk	*Buteogallus anthracinus*	migrant
WC1	Gray Hawk	*Asturina nitidus*	nesting
WC1	Ferruginous Hawk	*Buteo regalis*	rare migrant
WC1	Crested Caracara	*Polyborus plancus*	vagrant
FE/WC1	Northern Aplomado Falcon	*Falco femoralis septentrionalis*	hypothetical
WC1	Peregrine Falcon	*Falco peregrinus*	migrant
WC1	Yellow-billed Cuckoo	*Coccyzus americanus*	nesting
WC1	Violet-crowned Hummingbird	*Amazilia violiceps*	migrant
WC1	Belted Kingfisher	*Ceryle alcyon*	migrant
FE/WC1	Willow Flycatcher	*Empidonax traillii*	migrant
WC1	Tropical Kingbird	*Tyrannus melancholicus*	nesting
WC1	Thick-billed Kingbird	*Tyrannus crassirostris*	vagrant
WC1	Rose-throated Becard	*Pachyramphus aglaiae*	vagrant
WC1	Gray Catbird	*Dumetella carolinensis*	migrant
WC1	American Redstart	*Setophaga ruticilla*	migrant
FE	Lesser long-nosed bat	*Leptonycteris curasoae*	migrant
WC1	Red Bat	*Lasiurus borealis*	migrant
FE	Jaguar	*Panthera onca*	hypothetical
FE	Ocelot	*Leopardus pardalis*	hypothetical



Woody encroachment in the foreground at San Bernardino NWR. USFWS

treatments is to maintain open canopy semi-desert grassland and savanna communities to support native wildlife. The refuge has also expressed concern over the encroachment of acacia species. To determine the degree of woody plant encroachment into semi-desert grassland and savanna communities at San Bernardino NWR, we will evaluate our results in the context of two management assessment points:

- Tree and shrub cover in the subcanopy (0.5–2.0m height; >30% violates assessment point)
- Mesquite (*Prosopsis* sp.) cover in field or subcanopy layers (<0.5 m and 0.5–2.0 m heights; >10% violates assessment point)

1.5.4 Invasive non-native species

Biological invasions into new regions, whether accidental or deliberate, have increased at unprecedented rates in the past few hundred years (D'Antonio and Vitousek 1992). Non-native animals are currently a primary focus of management at the refuge. Introduction of the Asian tapeworm (*Bothriocephalus acheilognathi*) to the refuge has adversely affected the recovery of the endangered and threatened fish species and the non-native bullfrog (*Lithobates catesbeiana*) has caused severe decline or elimination of populations of Mexican garter snakes (*Thamnophis eques*), Sonoran mud turtles (*Kinosternon sonoriense*), Chiricahua leopard frogs (*Lithobates chiricahuensis*), and lowland leopard frogs (*Lithobates yavapaiensis*; Radke 2013b). Non-native animal monitoring is beyond the scope of this current report.

While invasive, non-native plants are not percieved to be a widespread problem on the refuge at present (L. Johnson, personal communication), some non-native plants are of concern including Russian thistle (*Salsola iberica*), Johnson grass (*Sorghum halapens*e), Lehmann lovegrass (*Eragrostis lehmanniana*), Malta starthistle (*Centaurea melitensis*), giant reed (*Arundo donax*), salt cedar (*Tamarix ramosissima*), and buffelgrass (*Pennisetum cilare*; Radke 2013b). It is a refuge priority to reduce the spread of these species and to prevent other introductions in order to protect the native habitats and restoration work (Radke 2013b). Forty-seven non-native plants (Table 1-2) have been detected in and around San Bernardino NWR per the SEINet data portal. While several of these have not invaded the refuge, their documented presence near the refuge is cause for concern and vigilant monitoring.

Once established, non-native plant species often lead to changes in ecosystem processes that are self-maintaining and evolving, resulting in functional as well as compositional change. Several studies have implicated environmental and climatic variables as potential drivers for sustaining or accelerating non-native plant dominance in semi-arid ecosystems (Shinneman and Baker 2009). In the American Southwest, historic and current land use practices, such as

Table 1-2. Non-native plants detected in and around San Bernardino NWR (SEINet 2017).

Family	Scientific Name	Common Name	Lifeform	Duration
AMARANTHACEAE	*Alternanthera caracasana*	washerwoman	Forb/Herb	Perennial
	Salsola tragus	prickly Russian thistle	Forb/Herb	Annual
ASTERACEAE	*Centaurea melitensis*	Maltese star-thistle	Forb/Herb	Annual
	Lactuca serriola	prickly lettuce	Forb/Herb	Annual
	Sonchus asper	spiny sowthistle	Forb/Herb	Annual
	Sonchus oleraceus	common sowthistle	Forb/Herb	Annual
BRASSICACEAE	*Nasturtium officinale*	watercress	Forb/Herb	Perennial
	Sisymbrium irio	London rocket	Forb/Herb	Annual
CAPRIFOLIACEAE	*Sambucus nigra*	European black elder	Shrub	Perennial
CHENOPODIACEAE	*Salsola iberica*	Russian thistle	Forb/Herb	Annual
CONVOLVULACEAE	*Ipomoea hederacea*	ivyleaf morning-glory	Vine	Annual
CUCURBITACEAE	*Citrullus lanatus*	watermelon	Vine	Annual
CYPERACEAE	*Cyperus esculentus*	yellow nutsedge	Graminoid	Perennial
FABACEAE	*Caesalpinia gilliesii*	bird-of-paradise shrub	Shrub	Perennial
	Melilotus albus	white sweet-clover	Forb/Herb	Annual
	Melilotus indicus	annual yellow sweetclover	Forb/Herb	Annual
GERANIACEAE	*Erodium cicutarium*	redstem stork's bill	Forb/Herb	Annual
LAMIACEAE	*Marrubium vulgare*	horehound	Subshrub	Perennial
LILIACEAE	*Asparagus officinalis*	garden asparagus	Forb/Herb	Perennial
MALVACEAE	*Sida abutifolia*	spreading fanpetals	Forb/Herb	Annual
POACEAE	*Arundo donax*	giant reed	Graminoid/Subshrub	Perennial
	Bothriochloa ischaemum	yellow bluestem	Graminoid	Perennial
	Bromus catharticus	rescuegrass	Graminoid	Annual
	Bromus rubens	red brome	Graminoid	Annual
	Bromus tectorum	cheatgrass	Graminoid	Annual
	Cynodon dactylon	Bermudagrass	Graminoid	Perennial
	Echinochloa colona	jungle rice	Graminoid	Annual
	Echinochloa crus-galli	barnyard grass	Graminoid	Annual
	Eragrostis barrelieri	Mediterranean lovegrass	Graminoid	Annual
	Eragrostis cilianensis	stinkgrass	Graminoid	Annual
	Eragrostis lehmanniana	Lehmann lovegrass	Graminoid	Perennial
	Eragrostis superba	Wilman lovegrass	Graminoid	Perennial
	Festuca arundinacea	tall fescue	Graminoid	Perennial
	Festuca pratensis	meadow ryegrass	Graminoid	Perennial
	Hordeum murinum ssp. *leporinum*	leporinum barley	Graminoid	Annual
	Pennisetum ciliare	buffelgrass	Graminoid	Perennial
	Pennisetum glaucum	pearl millet	Graminoid	Annual
	Poa annua	annual bluegrass	Graminoid	Annual
	Polypogon monspeliensis	annual rabbitsfoot grass	Graminoid	Perennial
	Polypogon viridis	beardless rabbitsfoot grass	Graminoid	Perennial
	Schismus barbatus	common Mediterranean grass	Graminoid	Annual
	Sorghum halepense	Johnsongrass	Graminoid	Perennial

Table 1-2 (continued). Non-native plants detected in and around San Bernardino NWR (SEINet 2017).

Family	Scientific Name	Common Name	Lifeform	Duration
POLYGONACEAE	*Rumex crispus*	curly dock	Forb/Herb	Perennial
TAMARICACEAE	*Tamarix chinensis*	five-stamen tamarisk	Tree	Perennial
	Tamarix pentandra	five-stamen tamarisk	Tree	Perennial
	Tamarix ramosissima	five-stamen tamarisk	Tree	Perennial
ZYGOPHYLLACEAE	*Tribulus terrestris*	puncturevine	Forb/Herb	Annual

livestock grazing and fire suppression, are thought to have contributed to the susceptibility of arid lands to invasion and subsequent loss of native species, as well as decreased biodiversity (Brown and Archer 1999). To assess the current state of non-native plant dispersal and invasion into native plant communities on the refuge, we will consider our monitoring data in the context of four management assessment points:

- Extent of exotic plants (>50% of monitoring plots violates the assessment point)
- New exotic species (annual or perennial) on any plot
- Existing exotic species detected on any new plot
- Total cover of exotic plants in the field layer (<0.5m height; >5% violates the assessment point)
- The ratio of exotic plant to total plant cover (>20% violates the assessment point)
- Buffelgrass cover in the field layer (<0.5 m; >1% violates the assessment point)
- Lehmann lovegrass cover in the field layer (<0.5 m; >10% violates the assessment point)

1.5.5 Altered fire regimes

Human activities have directly and indirectly altered natural fire regimes in many areas of the American Southwest (Swetnam 1990). A century of active fire suppression combined with the indirect impacts of intensive livestock grazing and other land uses have heavily modified fuels and favored fire intolerant vegetation over more fire adapted plant communities.

Fire imposes strong selective pressures on grassland species to develop life-history traits that avoid or mitigate the direct impacts of fire so as to persist and profit from the post-fire environment. Avoidance, either through leaf senescence and protection of growth points (meristems) or persistence as seeds, is the primary adaptation mechanism of semi-desert grassland species.

Most perennial grasses and mature woody plants exhibit the former, replacing lost photosynthetic tissue from buds protected within the soil surface or thick bark. Annual grasses are good examples of prolific seed producers, enduring the exposure to fire between successive generations by investing in their seed bank. Some perennial plants also exhibit this strategy.

The timing of grassland fires is critical to determining the vegetative outcome. Wildfires typically occur in conjunction with summer thunderstorms, whereas many prescribed fires are implemented just prior to the spring growing season to stimulate warm-season (C4) grass production, reduce recruitment of woody-plant seedlings and saplings, and decrease fine-fuel loads (Scifres and Hamilton 1993).

As these two fire regimes occur under dissimilar climatic conditions and on opposite ends of the growth cycle of most semi-desert grassland plants, the consequences for vegetation dynamics are often quite different. To ascertain the degree to which altered fire regimes and recent fire history may be inconsistent with the natural role of fire in grasslands and savannas at San Bernardino NWR, we will contrast our results with three management assessment points:

- Fuel loading (leaf litter and woody debris; >75% of ground cover violates assessment point).
- The ratio of annual plant cover to total plant cover (>20% violates the assessment point)
- Dead plant cover in the subcanopy layer (0.5–2.0 m; >15% violates the assessment point)

2 Methods

2.1 Response design

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

2.1.1 Vegetation and soil cover: line-point intercept

Line-point intercept is a common and efficient technique for measuring plant vegetation cover. 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 (Table 2-1) along each of the six transects using the line-point intercept method, with points spaced every 0.5 m (240 points total).

Table 2-1. Height categories for vegetation measurement.

Field	<0.05 m
Subcanopy	0.05–2.0 m
Canopy	>2.0 m

Perennial vegetation was recorded to species. Annual vegetation was recorded to lifeform, with the exception of a suite of annual non-native plants that were recorded to the species level. Soil cover was recorded by substrate class (e.g., rock, gravel, litter, woody debris; see SOP #5, Hubbard et al. 2012). Litter and woody debris were recorded to fuel type (fine fuels, 1-hour fuels, 10-hour fuels, 100-hour fuels, 1000-hour fuels; Deeming et al. 1977). Biological soil crust cover was recorded to morphological group (light cyanobacteria, dark cyanobacteria, lichen, moss). Vegetation and soil cover are reported as percent cover with standard error and the minimum detectable change (MDC) given the estimated statistical power of the study design.

2.1.2 Vegetation frequency: subplots

The area between any two adjacent transects formed the boundary of 10-m × 20-m subplots that were used to estimate within-plot frequency of perennial plant species, annual and perennial non-native plants, and all lifeforms. The occurrence of any species/lifeform that was not measured on the adjacent line-point intercept transect was recorded to determine a within-plot frequency based on number of subplots occupied relative to the total number of subplots (i.e., 5). Figure 2-1 shows the relationship between each subplot and its corresponding adjacent transect.

2.1.3 Soil aggregate stability

Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2005a). Within each plot, soil samples were attempted at 18 predetermined points along the line-point intercept transects. The dominant vegetation canopy cover and substrate cover at each point were determined. A uniformly sized (2–3 mm thick and 6-8 mm on each side) soil sample was collected at each predetermined point. Each sample was placed on a screen and soaked in water for five minutes. After five minutes, the samples were slowly dipped up and down in the water, with the remaining amount of soil recorded as an index of the wet aggregate stability of the sample. Samples were scored from 1 to 6, with 6 being the most stable (See Table 2-2; Herrick et al. 2005a).

2.1.4 Biological soil crust cover and frequency: Point-quadrats

At each line-point intercept, biological soil crusts were recorded as light cyanobacteria, dark cyanobacteria, bryophytes (moss and liverworts), and lichens by growth form (crustose, gelatinous, foliose, fruticose, and squamulose). The observer then visually surveyed the quadrat for any morphological group or lichen growth form that was present. Absolute cover and cover in available habitat were calculated.

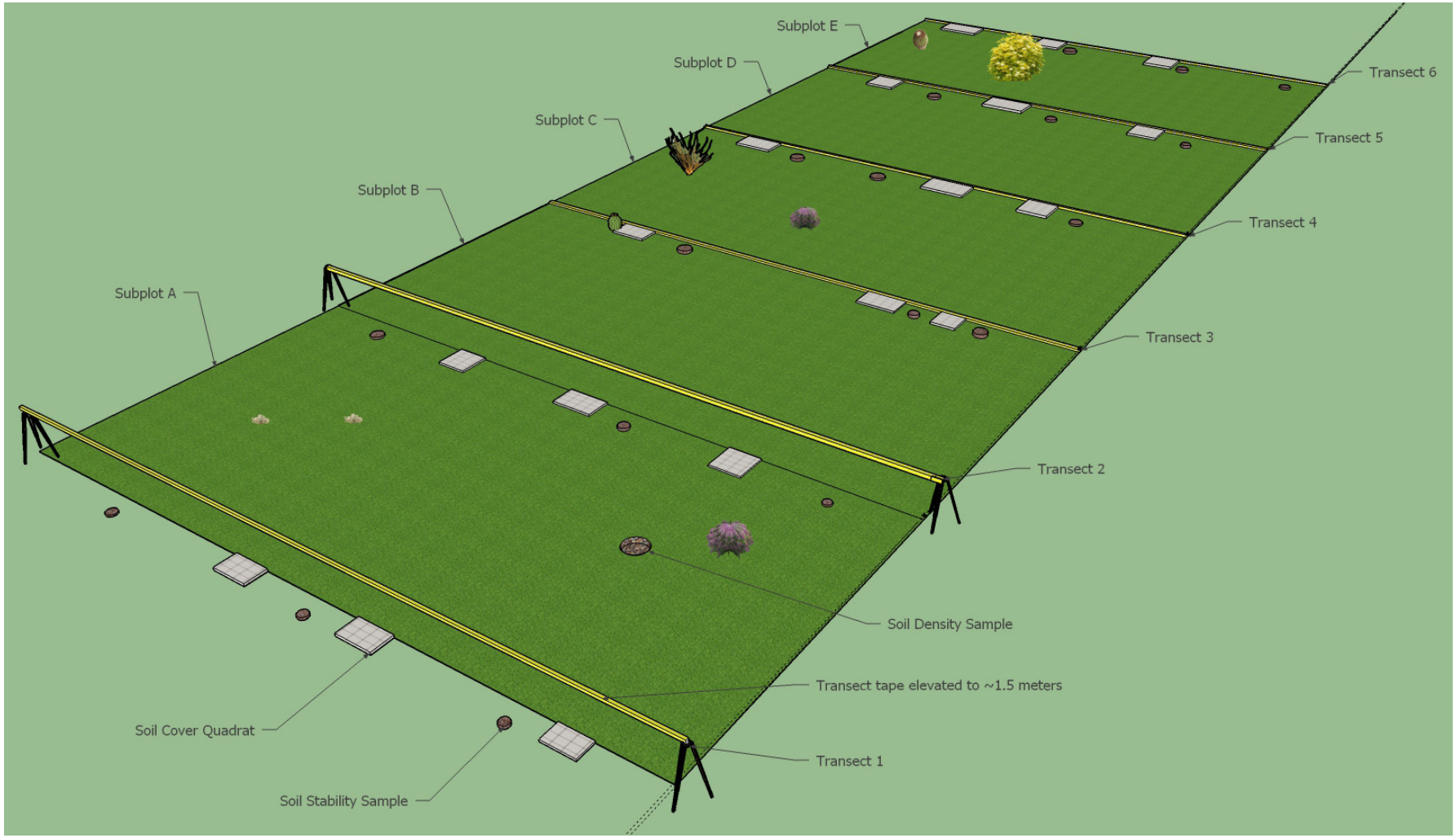


Figure 2-1. Terrestrial vegetation and soils monitoring plot design. See Hubbard and others (2012) for additional details on design and data collection.

Table 2-2. Categories for aggregate stability of surface soils.

Class	Category*	Criteria
1	Very unstable	50% of structural integrity lost (melted) within 5 seconds of immersion in water AND <10% of soil remained on sieve after 5 dipping cycles, OR soil too unstable to sample (fell through sieve)
2	Unstable	50% of structural integrity lost (melted) within 5-30 seconds of immersion in water AND <10% of soil remained on sieve after 5 dipping cycles.
3	Somewhat unstable	50% of structural integrity lost (melted) within 30-300 seconds of immersion in water OR <10% of soil remained on sieve after 5 dipping cyles
4	Moderately stable	10-25% of soil remained on sieve after 5 dipping cycles
5	Stable	25-75% of soil remained on sieve after 5 dipping cycles
6	Very stable	75-100% of soil remained on sieve after 5 dipping cycles

*Adapted from Herrick and others (2005a)

2.1.5 Soil and site characterization

Proximate soil and landform factors are known to influence vegetation and dynamic soil function parameters at local scales (McAuliffe 1999). To characterize plot soil and landscape attributes, a suite of topoedaphic variables were collected through site diagrams, repeat photo points, and a soil core. Landform and slope position, type, and inclination (%) were recorded at each plot. Erosion features were described by estimating broad areal percentage classes of areas affected by tunneling, sheets, rills, gullies, pedestals, terracettes, and burrowing. Permanent photo points were established at each plot corner to characterize general site physiognomy and as an aid to interpreting quantitative trend data in successive sampling periods. In addition, general site descriptions (including observed disturbances such as fire) were collected for each plot.

The soil core was collected at a predetermined random location within the first subplot, with alternate random locations sampled if the first location was not suitable. The soil core collection followed the compliant cavity method (Blake and Hartge 1986) and cores were approximately 10-cm deep. These soil samples were returned to a lab where they were processed to determine bulk density, rock fragment content, soil texture, total organic content, EC (electrical conductivity) and pH.

2.2 Sampling design

2.2.1 Overview

Stratification (see Section 3.2.3, Hubbard et al. 2012) is normally employed to reduce spatial variability and increase sampling efficiency. Terrestrial vegetation and soils plots are allocated to strata based on elevation and soil rock-fragment classes. We use surface soil coarse rock fragment content as an additional stratification variable, as this parameter is a reasonable proxy for soil development (Hubbard et al. 2012). At San Bernardino NWR, there was only one stratum (see Table 2-3 for all strata in the region) available based on soil survey information and surface soil coarse rock fragment content:

- Non-Rocky, Foothills:" 3,701-4,500 ft. (1,128-1,372 m), <35% surface soil rock fragments (stratum 301)

Therefore, inference from the plots at San Bernardino NWR is to all terrestrial areas of the park by soil and elevation strata, excluding the areas discussed in 2.2.3.

We allocated 15 permanent monitoring plots in a spatially balanced arrangement within San Bernardino NWR and sampled in 2013. Sample sizes were based on *a priori* expectations of required sample size to meet our criteria for statistical power and detectability (see Sections 2.2.5–2.2.6). Table 2-4 shows the allocation of permanent monitoring plots.

2.2.2 Spatial balance

The spatial sampling design for this protocol employs permanent, 20-m × 50-m sampling plots, allocated through a Reversed Randomized Quadrant-Recursive Raster (RRQRR) spatially balanced design (Theobald et al. 2007), using the Create Spatially Balanced Points tool (Geostatistical Analyst) in ArcGIS 10. This tool produces a design that is

Table 2-3. Number, name, and characteristics of sampling strata for terrestrial vegetation and soils.

Number	Name	Elevation	Rock-fragment Content
101	Non-Rocky Valley-Bottom	≤2,500 ft	<35% surface soil rock fragments
102	Rocky Valley-Bottom	≤2,500 ft	35 - 90% surface soil rock fragments
103	Valley-Bottom Rock Outcrops	≤2,500 ft	bedrock or rock outcrops
201	Non-Rocky Bajada	2,501 - 3,700 ft	<35% surface soil rock fragments
202	Rocky Bajada	2,501 - 3,700 ft	35 - 90% surface soil rock fragments
203	Bajada Rock Outcrops	2,501 - 3,700 ft	bedrock or rock outcrops
301	Non-Rocky Foothills	3,701 - 4,500 ft	<35% surface soil rock fragments
302	Rocky Foothills	3,701 - 4,500 ft	35 - 90% surface soil rock fragments
303	Foothills Rock Outcrops	3,701 - 4,500 ft	bedrock or rock outcrops
401	Non-Rocky Mid-Mountain	4,501 - 6,000 ft	<35% surface soil rock fragments
402	Rocky Mid-Mountain	4,501 - 6,000 ft	35 - 90% surface soil rock fragments
403	Mid-Mountain Rock Outcrops	4,501 - 6,000 ft	bedrock or rock outcrops
501	Non-Rocky High-Mountain	>6,000 ft	<35% surface soil rock fragments
502	Rocky High-Mountain	>6,000 ft	35 - 90% surface soil rock fragments
503	High-Mountain Rock Outcrops	>6,000 ft	bedrock or rock outcrops

Table 2-4. Allocation of permanent terrestrial vegetation and soils monitoring plots by strata, San Bernardino NWR.

Stratum	Elevation	% Rock Fragments	Total Area (acres)	Percentage of Total Refuge Area	Percentage of Total Frame Area	# Plots per Strata
0[a]	n/a	n/a	894	38%	0%	0
301	2,501 - 3,700 ft	<35%	1419	60%	96%	15
302[b]	2,501 - 3,700 ft	35 - 90%	56	2%	4%	0
Totals	–	–	**2,369**	**100%**	**100%**	**15**

[a]Stratum "0" includes all areas excluded from sampling as described in Section 2.2.3.

[b]Stratum 302 comprised <5% of the refuge so it was excluded from sampling.

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 and the Generalized Random Tessellation Stratified (GRTS) approach (Stevens and Olsen 2004), are increasingly being applied to ecosystem monitoring (e.g., Environmental Protection Agency Ecological Monitoring and Assessment Program) because they provide the advantages of a probabilistic design (Stehman 1999) and they ensure spatial balance regardless of overall sample size. RRQRR designs facilitate adding or removing sites in a spatially balanced manner if statistical power, financial considerations, or additional monitoring objectives warrant adjusting the sample size. This scaling ability is an important advantage, as (1) the number of plots per refuge cannot be adequately estimated *a priori* (see Section 3.4.2, Hubbard et al. 2012) and (2) future changes in technology, objectives, and budgets may necessitate increasing or decreasing sample sizes.

2.2.3 Sampling frame

The sampling frame for San Bernardino NWR includes all terrestrial areas within refuge boundaries, except for the following (Figure 2-2):

- Slopes of ≥ 45° (for crew safety)
- Roads and buildings (including a 100-m buffer)
- Trails, washes, streams, and the refuge boundary (including 50-m buffer)

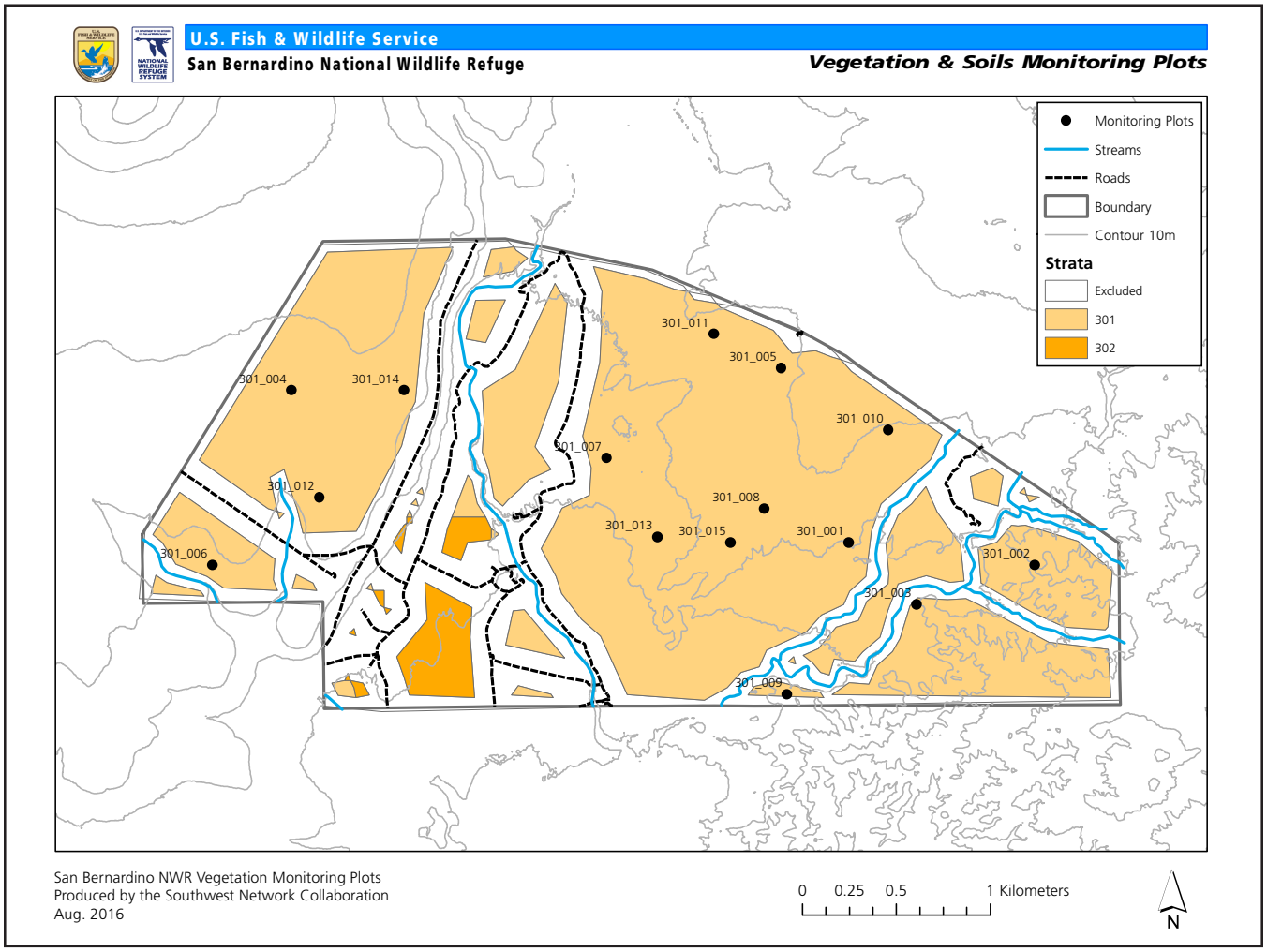


Figure 2-2. Sampling frame and allocation of monitoring plots for terrestrial vegetation and soils monitoring, San Bernardino NWR.

- Stratum comprising <5% of the total refuge area

The total area excluded under these criteria was approximately 385 hectares (950 acres), or 40% of the Refuge area.

2.2.4 Statistical power to distinguish status from management assessment points

Estimating our statistical power to distinguish current conditions - status- from management assessment points (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 et al. 2005b):

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

Where:

S = Standard deviation of the sample

Z_α = Z-coefficient for false-change (Type I) error (we set at 90%)

Z_β = Z-coefficient for missed-change (Type II) error (we set at 10%)

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.

2.2.5 Statistical power to detect trends

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

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

Where:

S_{diff} = Standard deviation of the differences between paired samples

Z_α = Z-coefficient for false-change (Type I) error (we set at 90%)

Z_β = Z-coefficient for missed-change (Type II) error (we set at 10%)

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

In this case, we only have one year of data, so 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.

$coor_{diff}$ = 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.

2.2.6 Evaluation of strata

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

To evaluate the efficiency and pertinence of preselected elevation strata, we contrasted the similarity of vegetation communities on each stratum using permutational multivariate analysis of variance on vegetation similarity matrices (PERMANOVA+), non-metric multidimensional scaling (MDS), and SIMPER, a permutation procedure that reveals species contributing the most to any between- and within-group dissimilarities. These non-parametric multivariate community analyses make few assumptions about the data, yielding a simple yet powerful analysis tool (Clarke and Warwick 2001). Based on the strata evaluation results, we may combine some strata or modify sample sizes for a given stratum.

2.2.7 Diversity of perennial plants

Biodiversity is a primary focus of ecological research, and maintaining native biodiversity is a central tenet of natural resource conservation (Keddy 2007). Diversity indices can provide an indicator of the ecological "well-being" of an ecosystem, and are well-established measures in ecology - see Izsák and Papp (2000) and Warwick and Clarke (1995) for one of many published overviews of traditional indices, their assumptions, and their limitations.

There are three major limitations for utilizing traditional diversity indices in an ecological monitoring context: (1) sampling effort has a large influence on diversity measures, restricting valid comparisons to sites with consistent methods and effort; (2) phylogenetic diversity (phylogeny is the evolutionary history of a group of organisms, as explained in a family tree) is not reflected in the measure—two species in the same genera are as "diverse" as two species from different orders; (3) and there are no statistical approaches for testing departure from expected diversity and potential effects of human perturbation (Warwick and Clarke 1995).

We address perennial plant diversity using two approaches:

- Average Within-Plot Species Richness (S_{plot})
- Taxonomic Distinctness Index (Δ^+)

Within-plot species richness (S_{plot}) is an index of diversity rather than actual species richness since it is dependent on sample effort. The taxonomic distinctness index is a measure of diversity that gives weight to the different levels of taxonomic hierarchy represented in the sample (i.e., the taxonomic breadth of a sample; Warwick and Clarke 1995). Examining both of these indices allows for a broader examination of biodiversity within and between strata.

3 Results

3.1 Design considerations

3.1.1 Evaluation of strata

Non-metric multidimensional scaling (MDS) and cluster analysis (Figure 3-1) of vegetation cover by plot suggested that the single stratum actually sorted into two groups based on vegetation similarity. This pattern was confirmed by PERMANOVA+ results (Pseudo F = 14.367, P [Perm] = 0.002) within the non-rocky foothills stratum—the only stratum sampled within the refuge based on our sampling criteria (see Section 2.2.3 and Table 2-4), suggesting these two groups are not explained by our *a priori* soil rock fragment stratification.

Based on the PERMANOVA+ and MDS results, we investigated the source of the two clusters within the non-rocky strata. Soil factors—especially texture and occurrence of shallow (but thick) claypans on some locations—correspond with the groupings, as does the location of the plots within the refuge. The smaller subgroup (plots 301_004, 301_006, 301_012, and 301_014) all occurred on the higher plateau on the western portion of the refuge, an area characterized by the shallow claypan. The other plots were all located on relatively deep clay loam soils in the central and eastern portions of the refuge. SIMPER analysis was then used to determine which species were most responsible for the within-group similarities and between-group differences of the two areas.

Based on these evaluations, all subsequent analysis was conducted by group (Figures 3-2 and 3-3), hereafter referred to as substratum 301-EAST or sandy clay loam, non-rocky, foothills and substratum 301-WEST or claypan, non-rocky, foothills. Potential causes of the differences between these substrata are difficult to directly assess, and include soil factors (particularly the soil pan), geographic context, and land use history. We discuss these factors and speculate on potential cause and effect relationships in Chapter 4.

3.1.2 Power to detect trends in plant lifeforms and common perennial species

Our design generally exceeded our expectations for statistical power to detect trends in plant lifeform and common perennial species (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 5% change (absolute foliar cover) for most detected perennial species and lifeforms (see Sections 3.3.2 and 3.4.2), with the balance meeting our 10% change criteria for this protocol.

3.1.3 Diversity of perennial plants

Within-plot species richness of the sandy clay loam, non-rocky, foothills substratum (301-EAST; S_{plot} = 11.5 ± 1.3 [mean ± SE]) greatly exceeded (F = 13.86, P = 0.003) that of the claypan, non-rocky, foothills

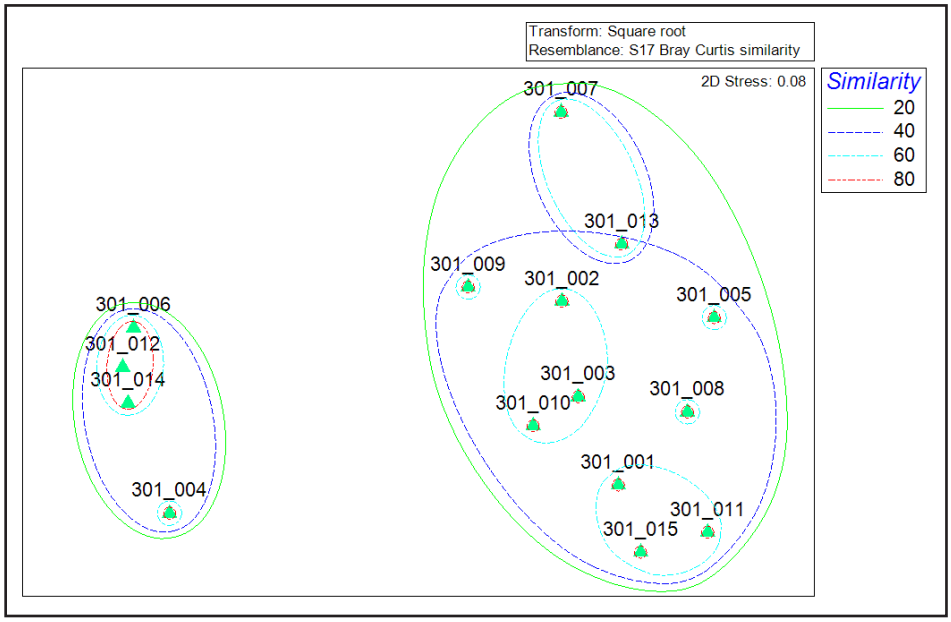


Figure 3-1. Non-metric multidimensional scaling (MDS) indicates similarity of vegetation communities by soil strata. MDS suggests two vegetation groupings within the 301 stratum. The distance between any two points increases as their composition and structure differ.

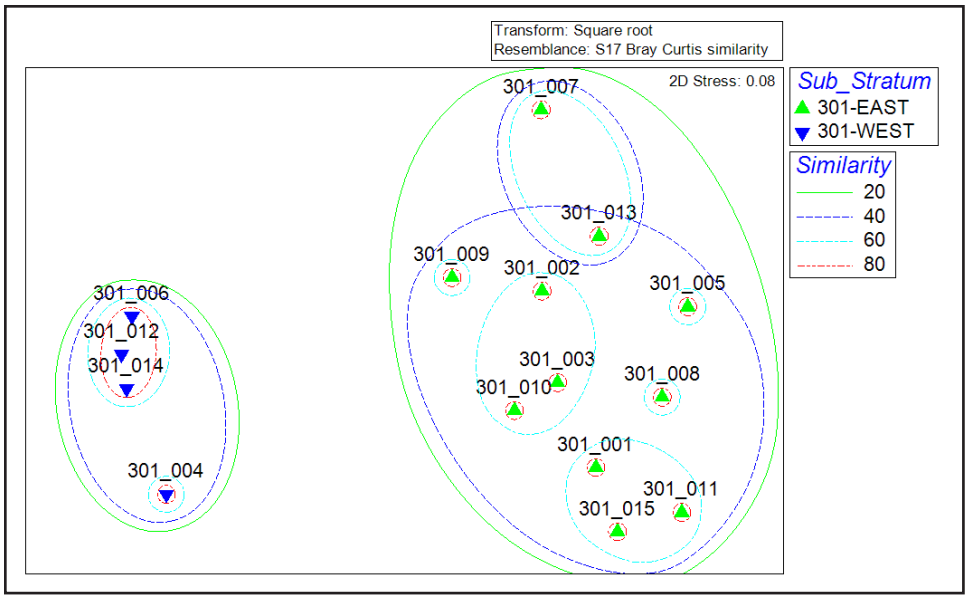


Figure 3-2. Non-metric multi-dimensional scaling (MDS) of vegetation similarity at San Bernardino NWR suggests two broad vegetation types within the *a. priori* soil strata. The distance between any two points increases as their composition and structure differ.

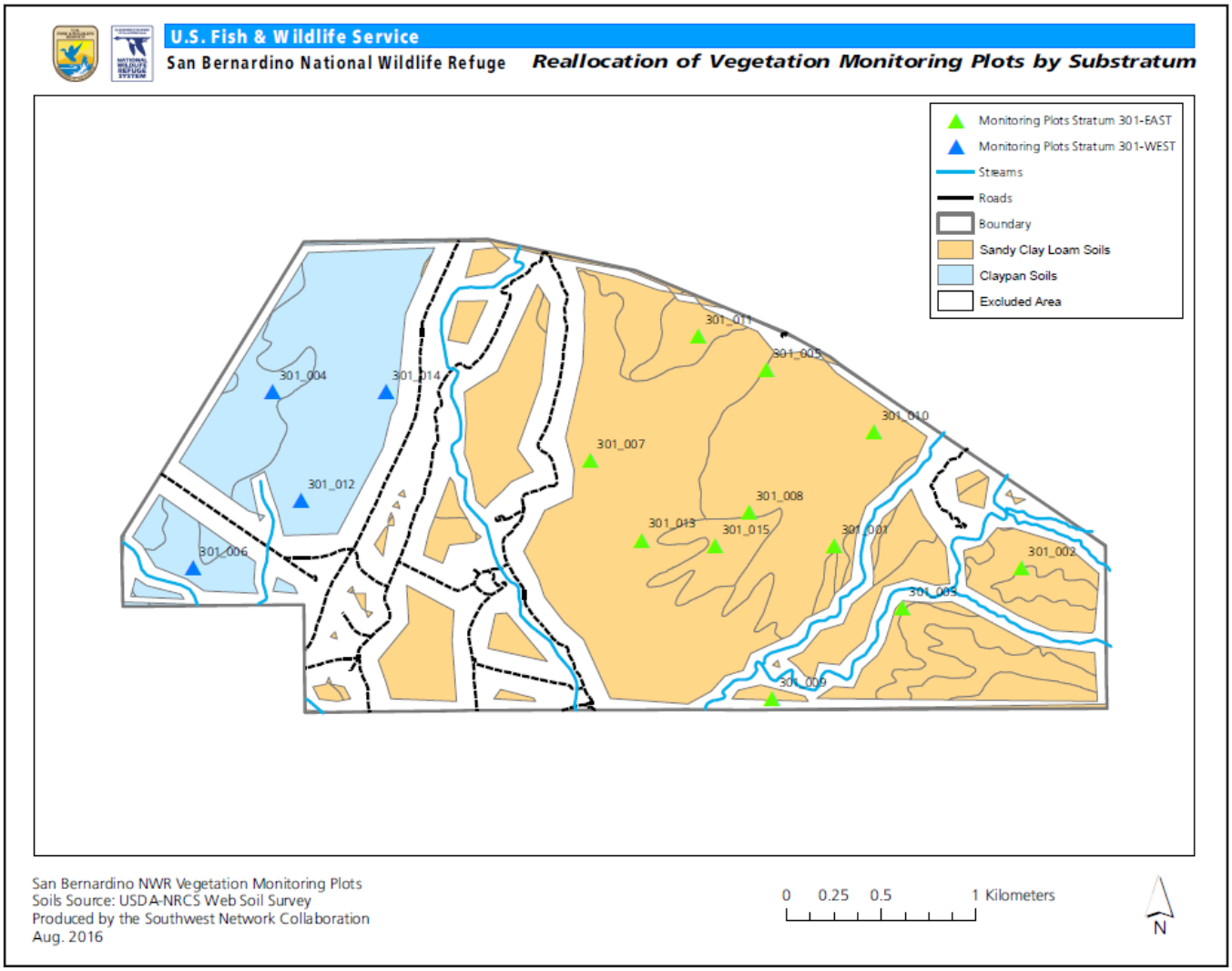


Figure 3-3. Locations of monitoring plots across the strata (301-EAST, 301-WEST), San Bernardino NWR, 2013.

substratum (301-WEST; S_{plot} = 3.0 ± 0.7). There was no significant difference (F = 0.49, P = 0.496) in perennial plant taxonomic distinctness between the two groups (301-EAST Δ^+ = 92.4 ± 1.4; 301-WEST Δ^+ = 95.0 ± 5.0). Three of the four plots in substratum 301-WEST (301_006, 301_012 and 301_014) had a Δ^+ of 100, indicating that all species detected within these plots were in different families. This is unsurprising given the low number of perennial species detected on these plots and across the entire substratum.

We developed species accumulation curves for each of the substrata to examine our ability to detect perennial plant species within each substratum (Figures 3-4 and 3-5). These graphs show the Sobs (actual species observed) and the UGE (analytical

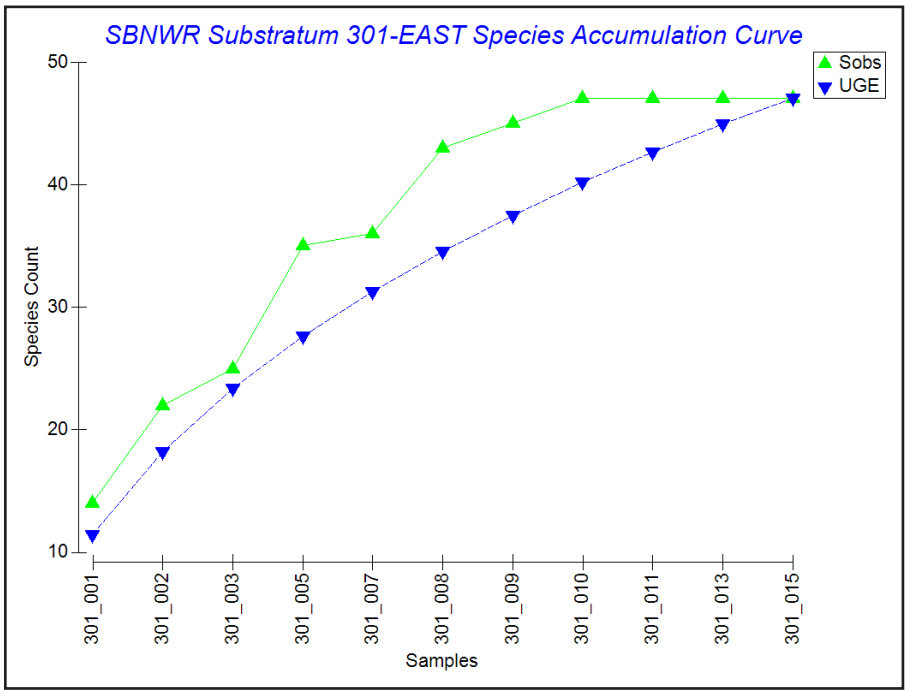


Figure 3-4. Species accumulation curves for sandy clay loam, non-rocky, foothills sites (substratum 301-EAST) suggest diminishing returns with increased sampling intensity. Sobs = the observed species richness. UGE = the modelled species richness.

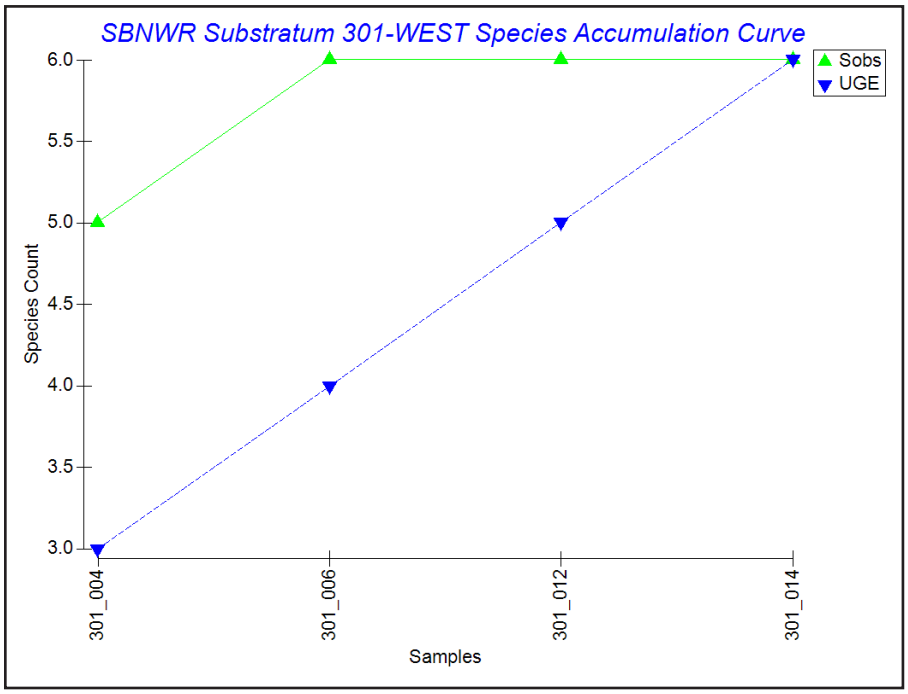


Figure 3-5. Species accumulation curves for the claypan, non-rocky, foothills sites (substratum 301-WEST) indicates the low species richness of the site. Sobs = the observed species richness. UGE is the modelled species richness.

species accumulation curve as proposed by Ugland and others [2003]). Slope decreased on the species accumulation curve of substratum 301-EAST, suggesting diminishing returns for detecting new species with increased sampling intensity. In contrast, the species accumulation curve for substratum 301-WEST maintained its upward trajectory. This may indicate that additional sampling may yield a substantial increase in new detections, but is more likely an artifact of the unusually low species richness on these sites—that is, so few species were detected that any new species would dramatically increase the slope of the curve.

3.2 Non-rocky, foothills stratum (301)

The terrestrial uplands of San Bernardino NWR are primarily comprised of non-rocky (<35% surface soil rock fragments) foothills (3,701-4,500 ft elevation [1,128-1,372 m]). Non-rocky, foothills sites, while uncommon in the Sonoran Desert, are more common across the Chihuahuan Desert, occurring at Guadalupe Mountains National Park, Big Bend National Park, Carlsbad Caverns National Park and White Sands National Monument. This stratum covered a total of 574 ha (1,419 ac) or 60% of the refuge area. We sampled a total of 15 monitoring sites in this stratum at San Bernardino NWR in 2013 (Figure 3-3).

PERMANOVA^{+} and SIMPER analysis of the data revealed that the non-rocky, foothills stratum supported two distinct vegetation communities (90.2% avg. dissimilarity). Soil texture may explain this community division. For this report, we discuss these two groupings in the 301 stratum separately as "substratum" (301-EAST and 301-WEST) as mentioned in Section 3.1. If future vegetation and soils monitoring continues to support this division in the stratum based on soil texture, a long-term post-stratification may be warranted.

3.3 Sandy clay loam, non-rocky, foothills substratum (301-EAST)

Found on the eastern part of the refuge (at slightly lower elevations than the narrow band of substratum 301-WEST on the western edge of the refuge), sandy clay loam, non-rocky, foothills sites (301-EAST) comprise about 76% (436 hectares) of the terrestrial uplands of San Bernardino NWR. Eleven of the 15 sites we sampled were in this substratum.

3.3.1 Vegetation formations, lifeforms, and perennial plant diversity (301-EAST)

The sandy clay loam, non-rocky, foothills sites (301-EAST) were primarily big sacaton/mixed shrub savannas. Perennial grasses and shrubs dominated these sites. With the exception of vines and ferns, all plant lifeforms were encountered. The tree, velvet mesquite (*Prosopis velutina*) was present on all sites and forbs (primarily annual forbs), shrubs, and succulents were present; only one succulent species was detected on line-intercept transects while five additional succulents were detected on frequency subplots.

Annual grasses and forbs comprised about 29% of the total cover (Table 3-1). There was considerably more total live vegetation cover in the field layer (<0.5 m height) than in the subcanopy layer (0.5–2.0 m). The very sparse (~ 2% cover) canopy layer (>2.0 m) had only velvet mesquite (Table 3-1; Figure 3-6). The greatest lifeform diversity was found in the field layer, with grasses (perennial and annual) dominating the height class and shrubs following in second (Figure 3-6). The subcanopy layer was dominated by shrubs (Figure 3-6).

The average similarity within substratum 301-EAST was 46.9% (SIMPER). Within-plot species richness of perennial plants (Splot) was 11.5 ± 1.3 (mean ± SE). Perennial plant taxonomic distinctness (Δ+) was 92.4 ± 1.4.

3.3.2 Cover and extent of perennial plant species (301-EAST)

Sandy clay loam, non-rocky, foothills monitoring sites were dominated by the grass, big sacaton (*Sporobolus wrightii*); the shrubs, American tarwort (*Flourensia cernua*) and creosote bush (*Larrea tridentata*); and the tree/shrub, velvet mesquite, in the field and subcanopy layers (based on cover, extent, and SIMPER results; Table 3-1). These dominant species occurred on at least 9 of the 11 sites. Subdominant species included tobosagrass (*Hilaria mutica*; 7 sites) in the field layer and the shrub, fourwing saltbush (*Atriplex canescens*; 9 sites), in the field and subcanopy layers (Table 3-1 and SIMPER results). The grasses, bush muhly (*Muhlenbergia porteri*) and stinkgrass (*Eragrostis cilianensis*) were common, occurring on 10 sites (Table 3-1). All species detected in substratum 301-EAST were unique to this substratum on San Bernardino NWR except for velvet mesquite and tobosagrass.

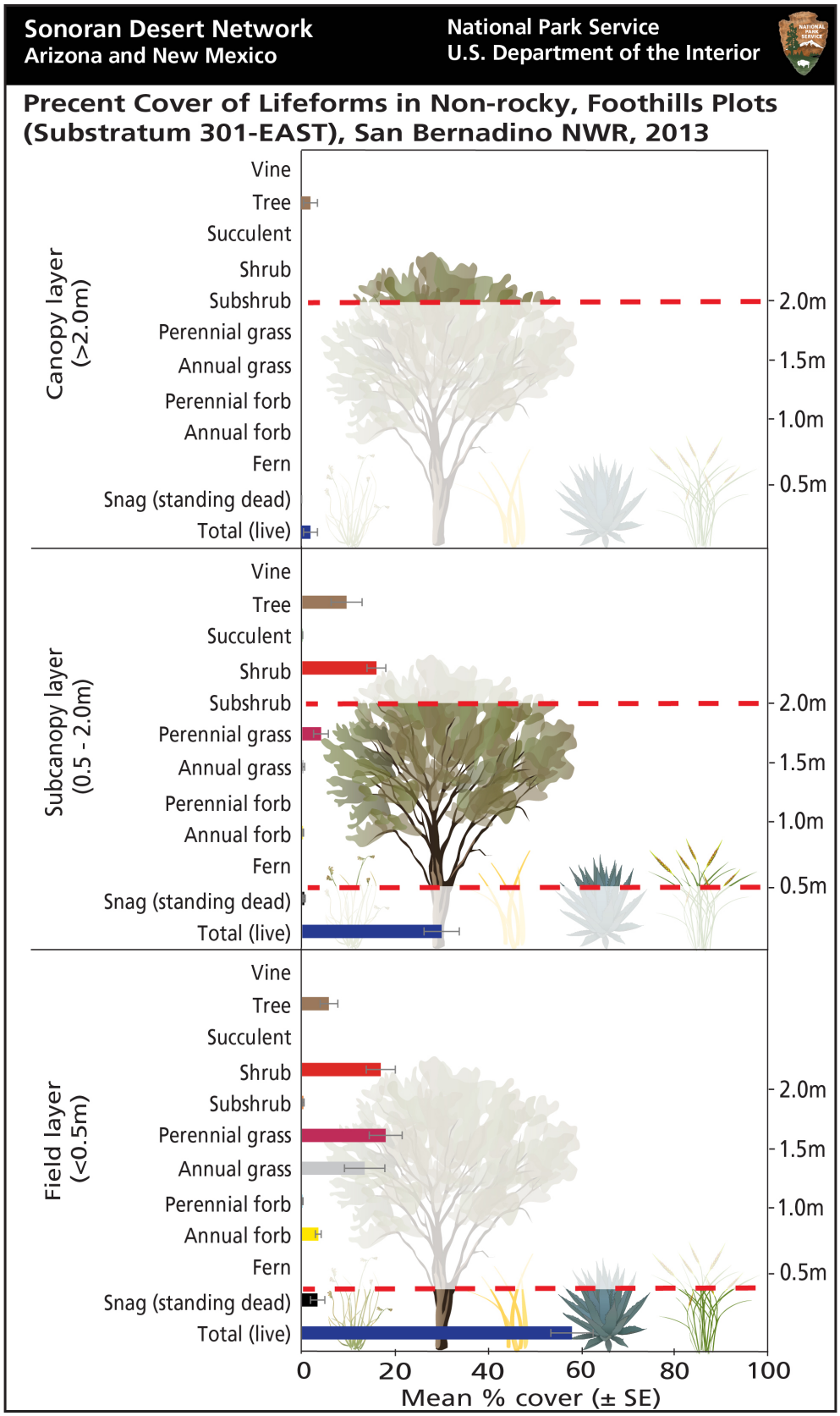


Figure 3-6. Lifeform cover in terrestrial vegetation monitoring plots on sandy clay loam, foothills 3,701-4,500 ft) sites with non-rocky soils (substratum 301-EAST) at San Bernardino NWR, 2013.

Table 3-1. Cover values (%) for perennial and non-native annual species (by lifeform) measured in the field (<0.5 m stature), subcanopy (0.5-2.0 m), and canopy (>2.0 m) layers of sandy clay loam, non-rocky, foothills (301-A substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. "AVG" = average on transects, "SE" = standard error, "MDC" = minimum detectable change (% cover), "Extent" is the number of plots in which the species was detected (out of 11) on transects or subplots, and "T1" = time one (first sampling year, 2013).

			Field			Subcanopy			Canopy			
Lifeform	**Species Name**	**Common Name**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**Extent**
Tree	*Prosopis velutina*	velvet mesquite	5.76%	1.91%	5.00%	9.51%	3.32%	8.00%	1.97%	1.49%	6.00%	11
Succulent	*Yucca elata*	soaptree yucca	–	–	5.00%	0.04%	0.04%	5.00%	–	–	–	3
Shrub	*Atriplex canescens*	fourwing saltbush	2.99%	1.12%	5.00%	1.90%	0.81%	5.00%	–	–	–	9
	Ephedra sp.	jointfir	0.04%	0.04%	5.00%	0.04%	0.04%	5.00%	–	–	–	3
	Flourensia cernua	American tarwort	5.61%	1.25%	5.00%	4.13%	0.87%	5.00%	–	–	–	10
	Larrea tridentata	creosote bush	5.95%	1.56%	5.00%	9.74%	2.09%	5.00%	–	–	–	9
	Parthenium incanum	mariola	2.20%	1.48%	8.00%	0.04%	0.04%	5.00%	–	–	–	5
	Ziziphus obtusifolia	lotebush	0.11%	0.08%	5.00%	0.08%	0.05%	5.00%	–	–	–	2
Subshrub	*Gutierrezia sarothrae*	broom snakeweed	0.04%	0.04%	5.00%	–	–	–	–	–	–	4
	Menodora scabra	rough menodora	0.11%	0.11%	5.00%	–	–	–	–	–	–	2
	Thymophylla pentachaeta	fiveneedle pricklyleaf	0.04%	0.04%	5.00%	–	–	–	–	–	–	2
	Zinnia acerosa	desert zinnia	0.08%	0.05%	5.00%	–	–	–	–	–	–	7
Grass	*Bothriochloa barbinodis*	cane bluestem	0.04%	0.04%	5.00%	0.04%	0.04%	5.00%	–	–	–	1
	Bothriochloa ischaemum*	**yellow bluestem***	0.91%	0.91%	5.00%	0.72%	0.72%	5.00%	–	–	–	1
	Bouteloua curtipendula	sideoats grama	0.68%	0.41%	5.00%	0.23%	0.16%	5.00%	–	–	–	6
	Bouteloua erecta	false grama	0.04%	0.04%	5.00%	–	–	–	–	–	–	1
	Bouteloua eriopoda	black grama	0.42%	0.30%	5.00%	–	–	–	–	–	–	6
	Dasyochloa pulchella	low woolygrass	0.30%	0.15%	5.00%	–	–	–	–	–	–	8
	Digitaria californica	Arizona cottontop	0.08%	0.08%	5.00%	–	–	–	–	–	–	8
	Enneapogon desvauxii	nineawn pappusgrass	0.04%	0.04%	5.00%	–	–	–	–	–	–	1
	Eragrostis cilianensis*	**stinkgrass***	0.08%	0.08%	5.00%	–	–	–	–	–	–	10
	Eragrostis lehmanniana*	**Lehmann lovegrass***	0.30%	0.30%	5.00%	–	–	–	–	–	–	2
	Hilaria mutica	tobosagrass	5.38%	2.53%	8.00%	0.15%	0.10%	5.00%	–	–	–	7
	Hopia obtusa	vine mesquite	0.15%	0.15%	5.00%	–	–	–	–	–	–	1
	Muhlenbergia polycaulis	cliff muhly	0.08%	0.05%	5.00%	–	–	–	–	–	–	2
	Muhlenbergia porteri	bush muhly	2.08%	1.27%	5.00%	0.08%	0.08%	5.00%	–	–	–	10

*Non-natives (in bold)

Table 3-1 (continued). Cover values (%) for perennial and non-native annual species (by lifeform) measured in the field (<0.5 m stature), subcanopy (0.5-2.0 m), and canopy (>2.0 m) layers of sandy clay loam, non-rocky, foothills (301-A substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. "AVG" = average on transects, "SE" = standard error, "MDC" = minimum detectable change (% cover), "Extent" is the number of plots in which the species was detected (out of 11) on transects or subplots, and "T1" = time one (first sampling year, 2013).

			Field			Subcanopy			Canopy			
Lifeform	**Species Name**	**Common Name**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**Extent**
Grass, cont.	*Setaria leucopila*	streambed bristlegrass	0.04%	0.04%	5.00%	–	–	–	–	–	–	6
	Sporobolus contractus	spike dropseed	0.08%	0.05%	5.00%	–	–	–	–	–	–	2
	Sporobolus wrightii	big sacaton	7.23%	2.91%	7.00%	2.69%	1.18%	5.00%	–	–	–	9
	Trichloris crinita	false Rhodes grass	0.11%	0.11%	5.00%	0.11%	0.11%	5.00%	–	–	–	1
Forb/herb	*Chamaesaracha coronopus*	greenleaf five eyes	0.11%	0.08%	5.00%	–	–	–	–	–	–	3
	Salsola tragus*	**prickly Russian thistle**	0.11%	0.11%	5.00%	–	–	–	–	–	–	2
Vine	–	–	–	–	–	–	–	–	–	–	–	–
Tree	–	–	5.76%	1.91%	5.00%	9.51%	3.32%	8.00%	1.97%	1.49%	6.00%	–
Succulent	–	–	–	–	–	0.04%	0.04%	5.00%	–	–	–	–
Shrub	–	–	16.89%	3.10%	7.00%	15.91%	2.03%	5.00%	–	–	–	–
Subshrub	–	–	0.27%	0.15%	5.00%	–	–	–	–	–	–	–
Perennial Grass	–	–	17.96%	3.52%	8.00%	4.02%	1.58%	5.00%	–	–	–	–
Annual Grass	–	–	13.45%	4.34%	10.00%	0.27%	0.23%	5.00%	–	–	–	–
Perennial Forb	–	–	0.11%	0.08%	5.00%	–	–	–	–	–	–	–
Annual Forb	–	–	3.49%	0.62%	5.00%	0.15%	0.10%	5.00%	–	–	–	–
Fern	–	–	–	–	–	–	–	–	–	–	–	–
Snag	–	–	3.33%	1.55%	5.00%	0.42%	0.24%	5.00%	0.04%	0.04%	5.00%	–
Total (live)	–	–	57.96%	4.56%	10.00%	29.93%	3.77%	8.00%	1.97%	1.49%	6.00%	–
Annuals	–	–	16.93%	4.52%	10.00%	0.42%	0.31%	5.00%	–	–	–	–
Exotics	–	–	1.40%	0.91%	5.00%	0.72%	0.72%	5.00%	–	–	–	–
Exotics: Total (lie)	–	–	2.65%	–	–	2.33%	–	–	–	–	–	–
Annuals: Total (live)	–	–	26.38%	–	–	0.89%	–	–	–	–	–	–

*Non-natives (in bold)

3.3.3 Frequency and extent of uncommon plant species (301-EAST)

Twenty uncommon plant species were detected on the frequency subplots, but not on line-point intercept transects of sandy clay loam, non-rocky, foothills sites (Table 3-2). Five species had a within-plot frequency of 11% or more; two of these species, Christmas cactus (*Cylindropuntia leptocaulis*) and lacy tansyaster (*Xanthisma spinulosum*), had frequencies of 27% and 29%, respectively (Table 3-2). Christmas cactus and lacy tansyaster were the most extensive uncommon plants across the sandy clay loam, non-rocky foothills sites, occurring on 6 out of 11 sites. All uncommon perennial species in Table 3-2 except walkingstick cactus (*Cylindropuntia spinosior*), were unique to this substratum at San Bernardino NWR.

3.3.4 Cover and frequency of exotic species (301-EAST)

Five exotic species were detected on the sandy clay loam, non-rocky, foothill plots of substratum 301-EAST. Stinkgrass was extensive, detected on ten of the eleven plots in this substratum, but occurred at very low cover (0.08% ± 0.08). The other four species were patchily distributed across the plots (Figure 3-7 and Table 3-3) at generally very low cover, although plot 301-005 contained a swath of the perennial grass, yellow bluestem (*Bothriochloa ischaemum*) at 10% cover in the field (>0.5 m height)—one of the more common species on this location. Plot 301_008 was also of note, as it contained four of the five detected exotic species. Overall, total cover for all exotic species was relatively low (1.4% ± 0.9 in the field layer; Table 3-1).

Table 3-2. Within-plot frequency (%), standard error (SE), and extent (out of 11 plots) of uncommon plant species (found only on subplots and not on transects) sampled on sandy clay loam, non-rocky, foothills (301-EAST substratum) on San Bernardino NWR. Extent is the number of plots (out of 11) each species was detected on.

Lifeform	Species	Common Name	Within-plot Frequency	SE	Extent
Succulent	*Cylindropuntia leptocaulis*	Christmas cactus	27%	11%	6
	Cylindropuntia spinosior	walkingstick cactus	4%	2%	2
	Echinocereus fendleri	pinkflower hedgehog cactus	7%	4%	3
	Opuntia engelmannii	cactus apple	4%	2%	2
	Opuntia phaeacantha	tulip pricklypear	2%	2%	1
Shrub	*Calliandra eriophylla*	fairyduster	2%	2%	1
	Sideroxylon lanuginosum	gum bully	2%	2%	1
Subshrub	*Desmanthus cooleyi*	Cooley's bundleflower	5%	5%	1
	Gutierrezia microcephala	threadleaf snakeweed	11%	8%	2
	Sphaeralcea angustifolia	copper globemallow	2%	2%	1
Grass	*Aristida purpurea*	purple threeawn	13%	9%	3
	Sorghum halepense*	**Johnsongrass***	4%	2%	2
	Tridens muticus	slim tridens	2%	2%	1
Forb/herb	*Abutilon parvulum*	dwarf Indian mallow	2%	2%	1
	Bahia absinthifolia	hairyseed bahia	11%	5%	4
	Hoffmannseggia glauca	Indian rushpea	4%	4%	1
	Jatropha macrorhiza	ragged nettlespurge	2%	2%	1
	Portulaca suffrutescens	shrubby purslane	2%	2%	1
	Xanthisma spinulosum	lacy tansyaster	29%	11%	6

*Non-native (in bold)

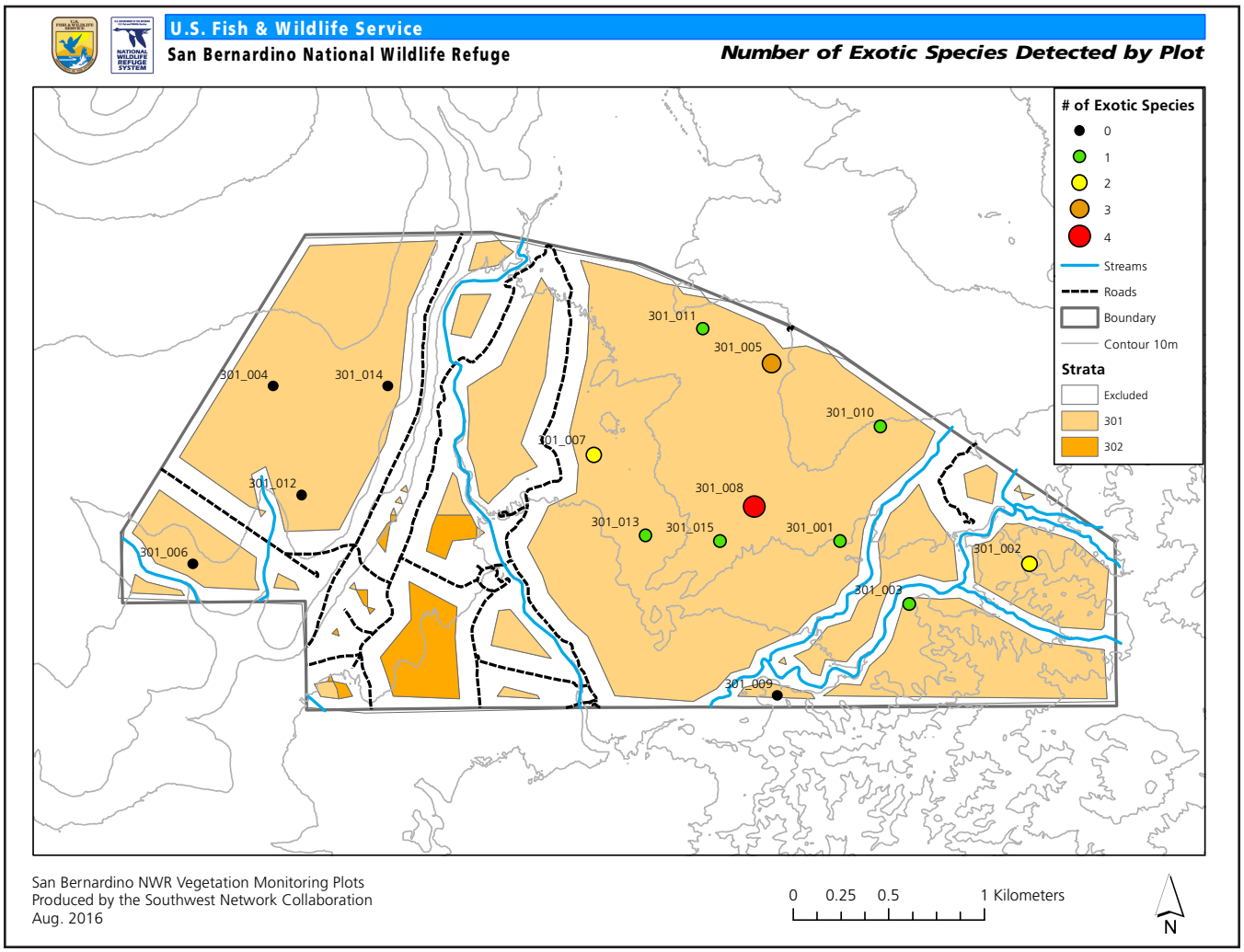


Figure 3-7. Number of exotic species detected by plot, San Bernardino NWR, 2013.

Table 3-3. Presence/absence of non-native plants detected on vegetation monitoring plots, San Bernardino NWR.

Substrata	Plot	Non-native Species	Total Species
301-EAST	301-001	*Eragrostis cilianensis*	1
	301-002	*Eragrostis cilianensis, Eragrostis lehmanniana*	2
	301-003	*Eragrostis cilianensis*	1
	301-005	*Eragrostis cilianensis, Bothriochloa ischaemum, Sorghum halepense*	3
	301-007	*Eragrostis cilianensis, Salsola tragus*	2
	301-008	*Eragrostis cilianensis, Eragrostis lehmanniana, Salsola tragus, Sorghum halepense*	4
	301-009	n/a	0
	301-010	*Eragrostis cilianensis*	1
	301-011	*Eragrostis cilianensis*	1
	301-013	*Eragrostis cilianensis*	1
	301-015	*Eragrostis cilianensis*	1
301-WEST	301-004	n/a	0
	301-006	n/a	0
	301-012	n/a	0
	301-014	n/a	0

3.3.5 Soil cover and biological soil crusts (301-EAST)

Along the line-point intercept transects of the sandy clay loam, non-rocky, foothills substratum, soil cover (Table 3-4) was dominated by gravel (2-76 mm diameter; 34.3% ± 7.7 cover) and leaf litter (21.3% ± 4.8). Bare soil without overhead vegetation cover—locations most susceptible to soil erosion—were 8.7% ± 2.1 of the soil surface and 10.9% ± 1.2 was bare soil protected by overhead canopy. Biological soil crusts were almost entirely composed of light cyanobacteria, which were fairly common (12.1% ± 4.9 cover), with dark cyanobacteria present at trace levels (1.5% ± 0.8; Figure 3-8). Lichen and moss were entirely absent across the substratum. Rocks (77-600 mm diameter) comprised only 2.4% ± 1.1 of soil cover, while bedrock was absent. We met or exceeded our expectations for statistical power (to detect a 10% absolute change in substrate cover with 90% power and 10% chance of false change error) for all substrate types, except gravel (minimum detectable change = 16%), which was highly variable across all plots.

3.3.6 Surface aggregate soil stability (301-EAST)

The high cover of gravel somewhat limited our ability to sample surface soil aggregates in 301-EAST, with 158 samples tested across the substratum. While surface soil aggregate stability was "somewhat unstable" (3.3 ± 0.3; see Table 2-2 for stability categories) across the entire substratum, samples collected on sites lacking an overhead canopy cover (n= 59) had a mean index of 2.8 ± 0.4 ("unstable" to "somewhat unstable).

3.3.7 Site and soil characterization (301-EAST)

Surface soil cores (10 cm deep) were collected on each plot to ascertain local soil conditions. The majority of the surface soils on substratum 301-EAST plots were (unsurprisingly), sandy clay loams or clay loams. Rock fragment content (fraction of soil sample >2 mm in diameter by mass) was highly variable and ranged from 2% to 52% with an average of 22%. Organic content averaged 1.2% across the samples, with a range of 0.3% to 2.0%. Bulk density ranged from 1.0 to 1.4 g/cm^3. Soils were

Table 3-4. Soil surface cover (% by category) for clay loam, non-rocky, foothills (301-EAST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. "MDC" = minimum detectable change. Highlighted values failed to meet our statistical power criteria.

Soil cover category	AVG	SE	MDC
Bare soil (<2 mm) - no overhead cover	8.67%	2.06%	5%
Bare soil (<2 mm) - under vegetation	10.83%	1.16%	5%
Total bare soil	19.51%	2.13%	5%
Light Cyano - no overhead cover	6.89%	2.91%	7%
Light Cyano - under vegetation	5.15%	2.12%	5%
Total light cyanobacteria	12.05%	4.94%	11%
Leaf litter - needles, leaves, and cones (fine fuels)	21.33%	4.76%	10%
Woody debris <0.062 cm in diameter (1-hour fuel)	4.77%	1.97%	5%
Woody debris 0.62-2.54 cm in diameter (10-hour fuel)	0.08%	0.05%	5%
Woody debris 2.54-7.62 cm in diameter (100-hour fuel)	0.00%	0.00%	5%
Woody debris >7.62 cm in diameter (1000-hour fuel)	0.08%	0.05%	5%
Total leaf litter and woody debris	26.25%	6.12%	13%
Dark Cyano	1.52%	0.82%	5%
Gravel: 2-76 mm	34.32%	7.74%	16%
Lichen	0.00%	0.00%	5%
Moss	0.00%	0.00%	5%
Rock: 77-600 mm	2.35%	1.11%	5%
Plant Base	3.90%	0.98%	5%
Bedrock	0.00%	0.00%	5%

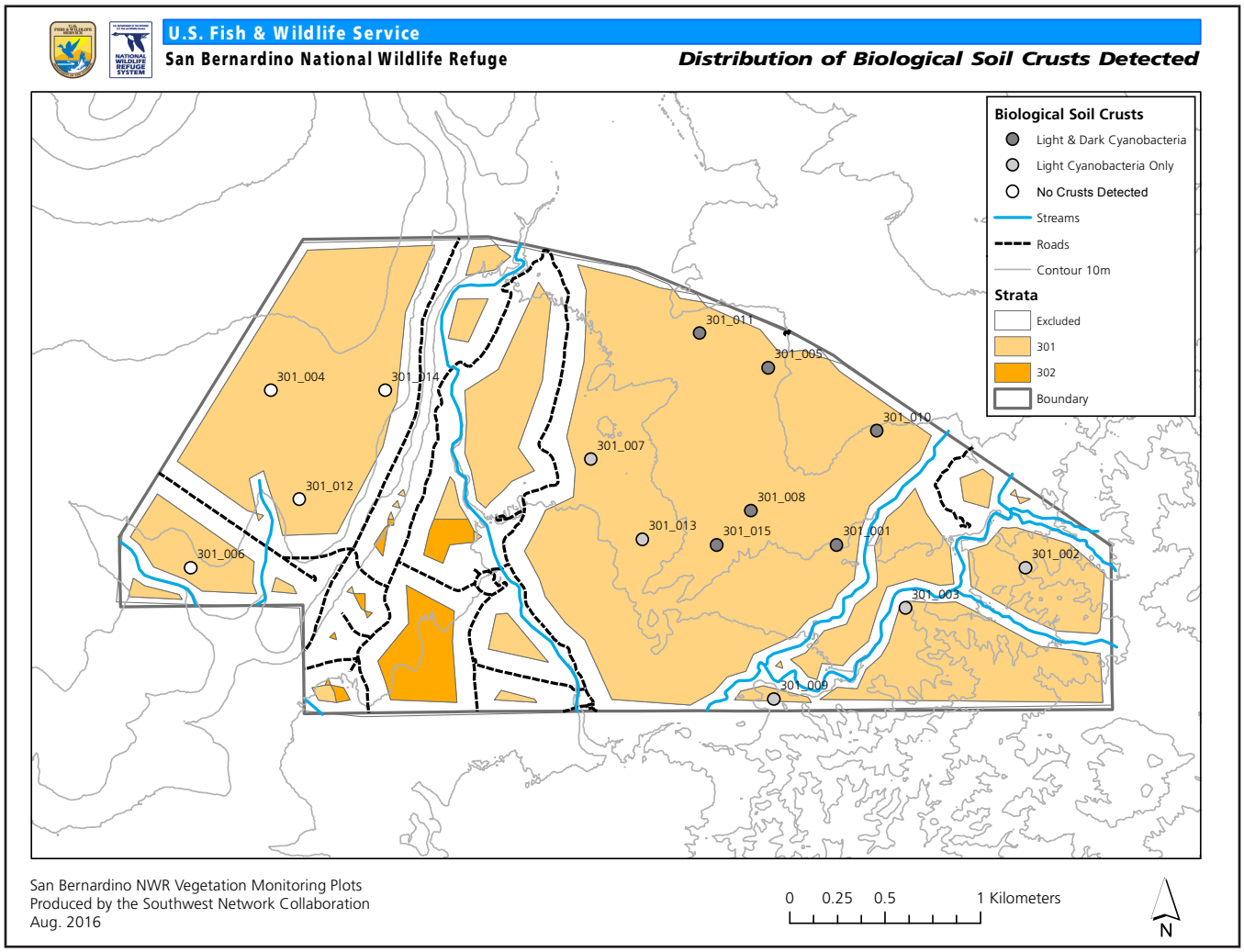


Figure 3-8. Distribution of biological soil crusts on monitoring plots, San Bernardino NWR, 2013.

slightly alkaline with an average pH of 7.8. An error in processing resulted in an inconclusive pH for plot 301_001. Plot-specific information is provided in Table 3-5.

Four plots had some degree of burrowing (Table 3-5). Several plots were crisscrossed with shallow rills, with these being accompanied by gullies on two plots. No other major erosion features were observed (see Appendix A and Table 3-5 for details).

3.3.8 Management assessment points (301-EAST)

Our results for sandy clay loam, non-rocky, foothills sites in the context of management assessment points (Section 2) suggest potential management concerns related to erosion potential, exotic plant colonization, and to a lesser extent, woody plant encroachment (Table 3-6). Both indicators of soil erosion breached assessment points, whereas one indicator of exotic plant dispersal—the extent of exotic plants across the 11 plots—greatly exceeded the assessment point threshold, as exotics were found on all but one plot, albeit at low cover (Table 3-6). It is important to note that 2 of the 3 exotic plant dispersal indicators can only be assessed after resampling. Mesquite cover in the subcanopy layer (0.5–2.0 m height) was the only woody plant encroachment indicator that touched the assessment point for that management issue. One fire hazard indicator approached the assessment point (annual plant cover: total plant cover).

Management assessment points for plant community resistance and resilience to disturbance, and exotic plant invasion were not approached by our results, suggesting that these resource issues are of secondary concern for sandy clay loam sites at San Bernardino NWR at this time.

Table 3-5. 2013 soil and site characterization for sandy clay loam, non-rocky, foothills (301-EAST substratum) monitoring sites (Elev. 3,701-4,500 ft), at San Bernardino NWR.

Character	Parameter	Plot 301_001	Plot 301_002	Plot 301_003	Plot 301_005	Plot 301_007	Plot 301_008	Plot 301_009	Plot 301_010	Plot 301_011	Plot 301_013	Plot 301_015
Slope	Average plot slope (%)	4	29	12.5	3	4.5	4	21	2	3	1.5	1.5
	Slope position	Toeslope	Backslope, Footslope	Footslope	Toeslope	Toeslope	Toeslope	Shoulder, Summit	Toeslope	Toeslope	Toeslope	Shoulder, Summit
Aspect	Degrees	206	332	246	248	322	142	1	171	169	291	10
	Description	SW	NW	SW	SW	NW	SE	N	S	SE	NW	N
Soil Lab Results	% Sand	74.16	58.16	72.16	64.16	28.16	52.16	58.16	60.16	62.16	59.16	58.8
	% Silt	10	16	12	14	30	22	22	18	18	19	21
	% Clay	15.84	25.84	15.84	21.84	41.84	25.84	19.84	21.84	19.84	21.84	20.2
	Soil Texture	Sandy Loam	Sandy Clay Loam	Sandy Loam	Sandy Clay Loam	Clay	Sandy Clay Loam	Sandy Loam	Sandy Clay Loam	Sandy Loam	Sandy Clay Loam	Sandy Clay Loam
	Rock Fragments (%)[a]	13	52	22	10	33	9	40	2	8	13	44
	Oven Dry Soil Bulk Density (g/cm^3)[b]	1.1	1.0	1.4	1.0	1.1	1.2	1.2	1.4	1.3	1.3	1.2
	Total Organic Content (%)	0.8	1.9	0.3	1.1	1.9	0.7	0.6	1.5	0.9	2.0	1.3
	Electrical Conductivity	209	261	183	257	373	241	361	278	242	314	251
	pH	not avail.	7.6	7.9	7.8	7.9	8	7.8	7.8	7.8	7.9	7.9
	Reserve Acidity	not avail.	0.2	0.3	0.3	0.3	0.4	0.1	0.2	0.2	0.4	0.4
Erosion Features	Tunneling	none	none	none	none	none	none	none	none	none	none	none
	Sheet	none	none	none	none	none	none	none	none	none	none	none
	Rill	<5%	6-25%	<5%	<5%	none	none	<5%	none	<5%	none	<5%
	Gully	none	6-25%	none	none	none	none	<5%	none	none	none	none
	Pedestals	<5%	none	none	6-25%	none	none	none	none	–[c]	none	none
	Terracettes	none	none	none	none	none	none	none	none	none	none	none
	Burrowing	none	none	none	none	none	none	<5%	6-25%	6-25%	6-25%	none
Landform	Description	Bajada	Drainage, Hill, Arroyo	Drainage	Bajada	Hill	Bajada	Drainage, Hill	Bajada	Bajada	Bajada	Bajada, Hill

[a]Rock Fragments (%) = fraction of soil >2 mm in diameter by mass

[b]Oven Dry Soil Bulk Density excludes the weight and volume of rock fragments in sample. Rock fragment density assumed to be 2.65 g/cm^3

[c] Missing data

Table 3-6. Vegetation and soils data for sandy clay loam, non-rocky, foothills (301-EAST substratum) monitoring sites in the context of management assessment points, San Bernardino NWR. Field layer = <0.5 m; subcanopy layer = 0.5–2.0 m; canopy layer = >2.0 m.

Issue	Management Assessment Point	Mean ± SE	Point met?	Recommendation
Erosion Hazard	Exposed bare ground (with no overhead vegetation) >10% cover[a]	8.67% ± 2.1[a]	yes	Meet and discuss
	Surface soil aggregate stability (with no overhead canopy) < Class 3[a]	2.8 ± 0.4[a]	yes	Meet and discuss
Plant Community Resistance and Resilience	Change in any lifeform cover >20%	n/a	[b]baseline; n/a	Continue monitoring
	Change in any perennial species cover >20%	n/a	[b]baseline; n/a	Continue monitoring.
	Foliar cover of perennial grasses <10% (field layer)	17.96% ± 3.52	no	Continue monitoring
	Cover of dead plants in any canopy layer >10%	field layer: 3.3% ± 1.6; subcanopy layer: 0.42% ± 0.24; canopy layer: 0.04% ± 0.04	no	Continue monitoring
Woody plant encroachment	Tree and shrub cover >30% (subcanopy layer)	25.42%±2.83	no	Continue monitoring
	Mesquite cover >10% (field layer)	5.76% ± 1.91	no	Continue monitoring
	Mesquite Cover >10% (subcanopy layer)[c]	9.51%±3.32[c]	yes	Warning to managers
Exotic plant dispersal	Extent of exotic plants >50%[a]	91% (10 of 11 plots)[a]	yes	Meet and discuss
	New exotic species (annual or perennial) on any plot	n/a	[b]baseline; n/a	Continue monitoring.
	Existing exotic species detected on any new plot	n/a	[b]baseline; n/a	Continue monitoring.
Exotic plant invasion	Total cover of exotic plants >5% (field layer)	1.40% ± 0.91	no	Continue monitoring
	Exotic plant cover: total plant cover >1:5 (20%)	2.65%	no	Continue monitoring
	Buffelgrass cover >1% (field layer)	0%	no	Continue monitoring
	Lehmann lovegrass cover >10% (field layer)	0.30% ± 0.30	no	Continue monitoring
Fire Hazard	Leaf litter and woody debris >75%	26.3% ± 6.1	no	Continue monitoring
	Annual plant cover: total plant cover >1:5 (20%)[c]	26.38%[c]	yes	Warning to managers Note: MDC = 13%
	Dead plants cover >15% (subcanopy layer)	0.42 ± 0.24	no	Continue monitoring

[a]Meet and discuss. Parameter exceeds assessment point (in red).

[b]2013 represents the first year of terrestrial vegetation and soils monitoring, assessments of relevant MAPs can be completed after future sampling efforts.

[c]Warning to management. Parameter approaches or is at assessment point (in yellow).

3.4 Non-rocky foothills stratum (claypan substratum 301-WEST)

Sites in the claypan, non-rocky (<35% surface soil rock fragments), foothills (1,128-1,372 m elevation) substratum (301-WEST) were all located on the western edge of the refuge in elevations slightly higher than those of substratum 301-EAST. This substratum is dominated by a claypan soil texture that begins just below the surface of the soil and extends about 80 cm deep and comprises about 24% (138 hectares) of the terrestrial uplands in San Bernardino NWR. Four of the 15 sites we sampled were in this substratum. (Figure 3-3).

3.4.1 Vegetation formations, lifeforms, and perennial plant diversity (301-WEST)

The claypan, non-rocky, foothills sites were primarily annual grass/tobosagrass grasslands. Dominant lifeforms in substratum 301-WEST were annual grasses and forbs in the field layer (Figure 3-9). There was considerably more total vegetation cover in the field layer (<0.5 m height) than in the sparse subcanopy (0.5–2.0 m) layer. The canopy layer (>2.0 m) was nearly nonexistent (Figure 3-9). The greatest lifeform diversity was found in the field layer, with perennial and especially annual grasses (perennial and annual) and annual forbs dominating the height class (Figure 3-6). The low-cover subcanopy layer was dominated by shrubs (Figure 3-9).

The average similarity within this substrata was 69.2% (SIMPER). Within-plot species richness of perennial plants (S_{plot}) on claypan, non-rocky, foothills sites was extremely low (3.0 ± 0.7). Taxonomic distinctness (Δ^+) was 95.0 ± 5.0.

3.4.2 Cover and extent of perennial plant species (301-WEST)

Perennial species were subdominant on claypan, non-rocky, foothills sites, with only tobosagrass (8.4% ± 2.7) in the field layer (<0.5 m height) and the shrub, viscid acacia (*Vachellia vernicosa*; 2.5% ± 0.7) in the subcanopy (0.5–2.0 m) being detected commonly (Table 3-7). Trace amounts of the warm-season perennial, spider grass (*Aristida ternipes*; 0.31% cover ± 0.31) and seedlings and sprouts of the tree, velvet mesquite (0.21% cover ± 0.21) were observed in the field layer (<0.5 m height; Table 3-7).

Of the four perennial species found on transects, only tobosagrass and viscid acacia were widespread, detected on all four plots. Velvet mesquite and spidergrass were detected on transects in only one plot each (Table 3-7) and only in the field layer, however velvet mesquite was detected on subplots for a total extent of three plots. Viscid acacia and spidergrass were unique to substratum 301-WEST in San Bernardino NWR.



Grasslands in the claypan, non-rocky foothills (substratum 301-WEST). USFWS

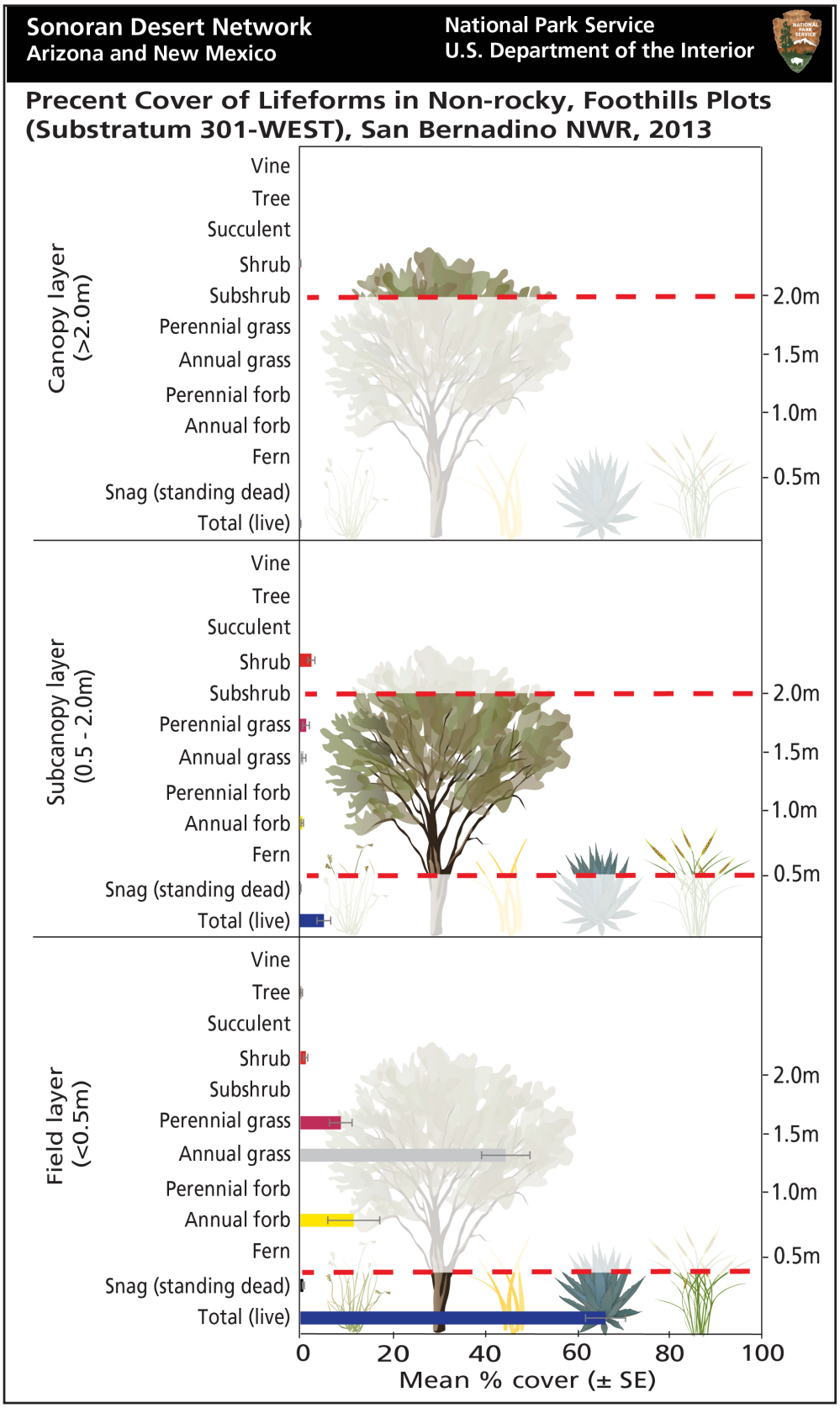


Figure 3-9. Lifeform cover in terrestrial vegetation monitoring plots on claypan, foothills (3,701-4,500 ft) sites with non-rocky soils (Substratum 301-WEST) at San Bernardino NWR, 2013.

Table 3-7. Cover values (%) for perennial and non-native annual species (by lifeform) measured in the field (<0.5 m stature), subcanopy (0.5-2.0 m), and canopy (>2.0 m) layers of claypan, non-rocky, foothills (301-WEST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. "AVG" = average on transects, "SE" = standard error, "MDC" = minimum detectable change (% cover), "Extent" is the number of plots in which the species was detected (out of 4) on transects or subplots.

			Field			Subcanopy			Canopy			
Lifeform	**Species**	**Common Name**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**AVG**	**SE**	**MDC**	**Extent**
Tree	*Prosopis velutina*	velvet mesquite	0.21%	0.21%	5.00%	–	–	–	–	–	–	3
Shrub	*Vachellia vernicosa*	viscid acacia	1.15%	0.43%	5.00%	2.50%	0.74%	5.00%	0.11%	0.11%	5.00%	4
Grass	*Aristida ternipes*	spidergrass	0.31%	0.31%	5.00%	–	–	–	–	–	–	1
	Hilaria mutica	tobosagrass	8.44%	2.72%	6.00%	1.35%	0.71%	5.00%	–	–	–	4
Vine	–	–	–	–	–	–	–	–	–	–	–	–
Tree	–	–	0.21%	0.21%	5.00%	–	–	–	–	–	–	–
Succulent	–	–	–	–	–	–	–	–	–	–	–	–
Shrub	–	–	1.15%	0.43%	5.00%	2.50%	0.74%	5.00%	0.11%	0.11%	5.00%	–
Subshrub	–	–	–	–	–	–	–	–	–	–	–	–
Perennial Grass	–	–	8.75%	2.45%	6.00%	1.35%	0.71%	5.00%	–	–	–	–
Annual Grass	–	–	44.59%[a]	5.26%	11.00%[a]	0.84%	0.45%	5.00%	–	–	–	–
Perennial Forb	–	–	–	–	–	–	–	–	–	–	–	–
Annual Forb	–	–	11.56%	5.65%	12.00%	0.52%	0.26%	5.00%	–	–	–	–
Fern	–	–	–	–	–	–	–	–	–	–	–	–
Snag	–	–	0.63%	0.21%	5.00%	0.11%	0.11%	5.00%	–	–	–	–
Total (live)	–	–	66.25%	4.33%	9.00%	5.21%	1.50%	5.00%	0.11%	0.11%	5.00%	–
Annuals	–	–	56.15%	3.81%	8.00%	1.36%	0.43%	5.00%	–	–	–	–
Exotics	–	–	–	–	–	–	–	–	–	–	–	–
Exotics: total	–	–	–	–	–	–	–	–	–	–	–	–
Annuals: total	–	–	84.80%	–	–	26.17%	–	–	–	–	–	–

[a] MDC >10% indicates the species or parameter failed to meet our statistical power criteria (highlighted)

Table 3-8. Within-plot frequency (%), standard error (SE), and extent (out of 11 plots) of uncommon plant species (found only on subplots and not on transects) sampled on sandy clay loam, non-rocky, foothills (301-EAST substratum) on San Bernardino NWR.

Lifeform	Species	Common Name	Within-plot frequency	SE	Extent
Succulent	*Cylindropuntia spinosior*	walkingstick cactus	10%	10%	1
Graminoid	*Hopia obtusa*	vine mesquite	10%	10%	1

3.4.3 Frequency and extent of uncommon plant species (301-WEST)

Only two uncommon plant species, walkingstick cactus and the grass, vine mesquite (*Hopia obtusa*) were detected on the frequency subplots of claypan monitoring locations, each with a within-plot frequency of 10%. However, both were only detected on one of the four monitoring plots (Table 3-8). As with the cover results, the detection of only two species on subplots across this substratum contributes to the extremely low perennial plant diversity within this substratum.

3.4.4 Cover and frequency of exotic species (301-WEST)

In contrast to the sandy clay loam, non-rocky foothills of substratum 301-EAST, no exotic species were detected on any of the plots in the claypan, non-rocky foothills of substratum 301-WEST (Table 3-3). Further discussion of exotic species, or in this case the lack thereof, at San Bernardino NWR can be found in Section 4.

3.4.5 Soil cover and biological soil crusts (301-WEST)

Soil cover (Table 3-9) on the claypan, non-rocky foothills sites was dominated by bare soil (45.7% ± 7.9) and gravel (2-76 mm diameter; 30.3% ± 4.4). Bare soil without overhead vegetative cover—the substrate most susceptible to erosion—comprised 14.5% ± 3.1 of total soil cover. Biological soil crusts were completely absent along the line-point intercept transects on this substratum. Rock (77-600mm diameter), leaf litter, and plant base made up the balance of soil substrate cover for clay pan sites. As on clay-loam sites, bedrock was absent (Table 3-9). We met or exceeded our expectations for statistical power (to detect a 10% absolute change in substrate cover with 90% power and 10% chance of false change error) for all substrate types.

3.4.6 Soil stability (301-WEST)

Surface soil aggregate stability was "unstable" (2.5 ± 0.3; see Table 2-2 for stability categories) across the claypan, non-rocky, foothills substratum. Only 1.4% ± 1.4 of the samples collected across the entire substratum were ranked as "very stable." Samples collected under vegetation canopies (n = 39) had a mean stability rating of 2.8 ± 0.2 ("unstable" to "somewhat unstable"). Those without overhead canopy cover (n = 33) had a mean stability rating of 2.3 ± 0.3 ("unstable").

3.4.7 Site and soil characterization (301-WEST)

Surface soil cores (10 cm deep) were collected on each plot to ascertain local soil conditions. Three of the four plots were clays, where one (301_004) was a clay loam (Table 3-10). The lone clay loam plot had much higher electrical conductance and soil organic matter (though still low from an absolute perspective), and much lower rock fragment content and pH (slightly acidic) as compared with the other clay pan plots. (Table 3-10).

Burrowing was the most common of erosion feature on the claypan plots, although at low absolute levels (>5%; see Appendix A and Table 3-10 for details).

3.4.8 Management assessment points (301-WEST)

Results for claypan, non-rocky, foothills substratum sites in the context of management assessment points (Section 2) indicate one primary and two secondary issues for management consideration (Table 3-11). Both indicators of soil erosion hazard (exposed bare soil and surface soil aggreagate stability) breached assessment point thresholds, suggesting that accelerated soil erosion potential on claypan sites is an area of potential management concern. Low perennial grass cover raises concern as to plant community resistance and resilience on claypan sites, although other indicators of this issue did not violate assessment point thresholds. The unusually high

Table 3-9. Soil surface cover (% by category) for claypan, non-rocky, foothills (301-WEST substratum) terrestrial vegetation and soils plots at San Bernardino NWR, 2013. "MDC" = minimum detectable change. Highlighted values failed to meet our statistical power criteria.

Soil cover category	AVG	SE	MDC
Bare soil (<2 mm) - no overhead cover	14.48%	3.08%	5%
Bare soil (<2 mm) - under vegetation	31.25%	7.01%	9%
Total bare soil	45.73%	7.9%	10%
Light Cyano - no overhead cover	0.00%	0.00%	5%
Light Cyano - under vegetation	0.00%	0.00%	5%
Total light cyanobacteria	0.00%	0.00%	5%
Leaf litter - needles, leaves, and cones (fine fuels)	10.31%	3.48%	5%
Woody debris <0.062 cm in diameter (1-hour fuel)	1.25%	0.29%	5%
Woody debris 0.62-2.54 cm in diameter (10-hour fuel)	0.11%	0.11%	5%
Woody debris 2.54-7.62 cm in diameter (100-hour fuel)	0.00%	0.00%	5%
Woody debris >7.62 cm in diameter (1000-hour fuel)	0.00%	0.00%	5%
Total leaf litter and woody debris	11.67%	3.64%	5%
Dark Cyano	0.00%	0.00%	5%
Gravel: 2-76 mm	30.31%	4.37%	6%
Lichen	0.00%	0.00%	5%
Moss	0.00%	0.00%	5%
Rock: 77-600 mm	9.48%	2.38%	5%
Plant Base	2.82%	0.43%	5%
Bedrock	0.00%	0.00%	5%

proportion of annuals to total plant cover on clay pan sites greatly exceeded the assessment point threshold for fire hazard, although other indicators (leaf litter/ woody debris and dead plant cover) of fire hazard did not approach their respective management assessment points.

Management assessment points for exotic plant dispersal, invasion, and woody plant encroachment were not approached by our results, suggesting that these resource issues are of lesser concern for clay-pan sites at San Bernardino NWR at this time (Table 3-11).

Table 3-10. 2013 soil and site characterization for claypan, non-rocky, foothills (301-WEST substratum) monitoring sites (Elev. 3,701-4,500 ft), at San Bernardino NWR.

Character	Parameter	Plot 301_004	Plot 301_006	Plot 301_012	Plot 301_014
Slope	Average plot slope (%)	1	3	2.5	2.5
	Slope position	Toeslope	Summit	N/A	Toeslope
Aspect	Degrees	198	220	268	130
	Description	SW	SW	W	SE
Soil Lab Results	% Sand	32.16	34.16	28.16	26.16
	% Silt	30	24	22	26
	% Clay	37.84	41.84	49.84	47.84
	Soil Texture	Clay Loam	Clay	Clay	Clay
	Rock Fragments (%)[a]	4	27	17	18
	Oven Dry Soil Bulk Density (g/cm^3)[b]	1.1	0.9	0.7	1.3
	Total Organic Content (%)	2.8	1.4	1.9	1.0
	Electrical Conductivity	604	278	387	216
	pH	5.7	7.8	7.2	7.1
	Reserve Acidity	0.2	0.3	0.2	0.2
Erosion Features	Tunneling	none	none	none	none
	Sheet	none	–[c]	none	none
	Rill	none	none	none	none
	Gully	none	none	none	none
	Pedestals	none	none	none	none
	Terracettes	none	none	none	none
	Burrowing	none	<5%	<5%	<5%
Landform	Description	Bajada	Hill	Bajada	Bajada

[a]Rock Fragments (%) = fraction of soil >2 mm in diameter by mass

[b]Oven Dry Soil Bulk Density excludes the weight and volume of rock fragments in sample. Rock fragment density assumed to be 2.65 g/cm^3

[c]Missing data

Table 3-11. Vegetation and soils data for claypan, non-rocky, foothills (301-WEST substratum) monitoring sites in the context of management assessment points, San Bernardino National Wildlife Refuge. Field layer = <0.5 m; subcanopy layer = 0.5–2.0 m; canopy layer = >2.0 m.

Issue	Management Assessment Point	Mean ± SE	Point met?	Recommendation
Erosion Hazard	Exposed bare ground (with no overhead vegetation) is >10% cover[a]	14.48% ± 3.08[a]	yes	Meet and discuss
	Surface soil aggregate stability (with no overhead canopy) < Class 3[a]	2.3 ± 0.3[a]	yes	Meet and discuss
Plant Community Resistance and Resilience	Change in any lifeform cover >20%	n/a	[b]baseline; n/a	Continue monitoring
	Change in any perennial species cover >20%	n/a	[b]baseline; n/a	Continue monitoring
	Foliar cover of perennial grasses <10% (field layer)[c]	8.75% ± 2.45[c]	yes	Warning to management
	Cover of dead plants in any canopy layer >10%	field layer: 0.63% ± 0.21; subcanopy layer: 0.11% ± 0.11; canopy layer: 0%	no	Continue monitoring
Woody Plant Encroachment	Tree and shrub cover >30% (subcanopy layer)	2.5%±0.8	no	Continue monitoring
	Mesquite cover >10% (field layer)	0.2% ± 0.2	no	Continue monitoring
	Mesquite Cover >10% (subcanopy layer)	0%	no	Continue monitoring
Exotic plant dispersal	Extent of exotic plants >50%	0% (0/4 plots)	no	Continue monitoring
	New exotic species (annual or perennial) on any plot	n/a	[b]baseline; n/a	Continue monitoring
	Existing exotic species detected on any new plot	n/a	[b]baseline; n/a	Continue monitoring
Exotic plant invasion	Total cover of exotic plants >5% (field layer)	0%	no	Continue monitoring
	Exotic plant cover: total plant cover >1:5 (20%)	0%	no	Continue monitoring
	buffelgrass cover >1% (field layer)	0%	no	Continue monitoring
	lehmann lovegrass cover >10% (field layer)	0%	no	Continue monitoring
Fire Hazard	Leaf litter and woody debris >75%	11.67% ± 3.64	no	Continue monitoring
	Annual plant cover: total plant cover >1:5 (20%)[c]	84.80%[c]	yes	Warning to management
	Dead plant cover >15% (subcanopy layer)	0.11 ± 0.11	no	Continue monitoring

[a]Meet and discuss. Parameter exceeds assessment point (in red).

[b]2013 represents the first year of terrestrial vegetation and soils monitoring, assessments of relevant MAPs can be completed after future sampling efforts.

[c]Warning to management. Parameter approaches or is at assessment point (in yellow).

4 Discussion

4.1 Sacaton grasslands and savannas: linking riparian corridors and uplands at San Bernardino NWR

Big sacaton/mixed shrub savannas (Figure 4-1) characterized the clay loam sites on the terraces flanking the Blackwater Draw and Hay Hollow drainages, extending to the low rolling hills in the center of the refuge (301-EAST). These sites occupied about 45% of the refuge (301-EAST), and included areas that were recovering from past agricultural and pastoral uses, as well as more arid (and less disturbed) locations between the two riparian areas. Vegetation within this stratum was arranged along a soil moisture gradient from the lush riparian corridors to the semi-arid uplands dividing Blackwater Draw from Hay Hollow.

A diverse mix of native shrubs such as creosote bush (*Larrea tridentata*), American tarwort (*Flourensia cernua*), mariola (*Parthenium incanum*), and four-wing saltbush (*Atriplex canescens*) in a matrix of tobosagrass (*Hilaria mutica*) and other native bunchgrasses comprised the shrub savannas of the rolling hills between the two drainages (Figure 4-2). These slightly elevated and drier locations contained vegetation characteristic of semi-desert grasslands and savannas of the Apache Highlands ecoregion (Gori and Enquist 2003). Although most abundant on this drier end of the soil moisture gradient within the refuge, these species were common on the more mesic sites closer to the drainages as well (Table 3-1).

Relatively moist terrace locations closer to the drainages were compositionally similar to the drier end of the gradient (Figure 4-3), but also supported patches of big sacaton (*Sporobolus wrightii*) and small velvet mesquite (*Proposis velutina*) trees interspersed with sparse areas of weedy natives and a few non-native grasses and forbs, reflecting a degree of recovery from past farming activities. Linking the lush riparian forests and mesquite bosques to semi-desert upland vegetation, these relatively productive sites have great potential to serve as habitat for focal wildlife species, and mitigate flooding and erosion potential along the riparian corridors.

Perennial plant and lifeform diversity throughout the clay-loam stratum were relatively high (Figure 4-4), although native bunchgrass composition—dominated by big sacaton and tobosagrass—was less diverse than we have observed on similar sites elsewhere in the region (e.g., Hubbard et al. 2010). Although recovery from past land use may be a factor in the relatively low perennial grass diversity (and high diversity of shrubs), sacaton grasslands tend to be lower diversity as compared to other semi-desert grassland ecosystems (Gori and Enquist 2003).



Figure 4-1. Example of the big sacaton/mixed shrub savanna (301-EAST) found on non-rocky (<35% surface soil rocks) sites in central and eastern portions of San Bernardino NWR. USFWS

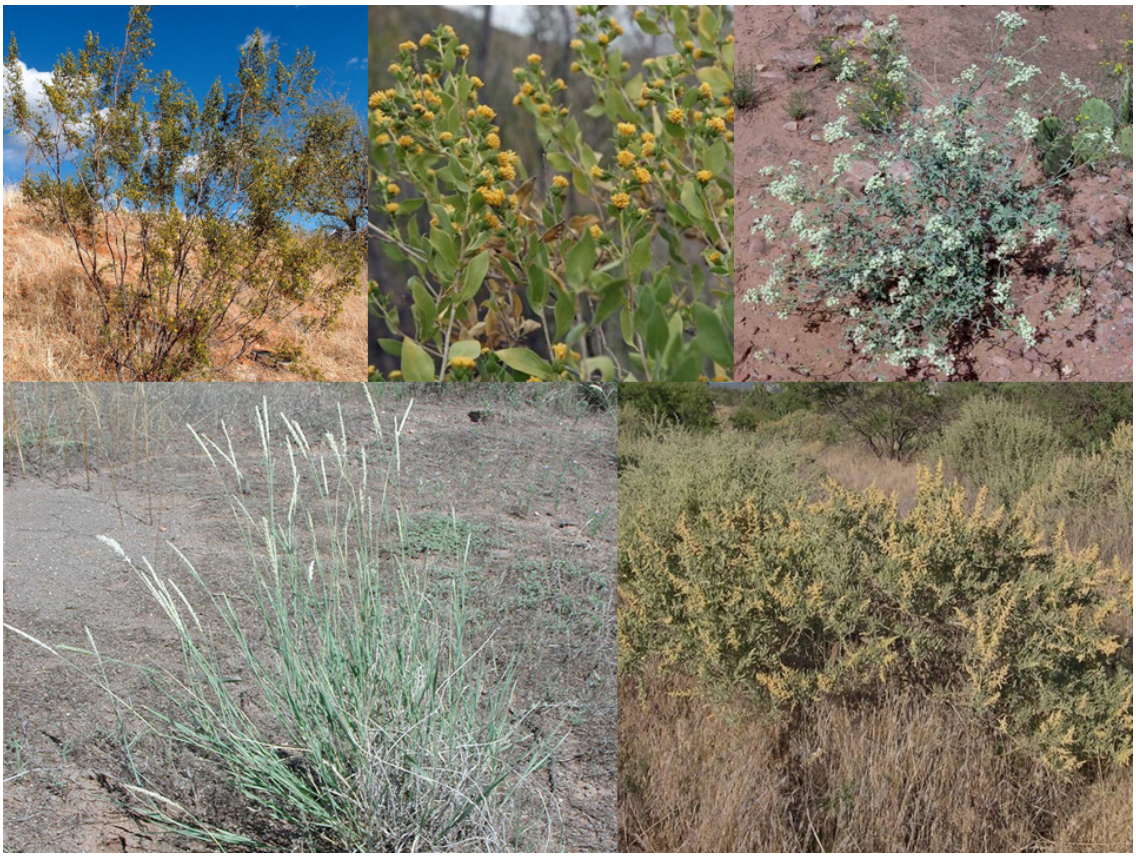


Figure 4-2. Dominant species on the drier end of the 301-EAST stratum (clockwise from upper left) at San Bernardino NWR, 2013: creosote bush (*Larrea tridentata*), American tarwort (*Flourensia cernua*), four-wing saltbush (*Atriplex canescens*), mariola (*Parthenium incanum*), and tobosagrass (*Hilaria mutica*). CARNAHAN/MAKINGS/LICHER/USFWS

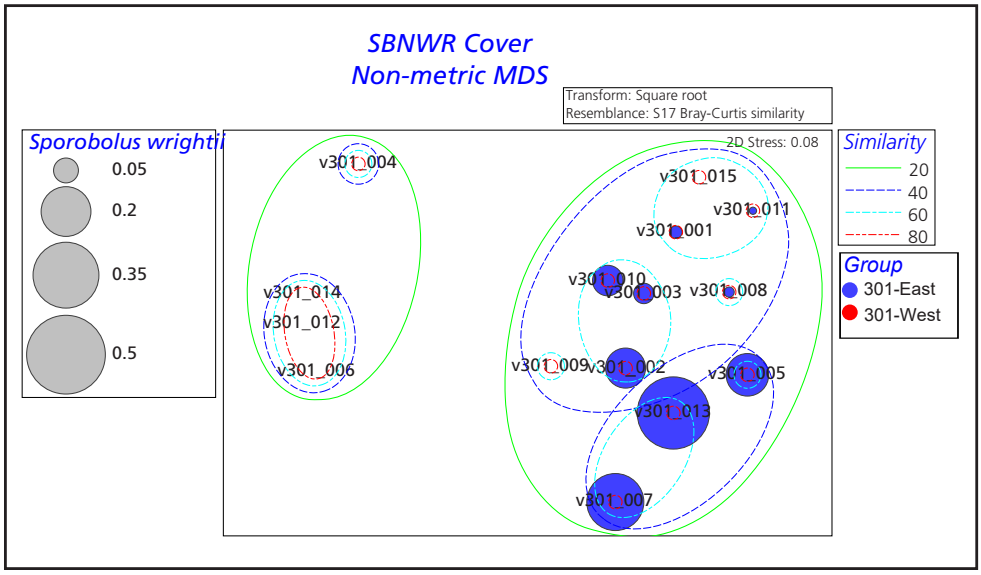


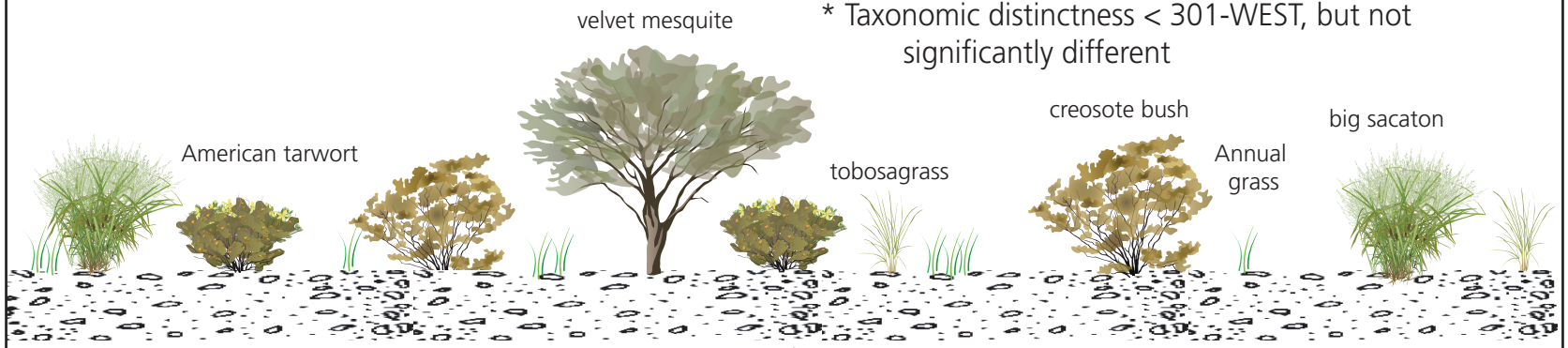
Figure 4-3. Non-metric multi-dimensional scaling (MDS) of terrestrial upland vegetation, San Bernardino NWR, 2013. Bubble size for each location represents the cover (%) of big sacaton (*Sporobolus wrightii*). MDS follows Figure 3-2.

Sandy Clay Loam, Non-Rocky, Foothills (301-EAST)

Big Sacaton, Mixed Shrub Savanna

Average similarity: 46.9%
Perennial species richness: 11.5 ± 1.3
Taxonomic distinctness: 92.4 ± 1.4

* Non- rocky soils (< 35% surface soil rock fragments)
* 301 stratum = 60% of San Bernardino NWR; 301-EAST substratum = 76% of 301 stratum
* More perennial species than in 301-WEST substratum
* Taxonomic distinctness < 301-WEST, but not significantly different



	Point	
Plant Community Resilience	<10%	Perenn. grass cover (field): 18.0%±3.5
	>10%	Dead plant cover: 3.3%± 1.6 (field); 0.4%±0.2 (subcanopy); 0.04%±0.04 (canopy)
Woody Plant Encroachment	>30%	Tree + shrub cover (subcanopy): 25.4%±2.8
	>10%	Mesquite cover: 5.8%±1.9 (field); 9.5%±3.3 (subcanopy)
Erosion Hazard	>10%	Exposed bare ground (no overhead vegetation): 8.7%±2.1
	<class 3	Soil surface stability: 2.8±0.4

	Point	
Exotic Plant Dispersal/ Invasion	>50%	Exotic plant extent: 91% (10/11 plots)
	>5%	Exotic total cover (field): 1.4%±0.9
	>20%	Exotic: total cover (field): 2.7%
	>1%	Buffelgrass cover (field): 0%
	>10%	Lehmann lovegrass cover (field): 0.3%±0.3
Fire Hazard	>75%	Leaf litter and woody debris: 26.3% ±6.1
	>20%	Annual: total cover: 26.4%
	>15%	Dead plant cover (subcanopy): 0.4%±0.2

Figure 4-4. Vegetation and soils data for sandy clay loam, non-rocky, foothills (301-EAST) monitoring sites in the context of management assessment points, San Bernardino NWR, 2013.

Sustaining sacaton grasslands is a widely held management goal in the American Southwest, and a local focus at San Bernardino NWR (USFWS 2010). Humphrey (1960) estimated that less than 5% of the presettlement distribution of this iconic riparian grassland type persisted into the mid-20th century, due to a combination of groundwater declines and surface water diversions, conversion to cropland, overuse by livestock, and invasion by mesquite from adjacent mesquite bosque (riparian woodlands; Cox et al. 1983).

Our data suggest a degree of mesquite invasion into sacaton grasslands at San Bernardino NWR, closely following the "Sacaton-Mesquite (C1)" vegetation types described for nearby Las Cienegas National Conservation Area (Tiller et al. 2012). Tiller and others (2012) provide detailed restoration recommendations for mediating mesquite encroachment into sacaton grasslands, including spot treatment of individual mesquites with herbicide followed by prescribed summer burning on 7–10 year intervals.

Based on the habitat management priorities (USFWS 2010) and the restoration potential for sacaton grasslands and savannas within the central and eastern portions of the refuge, we recommend managers focus on mesquite reduction within this important native plant community, and engage partners at the Bureau of Land Management and Nature Conservancy (Arizona) in developing effective management strategies.

4.2 Annual grasslands: claypans or land use history?

Annual grass/tobosagrass grasslands (Figure 4-5) were found on shallow clay pan sites on the plateau west of San Bernardino cienega (301-WEST). Restricted to only about 15% of the refuge, these sites were characterized by very low perennial plant diversity (Figure 4-6)—comparable to that of the most arid valley-bottom locations that we have sampled at Organ Pipe Cactus National Monument and Cabeza Prieta NWR (unpublished data).

Although past livestock grazing and other land management practices may have influenced the composition of these habitats, we speculate that the most likely causal factor is the occurrence of a thick clay pan at shallow soil depths. This dense clay layer likely reduces infiltration and restricts root growth, yielding soil moisture conditions that are effectively more xeric than predicted by annual precipitation, and perhaps coupling water availability more directly to particular rainfall events. Additional research, including greenhouse studies or in situ soil moisture experiments could determine the importance and particular role of this clay pan in structuring vegetation on the western plateau of the refuge. See a comparison of the two substrata (301-EAST and 301-WEST) in Figure 4-7.



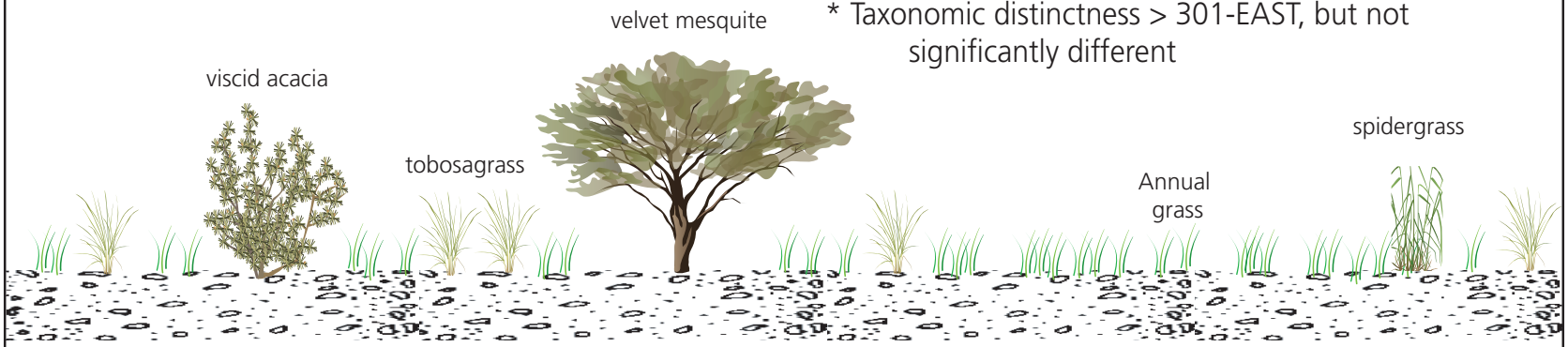
Figure 4-5. Example of the annual grass/tobosagrass grasslands (301-WEST) found on non-rocky (<35% surface soil rocks) sites in western portions of San Bernardino NWR.

Claypan, Non-Rocky, Foothills (301-WEST)

Annual Grass/Tobosagrass Grassland

Average similarity: 69.2%
Perennial species richness: 3.0 ± 0.7
Taxonomic distinctness: 95.0 ± 5.0

* Non- rocky soils (< 35% surface soil rock fragments)
* 301 stratum = 60% of San Bernardino NWR; 301-WEST substratum = 24% of 301 stratum
* Fewer perennial species than in 301-EAST substratum
* Taxonomic distinctness > 301-EAST, but not significantly different



	Point	
Plant Community Resilience	<10%	Perenn. grass cover (field): 8.8%±2.5
	>10%	Dead plant cover: 0.6%± 0.2 (field); 0.1%±0.1 (subcanopy); 0% (canopy)
Woody Plant En-croachment	>30%	Tree + shrub cover (subcanopy): 2.5%±0.8
	>10%	Mesquite cover: 0.2%±0.2 (field); 0% (subcanopy)
Erosion Hazard	>10%	Exposed bare ground (no overhead vegetation): 14.5%±3.1
	<class 3	Soil surface stability: 2.3±0.3

	Point	
Exotic Plant Dispersal/ Invasion	>50%	Exotic plant extent: 0% (0/4 plots)
	>5%	Exotic total cover (field): 0%
	>20%	Exotic: total cover (field): 0%
	>1%	Buffelgrass cover (field): 0%
	>10%	Lehmann lovegrass cover (field): 0%
Fire Hazard	>75%	Leaf litter and woody debris: 11.7% ±3.6
	>20%	Annual: total cover: 84.8%
	>15%	Dead plant cover (subcanopy): 0.1%±0.1

Figure 4-6. Vegetation and soils data for sandy claypan, non-rocky, foothills (301-WEST) monitoring sites in the context of management assessment points, San Bernardino NWR, 2013.

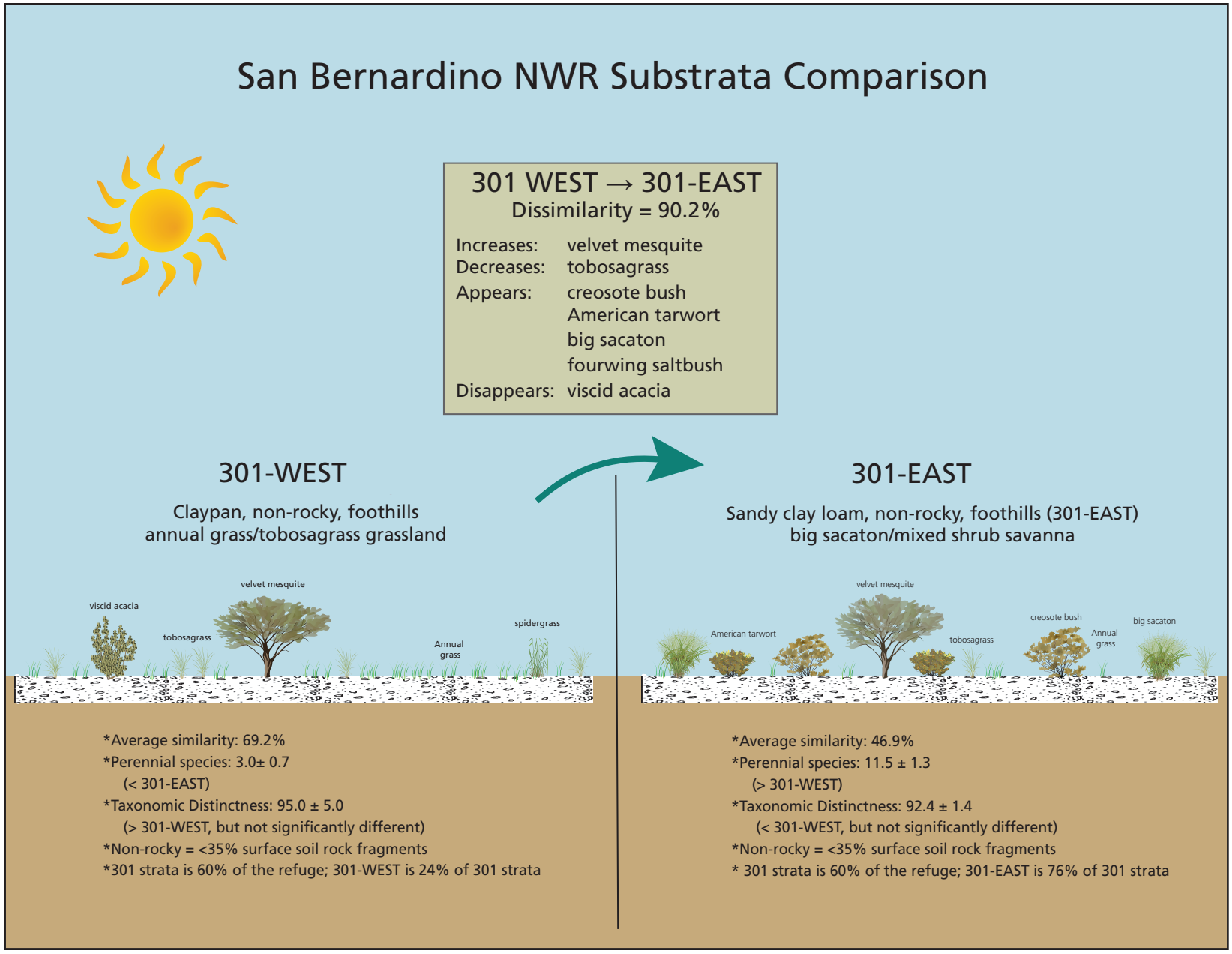


Figure 4.-7. Summary of the two primary terrestrial vegetation types at San Bernardino NWR, 2013: sandy clay loam, non-rocky, foothills (301-EAST) and claypan, non-rocky foothills (301-WEST). See results for details.

4.3 Substantial erosion potential throughout uplands

As discussed in section 1.4.5, the potential for accelerated soil erosion on a site is a combination of static and dynamic factors (Herrick et al. 2005a). We focus on dynamic factors—the amount and type of soil cover, and soil aggregate stability—that might be influenced by management.

4.3.1 Soil armor: some weak links

The total amount of soil substrate cover is the single most important dynamic factor affecting water erosion (Herrick et al. 2005a). Most soil loss occurs in "unprotected" areas (=bare soils without vegetative cover; Davenport et al. 1998), whereas rock, gravel, vegetation, biological soil crusts and even plant debris (litter and duff) can "armor" the soil (Figure 4-8), slowing the flow of water and permitting increased infiltration of water into the soil profile (Belnap et al. 2007).

Our data indicate that soil surfaces throughout both vegetation types at San Bernardino NWR are somewhat poorly armored against soil erosion (Figures 4-4 and 4-6). This was particularly true on the annual grasslands located on the western portion of the refuge (301-WEST), where exposed bare soil was much higher than our management assessment point thresholds (Figure 4-6), despite sampling during a year with above normal precipitation (Figure 1-3). Even on the more productive eastern savannas, exposed bare soil was still substantial—within the standard error of our assessment point—indicating a substantial degree of susceptibility to soil erosion (Figure 4-4).

For raindrops penetrating the canopies and overland flow, soil substrate under canopies provides the second line of defense against soil loss (Figure 4-8). Even on these more protected soils, the story is similar; poor resistance to soil erosion on the western annual grasslands, and somewhat more resistance on the eastern savannas. Bare soil dominated surface soil substrates of the annual grasslands (Table 3-9). Although most bare soil was protected by overhead canopies (Table 3-9), the dominance of annual grasses—ephemeral lifeforms that vary greatly by seasonal precipitation—suggests the potential for dramatic increases in unprotected soils during drought or disturbance, such as fire or herbivory (Figure 3-8). Soils beneath canopies on the shrub savannas on the eastern refuge lands (301-EAST) were somewhat better armored, with substrates dominated by gravels and leaf litter—a substrate type that varies greatly with drought and disturbance (Table 3-4).

4.3.2 Beneath the armor: unstable surface soil aggregates

The third line of resistance to soil erosion is surface aggregate stability, an indicator of soil structure and the potential for erosion of exposed soil (Figure 4-8). Surface soil aggregate stability ranged from "very unstable" to "unstable" across the terrestrial upland monitoring sites, indicating a widespread susceptibility to raindrop impact and overland flow on exposed soil surfaces, and violating the management assessment points for both terrestrial vegetation types (Tables 3-6 and 3-11).

As San Bernardino NWR is largely free of widespread land uses that would diminish soil aggregate stability, it is likely that this lower than expected stability is due to the inherent soil parent material properties and geology of the site, rather than any specific management issue. However, disturbance and management actions can interact with these relatively unstable soil conditions to produce dramatic soil loss in upland ecosystems of the refuge. We recommend careful consideration of management actions as they pertain to potential erosion, and suggest completing a detailed soil inventory and erosion hazard assessment for the refuge to better assess this potential issue for refuge management.

4.4 Erosion in uplands: implications for aquatic habitats at San Bernardino NWR

Soil erosion in terrestrial uplands can directly impact management goals for terrestrial uplands at San Bernardino NWR, such as impacting grassland habitat for various focal wildlife species (USFWS 2010). Reduced water holding capacity, disrupted nutrient cycles, and decreased soil organic matter and soil depth strongly govern vegetation productivity, structure, and composition in these semi-arid ecosystems (Pimental and Kounang 1998).

Sediment and nutrient transport from upland areas can also have important consequences for the aquatic habitats and the species they support, the primary management focus and mission of San Bernardino NWR. Increased turbidity and reduced dissolved

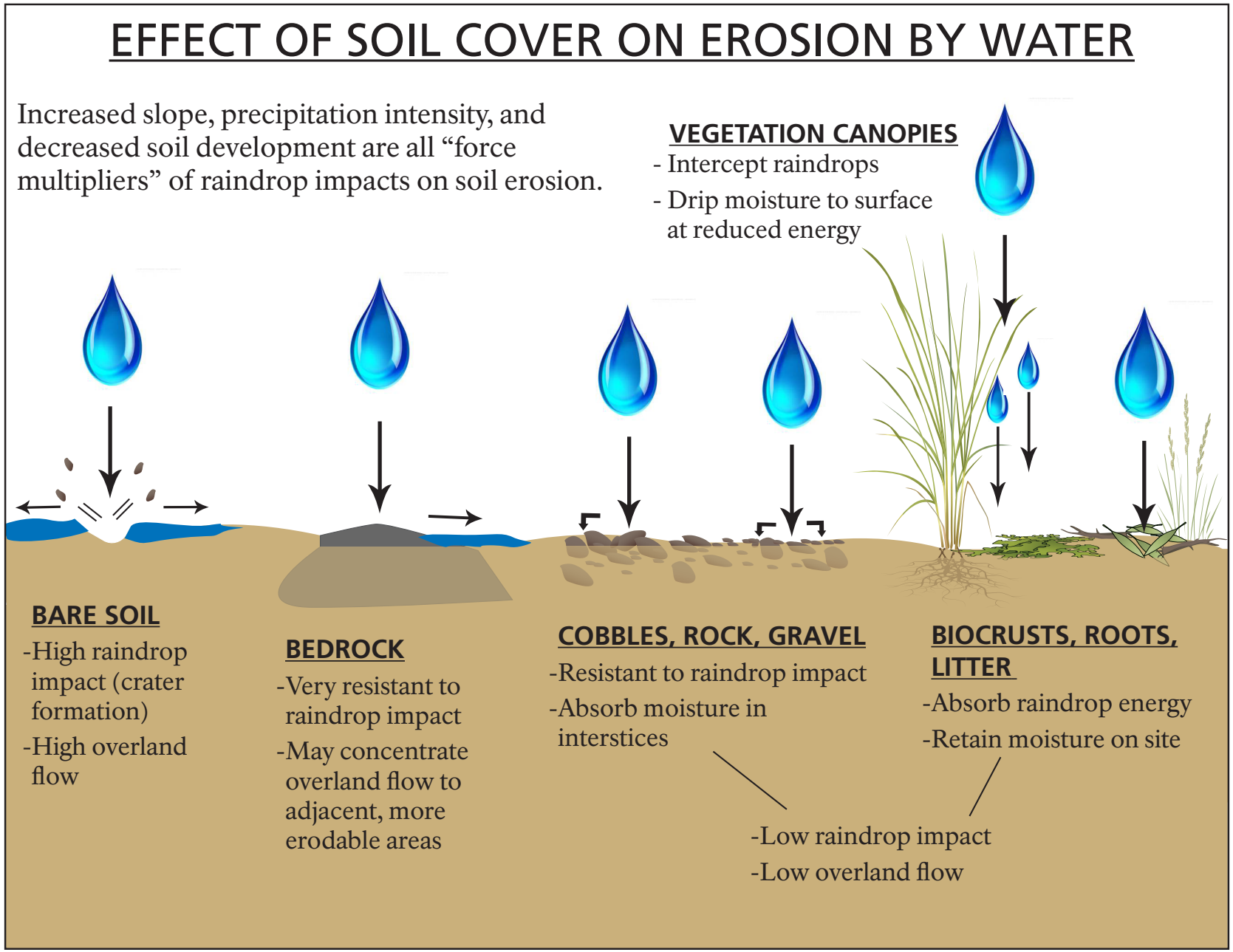


Figure 4.-8. Effect of soil cover on erosion by water.

oxygen from sediment loading in the ponds and channels of the refuge can directly impact aquatic and riparian fauna, flora, and hydrologic function. Sunlight intercepted by suspended sediment increases shallow water temperatures while reducing light penetration to biota at greater depths. Fine suspended sediment can also clog the gills of aquatic vertebrates, whereas deposited sediment alters substrate habitat for benthic invertebrates and vertebrates (EPA 1992).

Soil erosion increases the transport of nutrients such as nitrogen (N) and phosphorus (P) from uplands to aquatic systems, which can lead to nutrient loading and eventual eutrophication of aquatic ecosystems (NRC 2000). Erosion after wildfire can serve as a "nutrient multiplier" as soil losses and available soil organic matter typically increase sharply in the seasons immediately following the fire (Spencer et al. 2003).

Major erosion events in the watershed can also have direct consequences for hydrologic function at San Bernardino NWR through changes in channel morphology and substrate (Rosgen 1996). Gully formation and changes in sediment volume, composition, and location can alter streamflow, aquatic habitat (run/riffle/ pool), and stream depth (Brooks et al. 1991). The powerful influence of upland erosion on hydrologic function, chemistry, morphology, nutrients, and biological processes illustrates the critical need for mitigating erosion from uplands for successful management of aquatic resources at San Bernardino.

4.5 Woody plant encroachment: generally low, but mesquite has invaded sacaton grasslands.

Limiting encroachment of native woody plants into semi-desert grasslands and savannas is a major focus for land management in the American Southwest (Brown and Archer 1999). Locally, controlling mesquite within grasslands by mechanical and chemical treatments has been an ongoing effort since the refuge was established in 1981 (Radke 2014).

Overall woody plant encroachment was low across terrestrial uplands of San Bernardino NWR (Figures 4-4 and 4-6), but rates of mesquite invasion in the subcanopies (0.5–2.0 m) of clay-loam sites approached our management assessment point. In addition, sacaton-dominated lowlands exhibited a degree of mesquite invasion that may diminish the integrity of these critical native grasslands. As discussed in Section 4.1, we recommend implementation of mesquite control on the clay-loam sites containing sacaton grasslands. By contrast, mesquite was nearly absent from western claypan sites, and overall woody plant cover on these locations was very low (Figure 4-6). It is likely that the shallow claypan inhibits woody plant growth of deep-rooted woody plants on these unique site, although past control of acacia—which generally have a shallower root architecture—by refuge managers complicates this assessment (USFWS 2010).

4.6 Exotic plants: colonization but not invasion of clay loam sites

Exotic plants appear to have colonized clay loam sites (Figure 4-4) at San Bernardino NWR, as all but one plot contained at least one of five exotic species (Figure 3-7). These species are widespread, and not spatially limited from occurring on any location within the refuge—not surprising, given the small size of the unit and the pervasiveness of seeds of these species within the region. However, no exotic species had even 0.1% foliar cover, suggesting that they are far from common—let alone dominant—species within clay loam plant communities. At the present, exotic plant invasion looks unlikely, although local conditions such as drought and fire outside natural parameters might favor the expansion of exotic plants in the future. We recommend vigilance and an active monitoring program by refuge managers, but exotic plant treatments in terrestrial uplands is probably not warranted at this time. Exotic plants were not detected on any claypan plots (Figure 4-6).

4.7 Resistant and resilient plant communities

Resistance is the ability of an extant plant community to survive and persist following disturbance, whereas resilience is their ability to recover through recruitment after the disturbance (Enright et al. 2014). Measures of resistance and resilience across terrestrial plant communities at San Bernardino NWR suggest a degree of both resistance to change and resilience in the face of disturbance or stress (Figures 4-4 and 4-6), particularly if mesquite encroachment into sacaton-dominated areas can be somewhat mitigated.

One exception is the dominance of annual grasses and forbs and relatively low cover of perennial grasses on western claypan sites (Figure 4-6). The predominance of annual lifeforms indicates that resistance to drought may be relatively low, as short-lived ephemerals typically have relatively modest root systems and fewer traits for surviving dry conditions. Resilience of the annual grassland may still be high, as these species may persist in the seedbank and reemerge when more favorable conditions occur, but extended drought could deplete the seedbank and support soil erosion, potentially providing conditions for encroachment by other, more tolerant species. Active seeding (via seedballs) of the perennial tobosagrass may help stabilize these sites, although success in drier years may be relatively low.

4.8 Altered fire regimes

Wildfire plays an important role in maintaining intact semi-desert grassland (McPherson 1995), and most of the plant species observed during our surveys have life history traits that tend to favor survival—and even enhanced productivity—following fire. Fire suppression and a period of intensive overgrazing by livestock in the late 19th century (Bailey 1994) had important consequences for plant communities throughout the American Southwest (Swetnam 1990).

Our results generally indicate vegetation indicative of intact fire regimes within San Bernardino NWR, with one exception: the prevalence of annual lifeforms which may favor extreme wildfire events (Figures 4-4 and 4-6). On clay loam sites in central and eastern portions of the refuge (301-EAST), annual cover was highly variable and only approached our management assessment point (Figure 4-4). Patches of annual plant cover were greatest in the fallow fields that also contained substantial big sacaton cover– a highly productive perennial species that typically responds very positively to fire within natural regimes (Britton and Wright 1983). Managers at San Bernardino NWR are currently reintroducing fire to the refuge through application of prescribed fire (USFWS 2010). Particularly on the clay loam sites, fire is an essential tool in favoring sacaton grasslands and semi-desert grasslands more broadly.

On claypan sites, we urge caution in application of fire due to the ephemeral nature of the plant community (Figure 4-6). Annuals comprise nearly half the total cover of the sparse grasslands on the western plateau (Figure 4-6)—lifeforms that can produce large quantities of fine fuels following a pronounced wet-dry cycle. As limited soil water availability on claypan sites appears to be the most influential factor for vegetation composition, use of fire to favor native bunchgrasses or to reduce already very low woody plant cover is unlikely to succeed on these low productivity locations.

4.9 Recommendations for additional research and monitoring

Based on our findings, we recommend three additional research and monitoring efforts:

1. ***Compile an administrative history of land use and disturbance at San Bernardino NWR***

As we suggested for nearby Leslie Canyon NWR (Hubbard et al. 2016), an administrative history of use and disturbances at San Bernardino NWR could greatly inform resource issues and provide important context for research and monitoring results for both terrestrial and aquatic ecosystem management. By locating historic data, public records, area research, and interviewing local residents, a clearer picture of the past conditions and actions within the bounds of what is now the refuge could be compiled. Reviewing records and anecdotal data from historic Slaughter Ranch (located adjacent to the refuge) would be an excellent first step towards developing historic information that could be invaluable to effective resource management, and may address some lingering questions posed by this report and other research projects at the refuge. Good examples of administrative histories include Pinto and others (2000) and Russell (1992), for Fort Bowie National Historic Site and Montezuma Castle National Monument (respectively). As Leslie Canyon NWR and San Bernardino NWR are co-managed, the administrative history could be done in tandem.

2. ***Repeat the terrestrial vegetation and soils monitoring effort in 2018***

The 2013 effort described in this report provides a baseline of upland conditions, and also revealed a surprising diversity in vegetation structure within the relatively small area of San Bernardino NWR. Based on work throughout the region, we expect these

vegetation communities and soil function parameters to interact strongly with climate change and disturbance factors in a dynamic fashion. To maximize the value of this effort and promote an "early warning" approach to mitigating potential resource issues at San Bernardino NWR, we recommend repeating this effort on 5-year intervals, with the second round of sampling to occur in 2018.

3. ***Conduct a site-specific soil inventory coupled with erosion modelling***

Local soil conditions provide the foundation for terrestrial ecosystems at San Bernardino NWR, yet they are poorly understood. The Cochise County survey is mapped at a scale that is inappropriate for the relatively small size of the refuge, and the county survey focuses on agricultural and engineering applications rather than the ecosystem management mandate of San Bernardino NWR. When coupled with ecological site descriptions (as developed by the Natural Resources Conservation Service), an existing erosion model (e.g., Watershed Erosion Prediction Project, Rangeland Hydrology and Erosion Model), and the vegetation and dynamic soil function information collected in the current effort, a soil inventory could provide a very powerful tool for assessing potential ecosystem degradation at San Bernardino NWR.

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

Despite at least a century of varied—and at times, intensive—land uses, including row crop agriculture, livestock grazing, brush management, fire suppression, groundwater extraction, and more recently, creation of artificial ponds for managing aquatic species, terrestrial vegetation at San Bernardino NWR appears to be generally within the range of natural variability. Twenty-five years of succession on fallow agricultural fields has led to partial recovery of native sacaton grasslands—an important and regionally scarce vegetation community that supports a variety of ecosystem functions and habitat for wildlife. Reducing mesquite on these sites should help maintain their integrity within the refuge. More xeric upland vegetation is also well within the spatial and temporal variance of the site and ecoregion, although the shallow claypan vegetation on the western plateau is somewhat unusual within the Apache Highlands ecoregion.

Dynamic soil functional characteristics are likely well-within the range of natural variability as well, though the lack of a high-resolution soil survey limits our assessments. Relatively unstable surface soil aggregates throughout the refuge may reflect previous land uses (particularly intensive livestock grazing), although the extended period of recovery—more than 25 years—from those uses suggests that inherent soil factors and underlying geology may be more important determinants.

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Appendix A. Permanent Plot Photos

Figures begin on next page.

U.S. Fish & Wildlife Service

San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_001



Photo Point 2 (0m,20m corner): 166 degrees



Photo Point 3 (50m,20m corner): 218 degrees

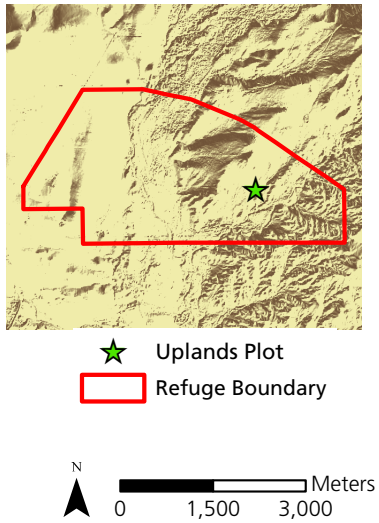


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Photo Point 4 (50m,0m corner): 338 degrees

Plot Location



Plot Layout

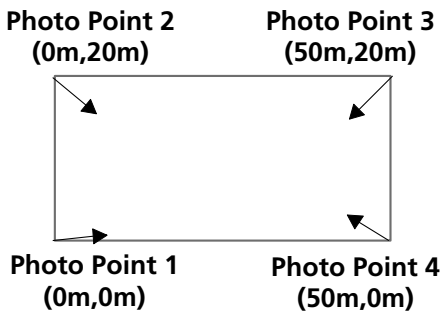


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m,20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

Produced by SCDZ
August 2016

U.S. Fish & Wildlife Service

San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_002



Photo Point 2 (0m,20m corner): 310 degrees



Photo Point 3 (50m,20m corner): 25 degrees

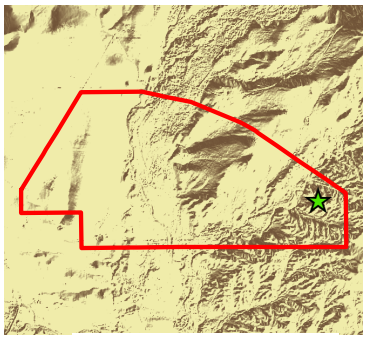


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Photo Point 4 (50m,0m corner): 100 degrees

Plot Location



Plot Layout

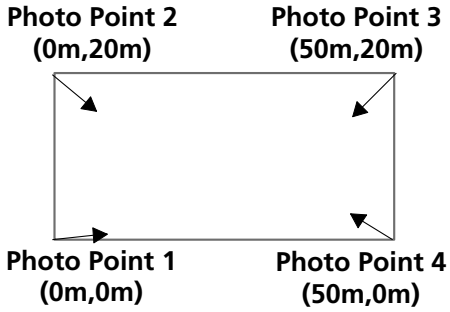


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Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

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U.S. Fish & Wildlife Service
San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_003



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Photo Point 3 (50m,20m corner): 298 degrees

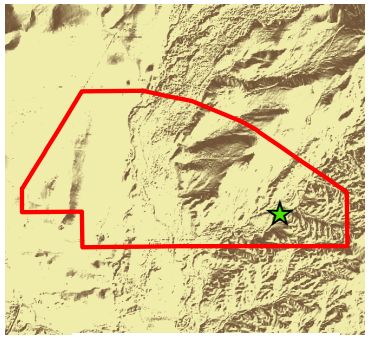


Photo Point 1 (0m,0m corner): 142 degrees



Photo Point 4 (50m,0m corner): 12 degrees

Plot Location



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 higher resolution photos are available from SCDZ.

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San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_004



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

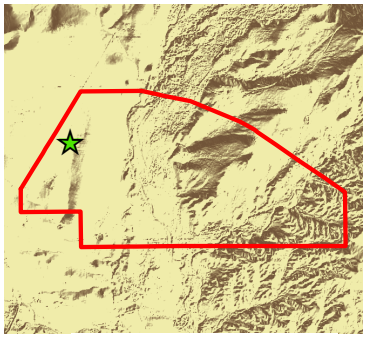


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Photo Point 4 (50m,0m corner): 330 degrees

Plot Location



Plot Layout

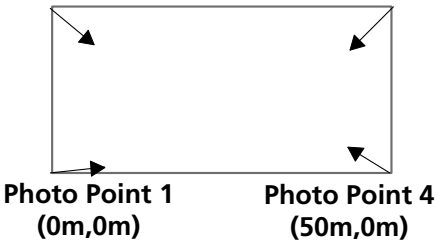


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Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

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U.S. Fish & Wildlife Service
San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_005



Photo Point 2 (0m,20m corner): 212 degrees



Photo Point 3 (50m,20m corner): 272 degrees

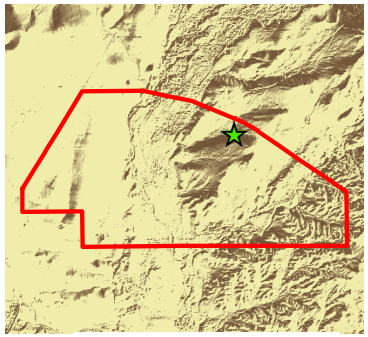


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Photo Point 4 (50m,0m corner): 20 degrees

Plot Location



Plot Layout

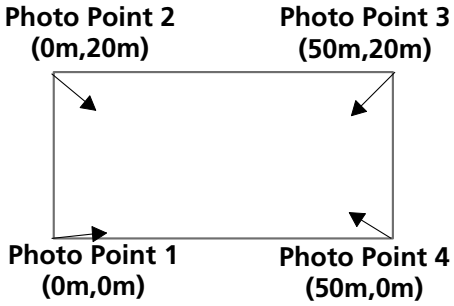


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m,20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

Produced by SCDZ
August 2016

U.S. Fish & Wildlife Service

San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_006



Photo Point 2 (0m,20m corner): 178 degrees



Photo Point 3 (50m,20m corner): 276 degrees

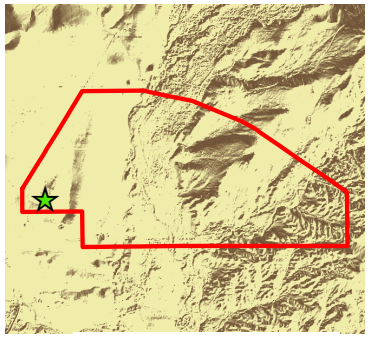


Photo Point 1 (0m,0m corner): 114 degrees



Photo Point 4 (50m,0m corner): 2 degrees

Plot Location



Plot Layout

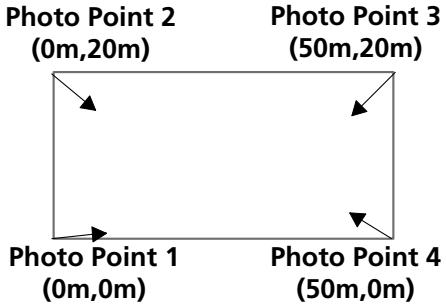


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m,20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

Produced by SCDZ
August 2016

U.S. Fish & Wildlife Service
San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_007



Photo Point 2 (0m,20m corner): 290 degrees



Photo Point 3 (50m,20m corner): 0 degrees

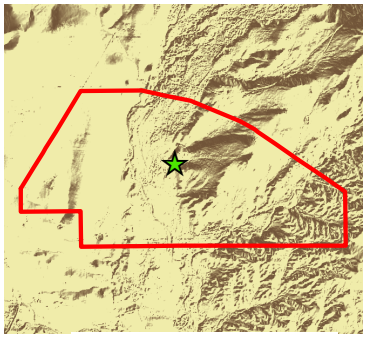


Photo Point 1 (0m,0m corner): 220 degrees



Photo Point 4 (50m,0m corner): 100 degrees

Plot Location



Uplands Plot
Refuge Boundary

N
Meters
0 1,500 3,000

Plot Layout

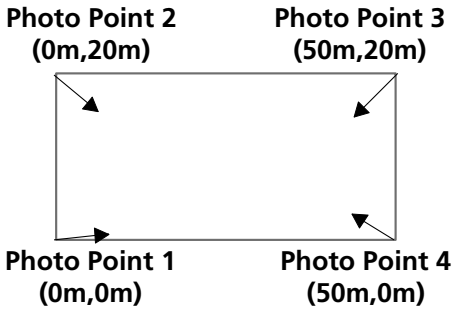


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m,20m) represent the spatial location of the plot corner.
Bearings, in degrees, reflect the direction of the photo into the plot.
Exact photo locations and higher resolution photos are available from SCDZ.

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August 2016

U.S. Fish & Wildlife Service

San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_008



Photo Point 2 (0m,20m corner): 97 degrees



Photo Point 3 (50m,20m corner): 184 degrees

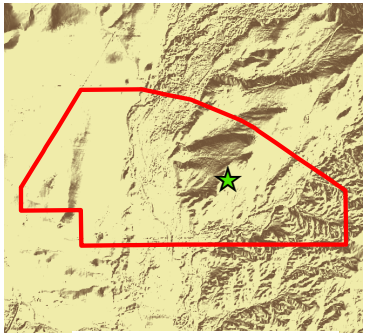


Photo Point 1 (0m,0m corner): 47 degrees



Photo Point 4 (50m,0m corner): 291 degrees

Plot Location



Plot Layout

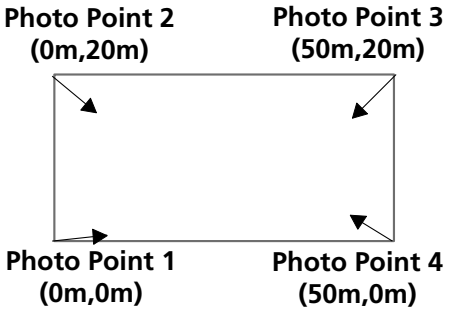


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U.S. Fish & Wildlife Service
San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_009



Photo Point 2 (0m,20m corner): 305 degrees



Photo Point 3 (50m,20m corner): 34 degrees

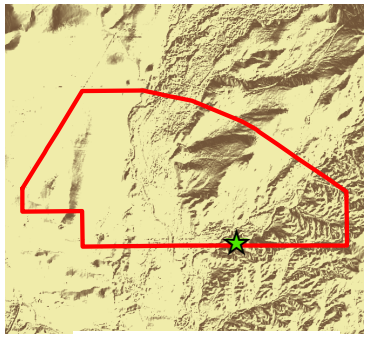


Photo Point 1 (0m,0m corner): 188 degrees



Photo Point 4 (50m,0m corner): 126 degrees

Plot Location



Plot Layout

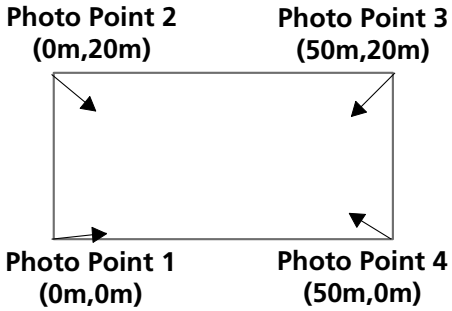


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2013 Photographs of Uplands Plot 301_010



Photo Point 2 (0m,20m corner): 140 degrees



Photo Point 3 (50m,20m corner): 220 degrees

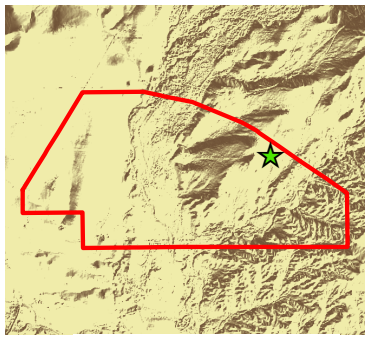


Photo Point 1 (0m,0m corner): 70 degrees



Photo Point 4 (50m,0m corner): 310 degrees

Plot Location



Plot Layout

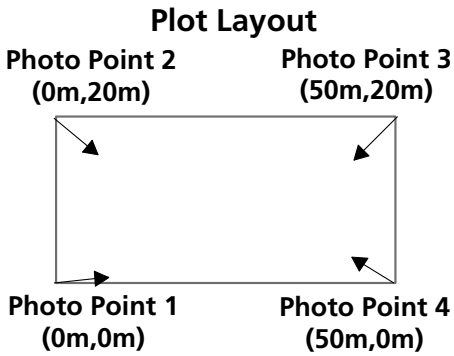


Photo points are located at each of the four plot corners. Meter marks (e.g., 0m,20m) represent the spatial location of the plot corner.
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2013 Photographs of Uplands Plot 301_011



Photo Point 2 (0m,20m corner): 110 degrees



Photo Point 3 (50m,20m corner): 218 degrees

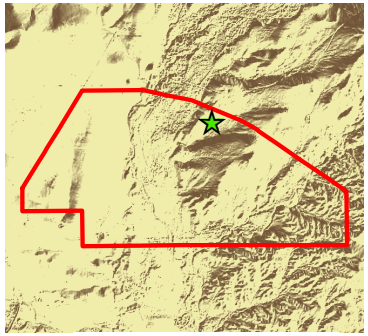


Photo Point 1 (0m,0m corner): 73 degrees



Photo Point 4 (50m,0m corner): 294 degrees

Plot Location



Uplands Plot

Refuge Boundary

N

0 1,500 3,000 Meters

Plot Layout

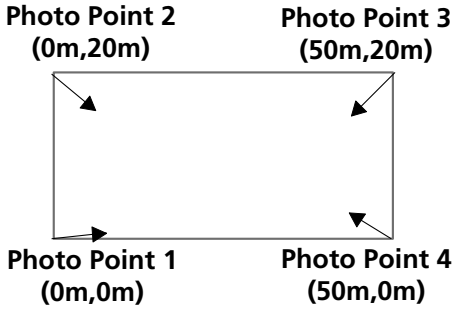


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2013 Photographs of Uplands Plot 301_012



Photo Point 2 (0m,20m corner): 221 degrees



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

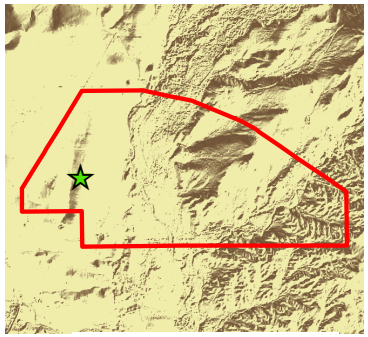


Photo Point 1 (0m,0m corner): 164 degrees



Photo Point 4 (50m,0m corner): 40 degrees

Plot Location



Plot Layout

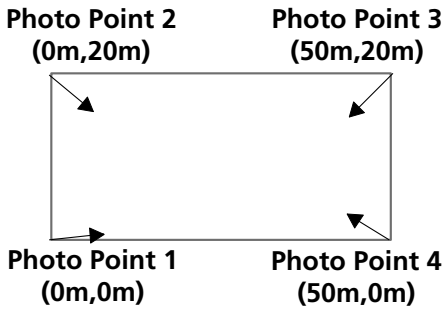


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San Bernardino National Wildlife Refuge

2013 Photographs of Uplands Plot 301_013



Photo Point 2 (0m,20m corner): 240 degrees



Photo Point 3 (50m,20m corner): 350 degrees

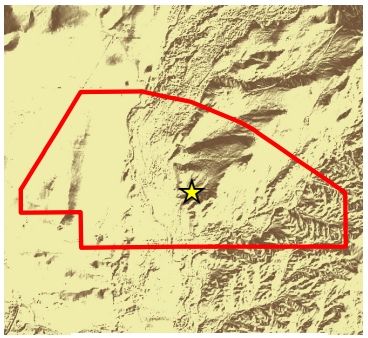


Photo Point 1 (0m,0m corner): 199 degrees



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

Plot Location



Uplands Plot

Refuge Boundary

N

0 1,500 3,000 Meters

Plot Layout

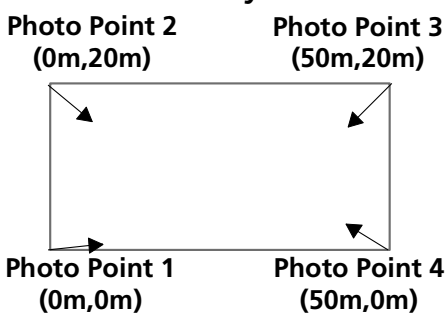


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2013 Photographs of Uplands Plot 301_014



Photo Point 2 (0m,20m corner): 70 degrees



Photo Point 3 (50m,20m corner): 172 degrees

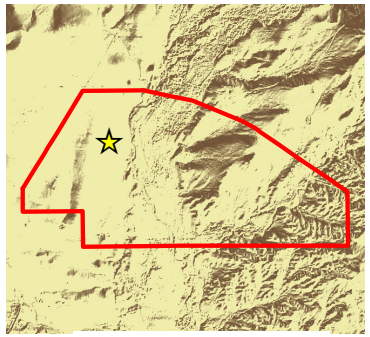


Photo Point 1 (0m,0m corner): 20 degrees



Photo Point 4 (50m,0m corner): 264 degrees

Plot Location



Plot Layout

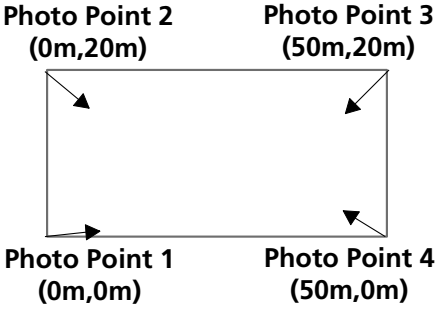


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2013 Photographs of Uplands Plot 301_015



Photo Point 2 (0m,20m corner): 334 degrees



Photo Point 3 (50m,20m corner): 66 degrees

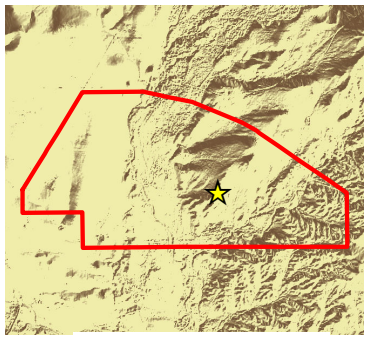


Photo Point 1 (0m,0m corner): 212 degrees



Photo Point 4 (50m,0m corner): 148 degrees

Plot Location



Plot Layout

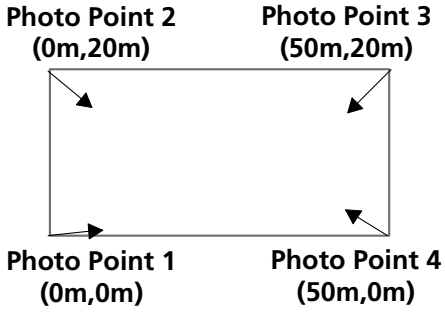


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August 2016

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 960/145308, May 2018

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525