Natural Resource Condition Assessment

Chiricahua National Monument, Coronado National Memorial, and Fort Bowie National Historic Site

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ON THE COVER

Clockwise, from upper left, Montezuma Canyon at Coronado National Memorial, fort ruins at Fort Bowie National Historic Site, and pinnacles at Chiricahua National Monument
Photos courtesy of (clockwise, from upper left) Sonoran Institute, NPS Sonoran Desert Network, and Sonoran Institute

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Publisher's Note: This was one of several projects used to demonstrate a variety of study approaches and reporting products for a new series of natural resource condition assessments in national park units. Projects such as this one, undertaken during initial development phases for the new series, contributed to revised project standards and guidelines issued in 2009 and 2010 (applicable to projects started in 2009 or later years). Some or all of the work done for this project preceded those revisions. Consequently, aspects of this project's study approach and some report format and/or content details may not be consistent with the revised guidance, and may differ in comparison to what is found in more recently published reports from this series.

Executive Summary

This report summarizes natural resources and conditions in and surrounding Chiricahua National Monument (NM), Coronado National Memorial (NMem), and Fort Bowie National Historic Site (NHS), located in southeastern Arizona. Developed as part of the National Park Service's natural resource condition assessment (NRCA) program, the report utilizes existing data, observations, and expert opinion to determine the ecological condition of resources relative to reference conditions. NRCAs do not establish management targets for study indicators. Decisions about management targets must be made through sanctioned park planning and management processes.

Regional Overview

The Madrean Archipelago, also called the Sky Islands Region, Sky Islands Archipelago, Madrean Sky Islands Region and other names, is an area mostly in southeastern Arizona and northeastern Sonora between the main mass of the Rocky Mountains to the north and the main mass of the Sierra Madre Occidental to the south. The region extends a little into adjacent New Mexico and Chihuahua. Within this area are 52 sky islands, defined as mountains with at least an acre of oak woodland on top, isolated by drier biological communities at lower elevations (usually desertscrub or grassland). The bounding ranges are the Baboquivari/Quinlan Mountains on the west, Animas Mountains on the east, the Santa Teresa-Pinaleño Mountains on the north, and the Sierra Mazatán on the south (east of Hermosillo, Sonora). The Nature Conservancy's Apache Highlands ecoregion is nearly the same area as the Madrean Archipelago. There are additional sky islands to the east of the defined region. Their floras are more associated with the Sierra Madre Oriental, and they are typically not included in the (western) Madrean Archipelago that is the subject of this study.

Use of the adjective "Madrean" may seem a bit misleading. The term refers to flora and fauna having their origins in the Sierra Madre Occidental of Mexico. Although much of the biota of the Sky Islands is montane Sierra Madre in origin, especially the oaks, not all of the flora originated from the south (and the Madrean component decreases moving northward, and higher in elevation). For example, most of the Sky Island oaks are southern species, but some are northern in distribution (e.g., Gambel oak, gray oak); and, while many of the conifers are southern in origin (e.g., Apache pine, Chihuahuan pine), most are temperate species (e.g., blue spruce, Englemann spruce, subalpine fir, corkbark fir, white fir, limber pine, ponderosa pine). The Madrean species reach their northern limits in southeastern Arizona's Sky Islands. These mixed vegetative origins were documented by Shreve in the early 1900s. Of all the National Park Service parks and monuments in the region, only three contain significant Madrean biota: Chiricahua NM, Coronado NMem, and Guadalupe Mountains National Park (NP).

The Madrean Archipelago lies within the Basin and Range geologic province, which spans from southern Idaho and Oregon to northern Mexico. Broad alluvial valleys separate roughly parallel mountain regions that trend from northwest to southeast. In some areas, the vertical relief between the valley and mountain top is 10,000 feet.

Geology within the Madrean Archipelago is complex. One important geologic feature are limestone outcrops, which are significant contributors to biodiversity and groundwater resources in the Madrean Archipelago. Water moves relatively easily through the fractured and porous limestone to recharge aquifers. Limestone outcrops are found in the Huachuca and Chiricahua mountains. T

The geology of most of Chiricahua NM is influenced by the eruption of the volcano associated with what is now known as the Turkey Creek caldera. As a result, soils at the monument were derived from numerous parent materials, including residuum, aeolian material, alluvium and colluvium. A recent soil survey identified thirteen soil types within twenty-four soil map units at the monument (Denney and Peacock 2000a). The complicated geology in the vicinity of

Publisher's Note: Some or all of the work done for this project preceded the revised guidance issued for this project series in 2009/2010. See Prologue (opposite page) for more information.

Coronado NMem resulted from the eruption of the Montezuma caldera volcano and subsequent volcanic events. The memorial is dominated by rock outcrop and alluvium. The geologic variation, and resulting differences in parent material, results in twenty-one major soil types combined into twenty soil map units at Coronado NMem (Denney and Peacock 2000b). Soils are deep on the lower slopes but shallow soils with high rock fragment content tend to dominate the steep slopes. The Apache Pass fault, Pennsylvanian and Cretaceous limestone on Precambrian granite, characterizes Fort Bowie NHS. The geologic variation, and resulting differences in parent material, combined with the diverse effects of pedogenic processes, results in seven major soil types and eight soil map units at Fort Bowie NHS (Denney and Peacock 2000c).

Dynamic soil properties, such as soil aggregate stability, soil surface cover, and biological soil crusts, can help provide a functional assessment of critical ecosystem processes, such as soil erosion and site fertility. Biological soil crusts are a highly specialized community of cyanobacteria ("blue-green algae"), algae, microfungi, lichens, and bryophytes and typically cover undisturbed open spaces and increase erosion resistance in arid and semiarid regions. Soil erosion can cause dramatic changes in vegetation. For instance, soil erosion from the foothills and bajadas of the Sky Island Archipelago can cause drastic and permanent changes in the vegetation. The presence of desert grassland or Chihuahuan desertscrub depends on whether the substrate is soil or rock.

The Madrean Archipelago's location between the mid-latitude and subtropical atmospheric circulation regimes strongly influences the region's climate and results in relatively low annual precipitation, warm temperatures and clear skies. While temperatures tend to be warm, there can also be a considerable range in daily and seasonal air temperature. Typically, precipitation increases dramatically with elevation due to the orographic effects of the sky islands. Across the region, precipitation is highly variable and falls in a bimodal pattern. According to 26 weather stations in the region, the annual average precipitation from 1971-2000 ranged from just under 12 inches to just under 25 inches. Approximately half of the annual precipitation falls from July through September in temporally and spatially variable monsoonal storms that derive their moisture primarily from the tropical Pacific Ocean and Gulf of California.

In contrast to the locally violent summer rains, the majority of the remaining annual precipitation falls in relatively gentle, widespread events from November through March. The winter storms cause widespread precipitation over a large geographical area. During the intervening months between the precipitation peaks, little rain falls. However, occasionally tropical storms move into the region in early fall. While tropical storms are infrequent, they have produced some of the largest rainfall events recorded in the region and can result in widespread flooding and severe erosion.

The Arizona portion of the Madrean Archipelago includes drainages of the San Pedro River, Santa Cruz River, Gila River, Rio de Bavispe, and the Willcox Playa. Seeps and springs are critical surface water sources in the semi-arid Madrean Archipelago. They are important sources of water for plants and animals and represent the primary interface between groundwater and surface water. Within the region, the groundwater basins consist of sediments deposited before the Basin and Range province formed and a layer of basin fill, up to 1,000 feet thick, of material eroded from the mountains. Typically, groundwater discharge occurs near the center of the basin as groundwater flows from the edges of the basin towards the center of the basin. Groundwater discharge includes pumpage, evapotranspiration, and discharge to streams and springs.

Air quality affects vegetation, wildlife, and water as well as scenery, vistas, and viewsheds. There are four main components used to measure air quality: visibility, particulate matter, ozone, and atmospheric deposition. Particulate matter is measured near Douglas, Aqua Prieta, Nogales, Sonora, and Nogales, Arizona and all four stations were in compliance for particulate matter for 2006–2008. Visibility monitoring occurs in

Class I airsheds, such as those associated with the wilderness at Chiricahua NM. In general, visibility shows signs of improvement at Chiricahua NM over the past 20 years. Ozone (O_3) is a component of the atmosphere that is produced through the reaction of water and oxygen with lightning and with anthropogenic pollutants. In the stratosphere, ozone blocks ultraviolet radiation but in lower levels of the atmosphere ozone can be toxic to humans and plants. Since 1990, the ozone level at Chiricahua NM has not exceeded the EPA standard. Total nitrogen emissions in the region, by county, average less than 5 tons per square mile per year. Total nitrogen deposition in the region averages less than 5 kilograms per hectare per year.

The most important biological characteristic of the Madrean Archipelago is its biodiversity. The Arizona portion of the Apache Highlands ecoregion (which includes the Madrean sky islands) contains about 2100 species of plants, which is slightly more than half of the entire flora of Arizona. When the Mexican ranges are included and subspecies are counted, the entire Madrean Archipelago is estimated to harbor 3000-3500 plant taxa. The fauna is also strikingly diverse. The 120 species of amphibians and reptiles in southeastern Arizona represents 80% of the state's herpetofauna. Southeastern Arizona's bird fauna of nearly 500 species is more than can be found in any similar-sized land-bounded area in the country, and is half the species in all of North America (957). The three National Park Service units discussed in this report are home to 92 species of mammals. The Chiricahua Mountains are unique in having all four North American skunk species.

The high biodiversity is largely due to the convergence of four biogeographic regions in the southeastern corner of the state. The warm-temperate Chihuahuan Desert and Desert Grassland biomes come in from the east. The tropical Sonoran Desert biome abuts on the western edge of the archipelago. The cold-temperate forests of the Rocky Mountains and Colorado Plateau extend into the area from the north. The warm-temperate forest and woodland biome of the Sierra Madre Occidental come up from the south. The tropical communities of thornscrub and tropical deciduous forest of Sonora do not enter Arizona, but a number of their more cold-tolerant tropical species have ranges extending into the region.

The highly diverse sky island topography supports many biotic communities and an extraordinary biogeographic mix in a small area. The desert and grassland communities grow in the lower, warmer, drier valleys. The highest mountains support the wetter, cold-adapted montane communities. The isolation of the woodlands and forests on the mountain islands would be expected to have fostered numerous endemic species, increasing diversity still further. However, the forests have been isolated only during the past nine to ten thousand years of the current interglacial period. During the last glacial period (the "Ice Age"), and presumably earlier glacial periods, the woodlands and forests occurred at lower elevations and were more contiguous than they are now. Therefore the number of endemics on the peaks of the Madrean Archipelago is much lower than on oceanic islands.

Eight biomes are well represented in the Sky Island Archipelago (Table ES.1).

Table ES.1. Biomes and riparian communities in the Sky Island Archipelago with summaries of areal coverage.

Biome	Sky Island Archipelago	Chiricahua	Coronado	Fort Bowie
Sonoran Desert	Minor	None	None	None
Chihuahuan Desert	Moderate	None	None	None
Desert grassland	Major	Minor	Moderate	Major
Interior chaparral	Minor	None[1]	Moderate	None
Madrean oak woodland	Major	Major	Major	Moderate
Madrean pine-oak woodland	Major	Major	Moderate	None
Rocky Mountain montane forest	Moderate	Minor	None	None
Rocky Mountain subalpine forest	Minor	None	None	None
Thornscrub	Minor	None	None	None
Riparian communities	Minor	Minor	Minor	Minor

[1]None shown on vegetation maps. The dwarf pine-oak woodlands on some mountain summits have the physiognomy of chaparral, although the species composition is anomalous for chaparral.

The Sky Island Archipelago has an unusually rich biota for the reasons identified above. Although the region has been extensively studied for over a century, the total number of known species of plants and vertebrates is still growing. There is only a very rough estimate of the number of invertebrates. Currently documented numbers within each park and estimates for the region are summarized in Table ES.2.

As described above, the Sky Island Archipelago is part of the Basin and Range geologic province. Its north-south trending mountains, valleys, and rivers create biological corridors of continental importance to migratory animals. In spring the south-to-north wave of plant flowering fuels the northward migration of hummingbirds, butterflies, and nectarivorous bats through the lowland habitats. Many other nonpollinating birds also migrate northward with the latitudinal advance of spring. The same bird and bat species migrate southward along the mountain spines in late summer and fall, feeding on high elevation flowers, fruits, and insects.

The north-south biological corridors also facilitate dispersion of species over longer time spans. The montane habitats of the Rocky Mountains and Sierra Madre Occidental are continuous from northern Canada to southern Mexico, except for the punctuated interruption in the sky islands (which provide stepping stones for the more mobile species). This has enabled alpine plants and animals to migrate southward and occupy suitable habitats well into the tropical latitudes. A number of plant genera and some species found at sea level in the arctic also occur on our highest mountains. The lowland corridors will facilitate northward colonization by tropical species as global warming progresses.

Despite the high biodiversity of the Sky Island Archipelago, there are few rare and endemic species and communities in the three parks. Four rare communities identified by the Arizona Gap Analysis Project (Madrean Montane Conifer Forest [Douglas Fir-Mixed Conifer], Scrub Grassland [Sacaton-Scrub], Rocky Mountain Montane Grassland [Rush], Rocky Mountain Riparian Deciduous Forest [Cottonwood-Willow]; Gebow 2001) are discussed further in section 4.1.2.11, but their corresponding NVCS names are not clear. Rare and endemic plants known or suspected to occur in the region and parks are listed in Table 4.3. The indicator tables in the main report identify important vertebrates in Chiricahua NM (Table 4.8), Coronado NMem (Table 4.12), and Fort Bowie NHS (Table 4.16).

Table ES.2. Species counts in the Sky Island Archipelago and the three parks, based on I&M inventories (Powell et al. 2007, Powell et al. 2008, and Schmidt et al. 2007), numerous publications, and the authors' experience.

	Arizona Sky Island Archipelago	Chiricahua	Coronado	Fort Bowie
Flora[1]	~2100	803	651	572
Invertebrates	150,000?[2]	Unknown	Unknown	Unknown
Amphibians and Reptiles	120	50	74[3]	73
Mammals	~100	69	67[4]	61
Birds	~500	192	200	188

[1]The floras of the three parks are being vouchered by Steve Buckley; these numbers can be updated soon.

[2]Estimate based on plant diversity and other algorithms.

[3]This is considerably more than the 54 herps listed in the I&M database

[4]Swann et al. (2010) documented 12 additional terrestrial mammals that are not in the current I&M inventory.

Fire is the main ecological process that is feasible to manage. Others may be useful in assessing and monitoring ecosystem health. These key processes include the cycling of water and nutrients, the flow of energy, natural disturbance, population dynamics, succession in response to disturbance or climate change, evolution, and ecological services such as pollination and purification of water and air. However, there is insufficient quantitative data for the Sky Island Region to enable useful evaluation of the condition of the parks.

An often overlooked ecological service is the influence of natural environments on human physical and psychological health. A growing body of research shows that people who have regular access to natural areas have lower rates of diabetes, heart disease, and psychological disorders (Hartig 2008). Contact with nature, even a view out a window, has been shown to accelerate healing from injuries and diseases.

Ecological services have tangible economic values, which ecologists and economists are collaborating to quantify (Edwards and Abivardi 1998; Naidoo and Tomasek 2009, Zhoua et al. 2009). In some cases the annual value of ecosystem services is more than twice the annual value of resource extraction (Jonsson and Wardle 2009).

Threats and Stressors

There are numerous threats to the Sky Islands Region including climate change, border pressures, population growth, exotic species, and habitat fragmentation. We summarize these threats below.

Scientists' understanding of the effects of climate change on ecosystems is rudimentary so the analysis here should not be considered to be more than informed speculation. While the cause is not certain, the global climate is warming. Precipitation is not increasing, and may be decreasing. If these trends continue, they will have major impacts on vegetation in the Sky Island Region. In the absence of increasing rainfall, rising temperatures increase the aridity of a habitat by increasing evapotranspiration. In response, biological communities will shift upslope where suitable conditions for their existence occur. The highest elevation communities may be pushed off the tops of the mountains.

Despite drier conditions, possible future changes in timing and amount of precipitation could result in flooding—putting people, ecosystems, and infrastructure at risk. Likewise, springs in the region will be affected by groundwater withdrawals, as well as by changes in runoff and groundwater recharge. The detrimental effect of downcutting of streambeds is well known. It is also important to minimize erosion from slopes, because vegetation is largely dependent on the depth and quality of soil. For example, loss of soil from desert grassland will cause a type conversion to Chihuahuan desertscrub. Such a change would be irreversible on a human time scale, because soils regenerate over geological time spans.

The U.S./Mexico border poses a threat to natural resources, which can be damaged by illegal immigration, narcotics smuggling, enforcement efforts, and related activities. Threats to natural resources include increased fire risk, wildlife disturbance, habitat destruction or modification, spread of invasive species, trash and human waste, and creation of new roads and trails. Numerous efforts are underway to understand the impact of the border-related infrastructure on ecological processes and communities.

The Southwest is one of the fastest growing regions in the United States. In terms of their impacts, cities are not geographically discrete areas in the sense that most of the impacts lie far beyond their borders. The total area of land required to sustain an urban region is at least ten times that contained within the municipal boundaries.

Although there are numerous exotic species established in the parks, the great majority do not appear to be invasive (e.g., they are not causing significant ecological harm or posing a health hazard). Some are invasive, but are already so widespread and well established that control is probably not feasible, e.g., Bermuda grass, filaree, and London rocket. Most of these species also seem to have attained their maximum invasive potential; they probably are not increasing further, at least not into undisturbed habitats. Those that should be monitored and may need management action are:

> Chiricahua NM Plants: Maltese starthistle, Russian olive, watercress (may compete with water umbel if present), saltcedar, and bigleaf periwinkle (invasive in riparian habitats).
>
> Coronado NMem Plants: tree of heaven, yellow bird-of-paradise, Maltese starthistle, Lehmann lovegrass (management techniques can reduce its dominance), and athel tamarisk. Animals: bullfrog.
>
> Fort Bowie NHS Plants: Lehmann lovegrass (management techniques can reduce its dominance), and curly dock.

The theory of island biogeography makes it clear that none of the three parks is large enough to support a healthy, self-sustaining ecosystem indefinitely if they are isolated from larger landscapes. The parks are part of a greater whole (their associated mountain range and the entire the Sky Island Archipelago); their management needs to be coordinated with the management of surrounding natural lands, mostly under U.S. Forest Service management. The Desert Managers Group in California (http://www.dmg.gov/) is a successful example of a forum for interagency cooperation. In February 2010 the Department of Interior ordered all the land management agencies it oversees to join with other federal, state and private land managers in 'landscape conservation cooperatives' to help to understand and respond to the effects of climate change (Nature 2011, DOI Secretarial Order 3289). This initiative needs to be expanded to include lands under other departments such as the National Forests, military reservations, and protected lands in adjacent countries.

Park-wide Conditions

A rigorous quantitative assessment of ecosystem health is not practical at this time. However, the NRCA team concludes that the three parks are currently in very good health. Park-wide conditions are summarized below. Insufficient information was available to assess conditions at the management area level. Our professional opinions are tempered by significant data gaps, and several actual and possible future threats are identified in this report.

Chiricahua NM

Of the regional threats and stressors, the most significant ones for Chiricahua NM are climate change, exotic species, and fire. No exotic species invasions are known to be occurring at this time.

Supporting Environment

Climate

Data from 2000-2009 for the "Chiricahua NM" COOP station were compared to the station's 30-year "normal" or "historic average" (1971-2000). Unfortunately, data for 2000-2009 were incomplete so we report on conditions with a low level of confidence.

Overall, Chiricahua NM temperature indicators (June maximum temperature, and January minimum temperature) were slightly above average compared to their respective reference conditions (30-year averages from 1971-2000). January minimum temperatures and June maximum temperatures from 2000-2004 were 1°F warmer than their respective 30-year averages. The precipitation indicator was below average compared to the 30-year average (1971-2000).

Air Quality

Five-year average (2004-2008) air quality data was compared to reference conditions developed by the NPS Air Resources Division. Because air quality is monitored at Chiricahua NM, the authors' confidence in the condition assessment is high.

The 5-year average (2004-2008) fourth-highest eight-hour ozone concentration was 69.2 ppb. Therefore, ozone at Chiricahua NM is rated as "moderate." The 5-year average for Visibility Condition at Chiricahua NM from 2004-2008 was 6.1 deciviews. Based on the reference condition set by the NPS Air Resources Division, the visibility condition at Chiricahua NM is rated as "moderate."

Between 2004 and 2008, the average total wet deposition of nitrogen was 2.7 kg/ha/yr and the average total wet deposition of sulfur was 1.3 kg/ha/yr. Vegetation at Chiricahua NM may be sensitive to nitrogen deposition. Therefore, nitrogen deposition condition is up one category to a "significant concern" while sulfur deposition is rated as "moderate."

Land Use

The NPScape landscape dynamics monitoring project provides data to evaluate land use surrounding NPS units. In 2001, nearly 95% of the area within 30km Chiricahua NM was considered "natural." Only 5% of the land was converted and developed or used as pasture or for crop cultivation. There are no reference conditions for land cover in the Madrean Archipelago.

Groundwater

The NPS Sonoran Desert Network initiated groundwater monitoring at Chiricahua NM in 2007. Recent depth to water measurements appear fairly stable and water levels are higher than when the three monitored wells were constructed decades ago. . While periodic water level measurements have been ongoing only for a short time, current water levels are very similar to those measured when the wells were drilled. In the Headquarters area, depth to water was 12.5 ft in 1956, while the average depth to water over the 2008 to 2010 monitoring period is 11.2 ft. In the campground area, depth to water in 1962 was 28.5 ft, compared to an average of 27 feet between 2008 and 2010. At Faraway Ranch, depth to water in 1979 was 18.5 ft, compared to an average of 17.1 feet between 2008 and 2010. In every case, water levels are higher than they were when these three wells were constructed decades ago.

Seeps and Springs

In June 2010, the NPS Sonoran Desert Network field crews surveyed eight seeps and springs at Chiricahua NM. Water was observed flowing at seven of the eight seeps and springs. This nearly meets the reference condition, based on the authors' professional opinion, that all springs should have surface water present in June, prior to the monsoon. Data from 2010 had not undergone quality assurance/quality control, so the authors' confidence that the data represent flow presence in June is moderate.

Abundance and diversity of invertebrates at six springs in Chiricahua NM were estimated but not in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

Water Quality

Natural water sources sampled at Chiricahua NM were reviewed and compared to State of Arizona standards for Aquatic and Wildlife designated use. All locations failed to meet the standard for dissolved oxygen at least once. However, natural processes are reasonable explanations for the presence of low dissolved oxygen levels in the springs sampled; therefore the presence of dissolved oxygen in these waters below state criteria is not considered to be problematic or requiring attention. All of the samples were in compliance with other A&W criteria for surface waters. For these reasons, water quality of springs at Chiricahua NM is considered to be in good condition.

Soils

Soil surface cover, biological soil crust composition and cover, and surface soil aggregate stability are important dynamic soil properties and relate to soil and site stability and hydrologic function. While biological soil crusts are an important component of the vegetation and soil community at Chiricahua NM, reference conditions for biological soil crust composition and cover are undetermined for the Madrean Archipelago. However, Hubbard and others (2010) proposed reference conditions for soil cover and surface soil aggregate stability for Fort Bowie NHS that we modified for Chiricahua NM.

Overall, Chiricahua NM soil indicators meet their respective reference conditions. However, the author's confidence in this assessment is moderate because the forty-five monitoring plots used in the assessment represent 75% of the intended sample size for the park. The areas of the park included in the NPS Sonoran Desert Network 2007-2010 monitoring effort appear to be well-protected from soil erosion. The overall soil aggregate stability of the sites was moderate, suggesting that the sites can resist erosion and that the soil-biotic system is functioning. However, several of the sites had low stability ratings, suggesting potential local erosion risks. Total cover of the sites was very high, with little exposed bare soil. A large amount of cover comes from litter and duff, which could leave the sites susceptible to erosion if fire or drought removed those materials. Biological soil crusts covered less than 1% of the soil surface within the monitoring plots.

Biological Integrity

Major Biomes

Chiricahua NM is covered mostly with Madrean oak woodland and Madrean pine-oak forest, with a little desert grassland in the western margin. There is a very small area of riparian vegetation. Chiricahua NM is one of only three NPS areas that contain Madrean biota (the others are Coronado NMem and Guadalupe Mountains National Park).

Biological Diversity

Chiricahua NM supports the high biodiversity that is expected for the region (Table ES.2). Although the monument is a small percentage of the area of the Chiricahua Mountains, its 803 documented and strongly suspected plant taxa comprise about two-thirds of the estimated 1200 taxa in the Chiricahua flora. It has nearly 40% of the estimated flora of the Arizona portion of the Sky Island Archipelago (AZ SIA) and has nearly 42% of the AZ SIA region's reptiles and amphibians (50 of 120). However, it has substantially fewer herps than the other two smaller parks, probably because its higher elevation is too cold for many reptiles. That it has nearly 70% of the known AZ SIA mammals (69 of approximately 100) is quite remarkable. The 192 documented bird species seems low, especially considering that smaller Coronado NMem and tiny Fort Bowie NHS have almost as many. Either Chiricahua NM has less habitat diversity than the other two parks, or substantially more birds may yet be found at the monument.

Biological Corridors

Chiricahua NM is mostly montane, so it is probably more important as part of the southward summer/fall migration corridor of birds and bats than it is as a spring corridor. See section 4.1.2.9 for the general treatment of biological corridors.

Exotic Species

Exotic species that should be monitored and may need management action are: Maltese starthistle, Russian olive, watercress (may compete with water umbel if present), saltcedar, and bigleaf periwinkle (invasive in riparian habitats).

Rare and Endemic Biocommunities and Species

Chiricahua NM has populations of the rare plants *Hexalectris warnockii* and *Perityle cochisensis*; more possibilities are listed in Table 4.3. Rare vertebrates that are currently or were historically present are jaguar, lesser long-nosed bat, Mexican spotted owl, and Chiricahua leopard frog (Table 4.8). The lists are probably incomplete; see the discussion of data gaps below.

Ecosystem Health

The grassland in and adjacent to Chiricahua NM is mapped as native and considered healthy (although we observed some Lehmann's lovegrass along the road).

The woodlands and forests away from heavily trafficked areas are presumed to be mostly healthy, because they have not been subjected to major disturbances such as heavy grazing, logging, or extensive crown fires for several decades. However, many pines in Chiricahua NM are dying from infestations of at least two bark beetle species. Outbreaks are correlated with weakening of trees by drought and lack of hard frosts that control beetle populations. This does not necessarily indicate an unhealthy community; but if this phenomenon is a result of long-term climate change, significant alteration of the species composition of the forest can be expected.

The forest along the creek and road is very dense. While high density of trees can develop naturally, it is likely a result of long-term fire suppression. Extensive areas of dense trees and buildup of dead biomass increases the probability of crown fire. Catastrophic fire is a significant threat to park facilities located in these dense vegetation patches. The deep shade probably also greatly reduces the diversity of water-dependent species that could be supported by Silver Spur Spring. (The proximity of the road also has a negative impact, e.g., from people and vehicles disturbing and running over wildlife.)

A small area adjacent to the parking lot at Massai Point is heavily trampled by visitors. There is a dense network of footpaths that are devoid of understory vegetation. Some of it is on rather steep slopes. Erosion may not be a problem because the area is mostly rock, but it should be monitored. The damaged area is quite limited and seemingly not a problem at this time.

Coronado NMem

Border pressures are probably the greatest threat to Coronado NMem. The impacts of border activity have not been fully quantified; they need to be monitored more precisely and studies are currently under way. The most likely early indicator of habitat degradation from the disturbance is invasion of exotic species. If any become established, they could spread rapidly along the fence, roads, and trails. Most other stressors such as climate change and regional population growth are beyond the control of park managers.

Supporting Environment

Climate

Data from 2000-2009 for the "Coronado NM Headquarters" COOP station were compared to the station's 30-year historic average (1971-2000). Unfortunately, data for 2000-2009 were incomplete so we report on conditions with a low level of confidence. Overall, Coronado NMem temperature indicators (June maximum temperature, and January minimum temperature) were at or slightly above average compared to their respective reference conditions. January minimum temperatures were greater than 1°F warmer than the 30-year average while the June maximum temperatures were near the 30-year average. The precipitation indicator was near average compared to the 30-year average (1971-2000).

Air Quality

Five-year average (2004-2008) modeled air quality data provided by the NPS Air Resources Division was compared to reference conditions developed by the NPS Air Resources Division. Because we utilized modeled air quality data, the author's confidence in this assessment is moderate.

Based on the comparison of the 2004-2008 fourth-highest eight-hour ozone concentration modeled for Coronado NMem of 69.4 ppb to the reference condition set by the NPS Air Resources Division, ozone at Coronado NMem is rated as "moderate." The modeled 5-year average for Visibility Condition at Coronado NMem from 2004-2008 was 7.8 deciviews. Therefore, the visibility condition at Coronado NMem is rated as "moderate." Between 2004 and 2008, the modeled average total wet deposition of nitrogen was 1.9 kg/ha/yr and the average total wet deposition of sulfur was 0.9 kg/ha/yr. Therefore, nitrogen and sulfur deposition conditions are rated as "moderate."

Land Use

The NPScape landscape dynamics monitoring project provides landscape-level data to evaluate land use surrounding NPS units. Data provided by the NPScape project includes land cover for a 30 kilometer (km) area around each park unit, called the "local area." In 2001, approximately 93% of the U.S. area surrounding Coronado NMem was considered "natural." Approximately 7% of the land was converted and developed or used as pasture or for crop cultivation. There are no reference conditions for land cover in the Madrean Archipelago.

Groundwater

Groundwater at Coronado NMem is a vital resource, providing potable water for park operations and sustaining numerous springs situated throughout the park. Groundwater levels in Montezuma Canyon were measured regularly prior to the 2006 debris flow event. Depth to water in Montezuma Canyon at the park's original water supply well were around 40 feet (ft) prior to the 2006 event. Following that time, depth to water in that well rose to around 20 ft below measuring point, and a level of only 5 ft below measuring point was measured in winter of 2008. Depth to water at a new water supply well that was constructed on the mountain slope near the park's water tank is about 210 ft.

NPS monitoring of water levels in the Montezuma Ranch area of the Memorial has been ongoing since 2002. There is a high density of wells in the Ranch area. Repeated measurement of these wells has revealed the presence of water levels that differ greatly within a relatively small area at the Ranch. Analysis of these water level data, which show similar water levels within groups of nearby wells, strongly suggests the presence of a series of buried step-like blocks upon which groundwater ponds and flows downward towards the center of the basin. One of the ranch wells shows significant response to drought and wet periods. The other three appear to be much less impacted by changes in water availability to the basin. The deepest well in the ranch area is Border Well, measured in 1975 with a water level 625 ft below the surface. The Border Well is not monitored by NPS due to its location and lack of an accessible cap.

Seeps and Springs

In July 2010, NPS Sonoran Desert Network field crews surveyed twelve seeps and springs at Coronado NMem. Water was observed flowing at nine of the twelve seeps and springs. Because the data were collected in July, after the monsoon rain started, the data cannot be evaluated against the reference condition of surface water presence in June.

Water Quality

Water quality samples from sites at Coronado NMem show high levels of variability, which is attributed to a diverse geologic environment, to the presence of abandoned mine features and possibly to the localized impact of unauthorized human use. Natural water sources sampled at Coronado NMem were reviewed and compared to State of Arizona standards for Aquatic and Wildlife designated use.

All locations failed to meet the standard for dissolved oxygen at least once, except for Yaqui Spring. However, natural processes are reasonable explanations for the presence of low dissolved oxygen levels in the springs sampled; therefore the presence of dissolved oxygen in these waters below state criteria is not considered to be problematic or requiring attention. With the exception of dissolved oxygen, only one of the locations, Blue Waterfall seep below an unnamed mine (Headquarters 93-025), was determined to be exceeding applicable water quality standards. That location has been identified as a target for closure and backfilling. For these reasons, water quality at Coronado NMem is considered to be in good condition.

Soils

Overall, Coronado NMem soil indicators meet their respective reference conditions. However, the author's confidence in this assessment is low because the six monitoring plots used in the assessment represent a fraction (40%) of the intended sample size for monitoring sites. Therefore, confidence in the data and its ability to assess current conditions is low.

The areas of the park included in the NPS Sonoran Desert Network 2009 monitoring effort appear to be well-protected from soil erosion. The overall soil aggregate stability of the sites was moderate to high, indicating that the sites can resist erosion and that the soil-biotic system is functioning. Total cover of the sites was very high, with little exposed bare soil. However, a large amount of cover comes from litter and duff that could leave the sites susceptible to erosion if fire or drought removed those materials.

Biological Integrity

Major Biomes

Coronado NMem is one of only three NPS areas that contain Madrean biota (the others are Chiricahua NM and Guadalupe Mountains NP). There is also a substantial area of desert grassland.

Biological Diversity

Coronado NMem is remarkably diverse for its modest size (Table ES.2). Its total of 651 plants is not far behind Chiricahua NM's 803. The memorial has more than half of the amphibians and reptiles (74) and two-thirds (67) of the mammals in the Arizona Sky Island Archipelago and the most birds (200) of the three parks, which is 40% of the total for the Arizona part of the region.

Biological Corridors

Because of its range of elevations, Coronado NMem is part of both the northward and southward migratory corridors described in section 4.1.2.9.

Exotic Species

Exotic species that should be monitored and may need management action are: tree of heaven, yellow bird-of-paradise, Maltese starthistle, Lehmann lovegrass (management techniques can reduce its dominance), athel tamarisk, and bullfrogs.

Rare and Endemic Biocommunities and Species

Coronado NMem has the rare plants *Astragalus hypoxylus*, *Pectis imberbis*, and possibly *Echinocereus coccineus* var. *arizonicus* (the taxonomic status of this population is not settled). Other possibilities are listed in Table 4.4. Rare vertebrates that are currently or were historically present are grizzly bear, Mexican gray wolf, jaguar, jaguarundi (improbable), ocelot, lesser long-nosed bat, American peregrine falcon, and Mexican spotted owl (Table 4.12). The lists are probably incomplete; see the discussion of data gaps below.

Ecosystem Health

Most of the grassland within Coronado NMem is native and healthy. The far western end of the park is classified as shrub-invaded nonnative grassland and is therefore degraded.

The woodlands and forests away from heavily trafficked areas are presumed to be mostly healthy, because they have not been subjected to major disturbances such as heavy grazing or logging for several decades. Extensive areas were severely burned recently. Natural succession appears to be proceeding with little or no human input, so these areas are also healthy even if they are unsightly.

Special Themes

Border Impacts

Numerous efforts are underway, or were recently completed, at Coronado NMem to understand the impact of the infrastructure and border activities on ecological processes and communities. Data collection on the impacts of the pedestrian fence on stream channel morphology is ongoing. In general, large floods are expected to cause significant morphological change (Natural Channel Design, Inc. 2008). However, there have not been flow events significant enough to alter the channel morphology (E. Gwilliam, pers. comm. 2011).

A new study is underway to evaluate and develop methods to document unlisted trains on NPS lands, including Coronado NMem (T. Esque pers. comm. 2011). Based on existing data, we cannot report on border impacts.

Fort Bowie NHS

The most significant threats to Fort Bowie NHS appear to be climate change, fire, and possibly exotic species invasion.

Supporting Environment

Climate

Fort Bowie NHS maintains a National Weather Service Cooperative Observer

Program-style weather station, located between the maintenance and administration area and the Visitor Center. These data cannot be compared to a 30-year average because 30-year averages were not calculated for the Fort Bowie weather station. While the data underwent one round of quality control and quality assurance, the quality assurance process was not completed. Therefore, the results presented here are with a moderate level of confidence.

Precipitation at Fort Bowie NHS is highly variable. Between 2000 and 2009, the average annual precipitation at Fort Bowie NHS was 15.03 inches, which is less than the 1988-2009 station precipitation average of 16.46 inches. During 2000-2009, the average maximum temperature for June for years with reliable data (2000-2001, 2003-2009) was 94.8°F, which is slightly warmer than the 1988-2009 station average (94°F). The average minimum temperature for January for 2000-2009 was 34.1°F, which is warmer than the 1988-2009 station average (33.4°F).

Air Quality

Five-year average (2004-2008) modeled air quality data provided by the NPS Air Resources Division was compared to reference conditions developed by the NPS Air Resources Division. Because NPS Air Resources Division models air quality data for Fort Bowie NHS (or uses data from Chiricahua NM), the author's confidence in this assessment is moderate.

Between 2004 and 2008, the modeled average total wet deposition of nitrogen was 2.4 kg/ha/yr and the average total wet deposition of sulfur was 1.1 kg/ha/yr. Therefore, nitrogen and sulfur deposition conditions are rated as "moderate." Based on the 2004-2008 fourth-highest eight-hour ozone concentration modeled for Fort Bowie NHS of 69.4 ppb and the reference condition, ozone at Fort Bowie NHS is rated as "moderate." The modeled 5-year average for Visibility Condition at Fort Bowie NHS from 2004-2008 was 5.9 deciviews Therefore, the visibility condition at Fort Bowie NHS is rated as "moderate."

Land Use

The NPScape landscape dynamics monitoring project provides landscape-level data to evaluate land use surrounding NPS units. Data provided by the NPScape project includes land cover for a 30 kilometer (km) area around each park unit, called the "local area." In 2001, approximately 90% of the U.S. area surrounding Fort Bowie NHS was considered "natural." Approximately 10% of the land was converted and developed or used as pasture or for crop cultivation. There are no reference conditions for land cover in the Madrean Archipelago.

Groundwater

Groundwater resources at Fort Bowie NHS are vital to both the cultural and natural history of the park. Threats to groundwater resources in the Apache Spring watershed are associated with vegetation change from grassland to shrubland and accelerated erosion in the area of the second fort, long-term drought, changes in weather patterns that result in more intense storm events, and increased consumption of limited resources by adjacent landowners. This watershed is the source of the area springs and water supply for the park and should be proactively managed to restore vegetative cover and to enhance infiltration and soil retention. Static water levels in the limestone aquifer have not changed substantially since 2002.

Seeps and Springs

In June 2010, the NPS Sonoran Desert Network field crews surveyed three springs at Fort Bowie NHS and water was observed flowing at all three springs. This meets the reference condition, based on the authors' professional opinion, that all springs should have surface water present in June, prior to the monsoon. Data from 2010 had not undergone quality assurance/quality control, so the authors' confidence that the data represent presence of flow in June is moderate.

Average flow rates at Apache Spring have declined from rates of 7.5 to 10 gallons per minute (gpm) reported in the 1970's by Werrell (NPS Water Resource Division) to rates between 3 and 6 gpm observed since 1999.

The cumulative effect of several processes resulted in the decreased flow. The most likely processes include: increased transpiration by plants, soil losses causing increased runoff and reduced infiltration, and drought (Filippone 2009).

Water Quality

Natural water sources sampled at Fort Bowie NHS from Apache Spring and Lower Mine Tunnel Spring were reviewed and compared to State of Arizona standards for Aquatic and Wildlife (A&W) designated use. Both locations failed to meet the standard for dissolved oxygen at least once.

Low dissolved oxygen may be to some degree attributed to the presence of iron-oxidizing bacteria in groundwater at Fort Bowie NHS, which has been well documented as a result of problems these bacteria have caused to the water system at the park. Fort Bowie NHS shows higher levels of nitrate than is typical for springs in the area. Sources of nitrogen compounds to groundwater at the park are limited, and application of fertilizers or introduction of nitrogen via the park's wastewater leach field may be responsible. However, there is no A&Ww standard for nitrate. Because all of the samples were in compliance with A&W criteria for surface waters other than dissolved oxygen, water quality at Fort Bowie NHS is considered to be in good condition.

Soils

Hubbard et al. (2010) summarize results of the NPS Sonoran Desert Network's of terrestrial vegetation and soils monitoring at Fort Bowie NHS and suggest reference conditions to which data can be compared. While the data was collected recently using peer-reviewed data collection methods, the area of inference was less than half of the park. Therefore, our confidence in the data and its ability to assess current is moderate.

Overall, Fort Bowie NHS soil indicators meet their respective reference conditions. The areas of the park included in the NPS Sonoran Desert Network 2008 monitoring effort appear to be well-protected from soil erosion. The overall soil aggregate stability of the sites was moderate to high, indicating that the sites can resist erosion and that the soil-biotic system is functioning. Total cover of the sites was very high, with little exposed bare soil. However, a large amount of cover comes from annual grass plant bases, litter, and duff, which could leave the sites susceptible to erosion if fire or drought removed those materials.

Biological Integrity

Major Biomes

Most of Fort Bowie NHS' area is in a transitional zone between desert grassland and oak woodland. Which of these dominates has probably changed in historic and prehistoric times in response to minor climatic fluctuations and human land use. Chihuahuan desertscrub occurs within a few miles of the park, and Fort Bowie NHS' hillsides could permanently convert to desert if the thin soils erode away.

Biological Diversity

Fort Bowie NHS is quite diverse considering its tiny area (Table ES.2). Compared to the Arizona portion of the Sky Island Archipelago, Fort Bowie NHS has more than a quarter of its plants (572), more than half of the amphibians and reptiles (73, one fewer than larger Coronado NMem and many more than much larger Chiricahua NMem), well over half of the mammals (61), and nearly 40% of the birds (188).

Biological Corridors

Because of its relatively low elevation, Fort Bowie NHS is part of the northward migratory corridor for birds and bats (section 4.1.2.9).

Exotic Species

Exotic species that should be monitored and may need management action are: Lehmann lovegrass (management techniques can reduce its dominance), and curly dock.

Rare and Endemic Biocommunities and Species

Fort Bowie NHS has no known rare or endemic plants. The list of possibilities is in Table 4.3. Rare vertebrates that are currently or were historically present are grizzly bear, jaguar, lesser long-nosed bat, and Chiricahua leopard frog (Table 4.16). The lists are probably incomplete; see the data gaps below.

Ecosystem Health: The grassland northeast of Fort Bowie NHS is shrub-invaded nonnative grassland, while the area to the southwest is native grassland with low shrub cover. The condition of the grassland within Fort Bowie NHS is not classified on the available GIS layers. The AZ GAP vegetation layer categorizes it as mixed grass-mixed scrub with some mixed grass-yucca-agave. Our site visit revealed that a shrub invasion appears to be under way.

Fort Bowie NHS is in the ecotonal zone between grassland, woodland, and Chihuahuan Desert (which is a few miles from the boundary). The vegetation is therefore very sensitive to climate change and human disturbance, so significant shifts in community structure and floristic composition may occur in the future. Such change does not necessarily indicate a health problem.

Special Themes

Erosion

Erosion within the Apache Spring watershed was identified by resource staff at Fort Bowie NHS as a threat to the cultural and natural resources of the site. Nauman (2010) mapped 551 active erosion features within the Apache Springs watershed (163 sheet erosion features, 212 as rills, and 176 as gullies. Overall, 54,000 square meters within the Apache Springs watershed were affected by erosion. Nauman (2010) estimates that the 551 mapped erosion features represent nearly 59,000 cubic meters (m^3) of soil loss. The majority of soil loss (90%) occurred in gullies (approximately 57,000 m^3).

Data Gaps

We identified several data gaps during the condition assessment, listed below.

Invertebrate inventory: Two major areas are chronically overlooked in biological assessments. One is the invertebrate fauna. Invertebrates comprise about 90% of all species in most communities, yet are rarely given more than cursory attention. In most regions the state of knowledge is still in the alpha taxonomy phase (discovering and naming new species). The Sky Islands Region is no exception, although some groups have been fairly well documented thanks to researchers who have worked at the Southwestern Research Station and elsewhere in the region. The life cycles and ecological functions of the vast majority of species are still unknown. Forty-five invertebrate species that occur, or could occur, in Chiricahua NM, Coronado NMem and Fort Bowie NHS are listed by federal agencies for protection or as “species to guide management decisions” (e.g., USDA Forest Service; see Table C.5).

Soil biology: The other major neglected area is soil science. Soils are often mapped from a geological perspective, but their status as biological communities is usually ignored. These living substrates are the foundations of the ecological web, and are thus of crucial importance in understanding the health of the macrobiotic communities above ground. Most soil organisms belong to poorly studied groups, i.e., non-insect invertebrates and the kingdoms of small to microscopic organisms such as bacteria, fungi, cyanobacteria, and lichens.

One readily visible component of the soil community is biological soil crusts. Field guides for identifying the major organisms of biological soil crusts are beginning to appear (e.g., Rosentreter et al 2007). While the NPS Sonoran Desert Network includes biological soil crusts as part of its vegetation and soils monitoring program, there is limited information on the distribution, abundance and ecological role of biological soil crusts in the Madrean Archipelago. Further research is needed in this area.

Ephemeral/Intermittent Washes: We have limited information on the channel morphology, vegetation, and streamflow of ephemeral washes within the three park units. The NPS Sonoran Desert Network continues to develop a wash monitoring protocol that should partially address this data gap.

Seeps and Springs: We have limited information on the flow and biodiversity of seeps and springs within the parks and the region. The NPS Sonoran Desert Network is developing a monitoring protocol that should address a portion of this data gap. However, additional research is needed.

Other species inventories: The National Park Service and other land management agencies generally lack sufficient data on biological diversity to prevent, and even to recognize, the loss of species from protected lands (Swann et al. 2010). Thorough and regularly updated inventories are essential baselines from which to monitor the effectiveness of conservation programs. A useful inventory is more than a species list; it must include long-term distribution and abundance data in order to detect significant population trends.

The Inventory and Monitoring (I&M) database is several years out of date with respect to Karen Krebbs' bat inventories. Other inventories may also be out of date. The difficulty of maintaining the inventories is exacerbated by the ever increasing rate of taxonomic revisions, which make the comparison of biotas between parks particularly troublesome. (An example is the claret cup cacti *Echinocereus triglochidiatus*, *E. coccineus*, and *E. arizonicus*. Until recently they were regarded as a single species. After the recent splitting and subsequent partial recombining, it is not known whether one, two, or all three entities occur in the three parks. Certain identification requires chromosome counts.) The current I&M database is a monumental accomplishment, but still more work to complete it and keep it up to date is needed to make it fully useful.

Fire history: According to available GIS data, only Coronado NMem has spatial fire data, and only for two fires in the 2000s. There is a fire intensity map for Coronado NMem but the time period covered is not indicated. Data for Chiricahua NM and Fort Bowie NHS identify only ignition points, with no areal extent mapped. Only Fort Bowie NHS has a fuel density map. Table 4.6 contains fire data found in printed records; the data appears to be incomplete.

Grazing history: We have no detailed data on grazing intensity over time. This is important to know, because grazing can alter the composition of biological communities.

Impacts of border activities: We have limited information on the impacts of border activity; they need to be researched and monitored more precisely. While studies are currently underway, this is a critical data gap for border parks.

Vegetation maps: National Vegetation Classification Standard (NVCS) mapping is incomplete for the Sky Island Archipelago. We could not find a map that covers the region at the formation level, which is roughly equivalent to the extensively used Brown-Lowe-Pase vegetation map (BLP map, 1980). Several federal land management agencies are currently mapping their respective areas to the Alliance and Association levels, but without interagency coordination (Todd Esque, USGS, pers. comm. 2010). As detailed as the protocol is, the NVCS system is not sufficiently standardized to produce consistent classification by different teams. The result is that regional maps by one agency or survey team are not comparable to those of adjacent lands managed and classified by other agencies and teams. Therefore it is not possible to use existing (and probably future) NVCS maps to assess the abundance and distribution of vegetation types throughout the region. The three parks have almost no associations in common, which seems unlikely to us.

The most detailed map we found for Chiricahua NM is the GIS layer chir_veg_3BLP_poly; it was found on the NPS website, but its origin is unknown. The map does not conform to the current monument boundary. It maps the vegetation to the levels of Association and Subassociation (the latter category is not in the NVCS 2008 hierarchy).

Historic photographs: A preliminary inquiry revealed that there are numerous photos of likely value to NPS that are scattered among several agencies, including the Arizona State Historical Society and the Desert Laboratory on Tumamoc Hill (repeat photography project). Many of them are not cataloged under subjects that clearly identify them as valuable to NPS purposes. It will require considerable research to locate and catalog them in a central database, but it is probably worth doing. Some photos are kept at Fort Bowie NHS headquarters, reportedly not under archival storage conditions.

Species of conservation concern: There appear to be no existing lists for the three parks. We have compiled some tentative lists based on our experience and on lists for adjacent lands. There are probably omissions in these lists. The list of vertebrates of management concern is especially weak except for the charismatic megafauna.

Rare and Endemic Biocommunities and Species: The Arizona Gap Analysis Project (Gebow 2001) identified 4 at-risk plant communities in the Sky Islands Archipelago. But none of the park maps compiled in the GIS product identify any of them under the Gap names. There may be a mismatch in naming, or perhaps none occur in the three parks. Even though there are relatively few endemic species in the Sky Island Archipelago, lists of rare and endemic species we found seem short to us. They are probably incomplete. We found no list of rare and endemic vertebrates, other than the well-known charismatic megafauna.

Conclusions and Recommendations

Based on our review of existing information about the Madrean Archipelago, Chiricahua NM, Coronado NMem, and Fort Bowie NHS and our professional experience, we make the following recommendations and conclusions:

1. It is easier and biologically wiser to manage ecosystems than to manage individual species. The number of species of management concern in southeastern Arizona is large and continually growing. Realistically, park resources will never be sufficient to deal with each species as a separate management issue. Focusing attention on maintaining healthy biological communities will assure the well being of nearly all of their component species, leaving only a small number of highly specialized species that may require individual attention.

2. There is little need to fight most naturally caused fires in areas where there is not excessive fuel accumulation or human structures. But forests and shrublands that have unnaturally dense biomass are at risk of being damaged by fires. Before the 20th century frequent ground fires burned throughout most biological communities in the Madrean Archipelago. These fires had a neutral to positive long-term impact on the communities, because they are adapted to periodic burning. The policy of aggressive fire suppression begun in the early 1900s has resulted in fuel accumulation that has in turn led to catastrophic crown wildfires (Swetnam 2005). With the added stresses of climate change in the 21st century, crown fires are more likely than ever to cause type conversion (permanent replacement of one community by another) of large tracts of land to more arid and perhaps less stable communities.

3. Many of the ecosystems in the Sky Island Archipelago (and all over the planet) are characterized as fragile. We encourage the adoption of a different perspective. In fact, most ecosystems are robust and resilient. That so many of them are threatened is not so much a result of fragility as an indication of the enormous magnitude of damage that humans are inflicting upon them. If we develop an understanding of their functions and learn their limitations, they should thrive with modest management efforts.

4. Park management should monitor large predators, which as a group are essential to a healthy ecosystem. Three of the region's four largest predators (grizzly bear, Mexican gray wolf, and jaguar) have been extirpated, leaving only the mountain lion. The structure of sky island communities is probably changing

because of their absence. Smaller predators (bobcat, coyote, bats, etc.) are also important indicators of healthy ecosystems and should be monitored.

5. Continue to inventory and monitor bat species in parks; they make up nearly a third of the mammals of the region. There are few (if any) long-term bat-monitoring projects at Arizona NPS units other than the Krebbs' (2000 to present) summer bat surveys at Chiricahua NM and Fort Bowie NHS. Winter bat surveys are also recommended. Acoustic monitoring would provide additional information. Continue to monitor the transient roost (State of Texas Mine) and small adits for the endangered lesser long-nosed bats and Mexican long-tongued bats at Coronado NMem during the summer months.

6. Participate in reintroductions of extirpated species such as prairie dogs, black-footed ferrets, aplomado falcons, thick-billed parrots, Mexican gray wolves, etc. Habitat is available for these species in the parks.

7. Anticipate and embrace the possible immigration of animals from Mexico (jaguar, thick-billed parrots, ocelot, etc.) and other tropical animals and plants into the border parks. Global warming also should support the northward extension of the ranges of other tropical species. Similarly, climate change may drive mesic and cold-tolerant species higher in elevation and farther north, perhaps beyond park boundaries.

8. Digitize and share climate data from Fort Bowie NHS with the National Oceanic and Atmospheric Administration, National Weather Service to make the data available to researchers and the public. Sharing the data will require quality assurance/quality control measures and will allow for 30-year historic average calculations.

9. Continue to monitor spotted owl nests and populations in the Chiricahua and Huachuca Mountains.

10. Facilitate research on the distribution, abundance and ecological function of biological soil crusts in the Madrean Archipelago.

11. The Apache Spring watershed is the source of the area springs and water supply for Fort Bowie NHS and should be proactively managed to restore vegetative cover and to enhance infiltration and soil retention.

12. All efforts should be made to protect biological corridors from northern Mexico (i.e.-Ajos-Bavispe Federal Reserve) to southeastern Arizona. Corridors provide connectivity and improve animal populations, health, and enhance adaptation in the face of widespread environmental change (e.g., climate change).

13. Identify species of management concern including invertebrates, and initiate surveys and monitoring efforts (several dozen species of insects are listed as of special concern to federal agencies – see Table C.5).

14. Develop cooperative management polices with the neighboring Forests (USDA Forest Service), for habitats and species that cross park boundaries, such as vegetative communities, riparian corridors, and large and/or vagile animal species. The Landscape Conservation Cooperative program of the Department of the Interior (Nature 2011; US DOI 2009) might be a good model for such cooperation.

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Chapter 1: Background Information

Publisher's Note: Some or all of the work done for this project preceded the revised guidance issued for this project series in 2009/2010. *See Prologue (p. xii) for more information.*

Over 270 U.S. national park units ("parks") include significant natural resources. These parks serve a common National Park Service (NPS) mission goal…to protect, restore, and maintain natural resources and associated values in good condition, and to manage those resources within their broader ecosystem context. Parks are highly diverse in terms of their resource setting, size, and primary management purposes. Guided by law and NPS management policies, each park must work toward a clear understanding of their desired conditions: what are the park's most important natural resource features, processes, and values to protect; what are their target condition states; how will they be measured and tracked over time; and, are target conditions the same across the entire park, or do they vary by management subareas?

Given the high diversity among parks in terms of their primary resource setting and management purposes, these questions must be addressed on a park-by-park basis. Natural resource condition assessments (NRCAs) give park managers an interdisciplinary synthesis of existing scientific data from varied sources: taken together, what does the best-available science say about current conditions, critical data gaps, and potential condition influences for that park's most important natural resources? The assessments seek to translate scientific data and knowledge into a more accessible form for use in park planning, decision making, and accountability reporting purposes.

NRCAs are intended to provide a spatially explicit multi-disciplinary synthesis of existing scientific data and knowledge, from multiple sources, to help answer the question: what are current conditions for important park natural resources? All NRCAs share standard elements related to study design and reporting products. Within those general guidelines many important study details remain flexible, to be decided on a park by park (individual project) basis. All NRCAs:

- are multi-disciplinary (ecological) in scope, though breadth and number of resources/indicators evaluated remain project-level decisions
- report on current conditions across the entire park, though for practical reasons some park areas will be excluded from consideration
- rely on existing data from NPS science support programs and other professional sources, but field-based rapid assessment techniques can be used with prior approval
- use hierarchical study frameworks that include the following components: natural resource indicators; reference conditions; current condition reporting by indicators, by ecological characteristics or attributes, and by park areas
- use the standard NRCA report outline as the template to report key study findings
- emphasize spatial analyses and reporting products which are especially helpful for the types of expected uses outlined above

NRCAs do not establish management targets for study indicators. Decisions about management targets must be made through sanctioned park planning and management processes. NRCAs do provide science-based and expert information that will help park managers with an ongoing, longer term effort to describe and quantify their park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning and help parks report to government accountability measures.

Due to their modest funding, relatively quick timeframe for completion and reliance on existing data and information, NRCAs are not intended to be exhaustive. Study methods typically involve an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in our present data and knowledge bases across these varied study components.

NRCAs can yield new insights about current park resource conditions but in many cases their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Over the next several years, the NPS plans to fund an NRCA project for each of the ~270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA Program information is posted at: http://www.nature.nps.gov/water/NRCondition_Assessment_Program/Index.cfm

Chapter 2: Park Resource Setting

2.1 Park Enabling Legislation and Setting

2.1.1 Chiricahua National Monument

Chiricahua National Monument (NM) was established by Presidential Proclamation No. 1692 (43 Stat. 1946) on April 18, 1924 under the authority of the Antiquities Act (NPS 1996). The proclamation stated that the monument was to "preserve certain natural formations, known as The Pinnacles, within the Coronado National Forest, in the state of Arizona, are of scientific interest, and it appears that the public interests will be promoted by reserving as much land as may be necessary for the proper protection thereof, as a National Monument (NPS 2005)." Initially managed by the U.S. Forest Service, the National Park Service (NPS) has managed the monument since 1933.

Chiricahua NM is located approximately 40 kilometers (km) southeast of Willcox, Arizona and contains 11,985 acres, of which 10,290 acres are designated as wilderness (NPS 1999a). Most of the land to the north, east, and south of the monument are managed by the U.S. Department of Agriculture (USDA) Forest Service. South and southeast of the monument lies the 87,700 acre Chiricahua Wilderness. The Sulpher Springs Valley, west of the monument, is largely in public ownership interspersed with Arizona State Land Department lands.

Chiricahua NM lies within the Chiricahua Mountains, which is part of a unique biotic community where deserts and grasslands separate mountain "islands." Locally distinctive plants and animals include Apache Fox Squirrel, Arizona Cypress, Apache Pine, and Chihuahuan Pine. The Chiricahua NM General Management Plan identified species of interest (because of their threatened or peripheral status) including jaguar, jaguarundi, peregrine falcon, elegant trogon, violet-crowned humming bird, and blue-throated hummingbird (NPS 1999a).

Cultural resources at Chiricahua NM are diverse and include evidence of prehistoric and historic occupation by Native Americans including the Cochise and Athabascan cultures and the Apaches. The monument also contains sites occupied by the U.S. Army during the Geronimo Campaign, an example of settlement of the west at the close of the Indian Wars as depicted by the Faraway Ranch, and classic structures built by the Civilian Conservation Corps (NPS 1999a).

2.1.2 Coronado National Memorial

Coronado National Memorial (NMem) was established by Presidential Proclamation No. 2995 (55 Stat. 630) on November 5, 1952 by President Harry S. Truman to commemorate the significance of Francisco Vasquez de Coronado's expedition and the resulting Spanish colonial cultural influences. The memorial encompasses 4,750 acres and is adjacent to the U.S./Mexico border, located approximately 30km south of Sierra Vista, Arizona (NPS 2004).

Private and Arizona State Land Department lands border the memorial on the east. The Bureau of Land Management's (BLM) San Pedro Riparian National Conservation Area lies approximately 8km east of the memorial. The San Pedro Riparian National Conservation Area encompasses nearly 57,000 acres along the San Pedro River between the international border and St. David, Arizona. USDA Forest Service lands surround the monument on the north and west. The 20,000 acre Miller Peak Wilderness lies immediately the northwest of the memorial. The U.S. Army's Fort Huachuca begins on the north side of the Miller Peak Wilderness and encompasses over 70,000 acres. Ridges with 1,000 feet of relief surround three sides of the memorial. Desert grasses and shrubs dominate the lower elevations while oak woodlands and piñon-juniper forest dominate the upper elevations of the memorial (NPS 2004).

While no physical evidence has been found, the Coronado Expedition (1540– 1542) probably entered the United States east of the memorial in the San Pedro River Valley. The memorial commemorates the international implications and subsequent Hispanic cultural development of the expedition, not the actual crossing point (NPS 2004).

2.1.3 Fort Bowie National Historic Site

An act of Congress dated August 30, 1964 (Public Law 88-510) created Fort Bowie National Historic Site (NHS) to preserve the site and structures of the "old Fort Bowie." In addition to the fort, the site commemorates the Chiricahua Apaches, soldiers, and the Butterfield Overland Trail and Stage Station (NPS 1999b). The NPS mission at Fort Bowie NHS is to "preserve the historic ruins of Fort Bowie, which was established by the U.S. Army in 1862, and interpret its significance in the military operations against Geronimo and his band of Chiricahua Apaches (NPS 1999b)."

The 1000-acre Fort Bowie NHS sits approximately 20km south of Bowie, Arizona. Lands managed by the Bureau of Land Management (BLM) border the site to the north and south. Much of the BLM land is within the Bowie Mountains Scenic Area of Critical Environmental Concern. Private land encompasses the areas west and east of the site.

Fort Bowie NHS contains most of Apache Pass and lies between the Chiricahua and Dos Cabezas Mountains. Apache Spring provided a reliable source of water to Native Americans, soldiers, and wildlife (NPS 199b). Elevations at the site range from 4,550 to 5,250 feet and the vegetation consists of riparian woodlands, desert scrub, woodlands, chaparral, and grasslands.

2.2 Resource Stewardship Science

Twelve basic natural-resource inventories have been authorized and funded through the National Park Service for all 270 park units deemed to have "significant" natural resources (NPS 2009). At the time of writing, ten of these inventories had been completed for Chiricahua NM and two others are in progress for completion at some future date. Eight of the inventories are complete for Coronado NMem and Fort Bowie NHS and four are in progress (Table 2.1). Coordinated at the national level, most of these inventories rely on existing information and deliver products ranging from electronic data sets to short reports. However, three inventories (species lists, species occurrence and distribution, and vegetation characterization) involved extensive fieldwork culminating in detailed reports.

The NPS Sonoran Desert Network covers 11 parks in the geologically and biologically diverse Sonoran Desert and Apache Highlands ecoregions of southern Arizona and southwestern New Mexico, including Coronado NMem, Chiricahua NM, and Fort Bowie, NHS. The NPS Sonoran Desert Network conducts long-term monitoring on air quality, birds, climate, groundwater, exotic plants, land use/land cover, terrestrial vegetation and soils, seeps, springs and tinajas, perennial streams, and ephemeral/intermittent washes. Details on these efforts are provided on the NPS Sonoran Desert Network website, http://science.nature.nps.gov/im/units/sodn/.

At Chiricahua NM, the Sonoran Desert Network is monitoring air quality, climate, groundwater, landbirds, and vegetation and soils. At Coronado NMem, the Sonoran Desert Network is monitoring climate, groundwater, landbirds, and vegetation and soils. At Fort Bowie NHS, the Sonoran Desert Network is monitoring air quality (station located at Chiricahua NM), climate, groundwater, landbirds, springs, and vegetation and soils. In 2010, the Sonoran Desert Network undertook a seeps and springs inventory at Chiricahua NM, Coronado NMem, and Fort Bowie NHS, with the goal of developing a monitoring protocol in 2011. In addition, the Sonoran Desert Network continues to develop a wash monitoring protocol that will be implemented at all three parks addressed in this assessment.

Assuming that much of the research taking place in the sky islands would be known to faculty at the University of Arizona, we placed an inquiry on the listserves of the School of Natural Sciences and the Environment and the Department of Ecology and Evolutionary Biology. We received only one response (below):

Table 2.1. Status of natural resource inventories at Chiricahua NM, Coronado NMem, and Fort Bowie NHS, October 2010.

Inventory	Description	Chiricahua Status	Coronado Status	Fort Bowie Status
Air Quality Data	Baseline air quality data collected both on and off-park	Complete	Complete	Complete
Air Quality Related Values	An evaluation of resources sensitive to air quality	Complete	In Update	In Update
Base Cartographic Data	A compilation of basic electronic cartographic materials	Complete	Complete	Complete
Baseline Water Quality	Assessment of water chemistry	Complete	Complete	Complete
Climate	A basic assessment of nearby climate stations and instrumentation	Complete	Complete	Complete
Geologic Resources	A synthesis of existing geologic data, resulting in a report and electronic map	Complete	In Progress	In Progress
Natural Resource Bibliography	An electronic catalog of natural resource-related information	Complete	Complete	Complete
Soil Resources	Electronic geospatial data regarding basic soil properties	Complete	Complete	Complete
Species Lists Species Occurrence and Distribution	Documentation of the occurrence and distributions of >90% of the vertebrates & vascular plant species, based on prior research and fieldwork	Complete	Complete	Complete
Vegetation Characterization	Description, classification, and mapping of vegetation communities, based on fieldwork	In Progress	In Progress	In Progress
Water Body Location and Classification	Basic geographic data on hydrologic units	In Progress	In Progress	In Progress

John Koprowski and students have been working in the region since 1994. All projects have been on mammals and funded through the Western National Parks Association (and their predecessor SWPMA), Desert Southwest Cooperative Ecosystem Studies Unit, National Geographic Foundation, or Arizona Game and Fish Department. They have worked on Mexican fox squirrels, white-nosed coatis, skunks, javelinas, and general carnivore surveys.

Many researchers conduct field work based at the Southwestern Research Station (SWRS) of New York's Museum of Natural History, in the Chiricahua Mountains. The Station's annual newsletter lists the long-term projects being conducted there. Most are on narrow topics; the full list is in Appendix D. The few topics that may be of interest to land managers include:

- Effects of climate change on butterflies: Timothy Bonebrake, Stanford University, CA.
- Ecology of small owls. Fred and Nancy Gehlbach. Baylor University, Waco, TX.
- Annual survey of winter plant species. Michele R. Schutzenhofer. Saint Louis Univ., St. Louis.
- The biogeographic role of large, deep canyons on invertebrate biodiversity. Lawrence E. Stevens. Stevens Ecological Consulting, Flagstaff, AZ.
- Linking pollination to population and community dynamics. Susan Elliot, University of Georgia.

- Plant-herbivore interactions along an environmental gradient. Josh Donlan, Cornell University.

- Catherine Hulshof, a PhD student at the University of Arizona, is evaluating plant species abundance, composition, diversity and function along the gradient from desert to mountain summit (more commonly known as Whittaker's or Forest Shreve's gradient) in Coronado NMem.

- Wendy Moore and Richard Brusca (University of Arizona) recently initiated a study of ground-dwelling arthropod biogeography in the Sky Islands of southeastern Arizona.

Chapter 3: Study Approach

3.1 Preliminary Scoping

Preliminary scoping was conducted for the purpose of selecting natural resources to be included in this assessment, as well as for identifying a relevant spatial context within which the assessment would be made. The National Park Service (NPS) conducted the preliminary scoping in three sessions. The first session was used to identify important natural and cultural resources, management themes, and concerns in each park. From this initial scoping session, a preliminary study framework was developed. A second scoping session brought together the NPS with the investigators and focused on prioritizing the list of potential natural resources to be included in the assessment based on a combination of importance to the parks and availability of data. Following the second scoping session, the study framework was revised to adhere in spirit to the 2009 NPS guidance on Natural Resource Condition Assessments. The NPS-only third session was used to identify and roughly delineate for each park areas that reflect potentially different priorities or concerns with respect to resources and management (management/thematic overlays). These overlays define the informal spatial context within which resources are viewed by NPS staff present at the meeting, as well as forming the basis upon which some reference conditions may be established. In addition, NPS staff identified preliminary management and interpretive themes for areas within the management overlays to articulate the basis of these overlays. The overlays and their corresponding management/interpretive themes are discussed in detail below.

3.1.1 Park Involvement

Park staff were engaged during the preliminary scoping, as described above, and throughout the development of the condition assessment. Table 3.1 describes the personnel and their roles in the condition assessment.

3.1.2 Other NPS Involvement

In addition to the park staff listed in Table 3.1, NPS Intermountain Region and Sonoran Desert Network staff participated in the preliminary scoping of the assessment and provided information and resources to the core team. Investigators from the Arizona-Sonora Desert Museum and Sonoran Institute visited the Sonoran Desert Network office to obtain spatial data. In addition, National Park Service staff conducted limited information and literature searches at the Western Archeological and Conservation Center.

3.2 Selection of Reporting Areas

3.2.1 Ecological Foundation

Chiricahua NM, Coronado NMem, and Fort Bowie NHS are relatively small parks within the Madrean Archipelago (see section 4.1 for further description of the Madrean Archipelago). Therefore, we used the Madrean Archipelago (or a portion of the Archipelago) as the ecological foundation.

3.2.2 Management/Thematic Overlays

During the third scoping meeting, NPS staff collaborated on the identification of reporting areas of management interest for the three parks. These areas do not represent officially designated management zones but represent an initial attempt to identify areas that differ in the resources they contain and/or management priorities, for which the park may benefit from reporting the condition relative to those areas in addition to other scales (e.g., parkwide). Unfortunately, data used in this assessment was not able to provide an assessment at the management area level.

The management areas for Chiricahua NM (Figure 3.1) are:

- Historic District – The historic district includes the historic Faraway Ranch, former Civilian Conservation Corps (CCC) camp, a Buffalo Soldiers encampment location, and the current and former administrative, maintenance, housing, visitor facilities and campground areas at the monument. Primary management themes and concerns for this area include cultural resource protection, visitor experience, park operations and vegetation management for cultural landscapes (Table 3.2).

- King of Lead Mine – This area surrounds the King of Lead Mine, located just across the northeastern boundary of the park. Effects of past and future mining, access concerns, and the mine's position in the upper reaches of the watershed are primary management themes and concerns for this area (Table 3.2)

- Non-wilderness – The non-wilderness area contains areas in the park that are not included in other management overlays. There are no specific management themes for non-wilderness areas.

- Pinnacles – The park was established for the protection of the Pinnacles. As such, primary management concerns and themes are protection of integrity of the rock formations and the influence of geology on ecology in the Pinnacles area. The Pinnacles area includes a high

Table 3.1. Personnel who contributed to the Natural Resource Condition Assessment. Also shown are their primary role and function as a contributor toward the assessment.

Name	Affiliation	Role	Team Function
Mark Dimmitt	Arizona-Sonora Desert Museum	Principle Investigator	Leads effort for completing NRCA within NRCA guidelines
Joel Viers	Arizona-Sonora Desert Museum	GIS Coordinator (Cooperator)	Provides primary GIS support
Richard Brusca	Arizona-Sonora Desert Museum	Investigator	Provides subject matter expertise
Karen Krebbs	Arizona-Sonora Desert Museum	Investigator	Provides subject matter expertise
Thomas R. Van Devender	Arizona-Sonora Desert Museum	Investigator	Provides subject matter expertise
Alix Rogstad	Arizona-Sonora Desert Museum	Investigator	Compiled data and wrote sections on biological threats/stressors
Cheryl McIntyre	Sonoran Institute	Principle Investigator	Leads effort for completing NRCA within NRCA guidelines
Lindsay Fitzgerald-DeHoog	Sonoran Institute	Investigator	Compiled data and literature
Alison Berry	Sonoran Institute	Investigator	Provides subject matter expertise
Colleen Filippone	NPS Regional Hydrologist	NPS Key Official	Provides project direction consistent with NRCA guidelines
Danielle Foster	Chiricahua NM, Fort Bowie NHS, Coronado NMem	Chief Natural Resources Management	Ensures direction is consistent with park information needs
Kym Hall	Coronado NMem	Superintendent	Ensures direction is consistent with information needs
Nancy Keohane	Coronado NMem	Natural Resource Manager	Compiles administrative history and documents
Deborah Angell	Southern Intermountain Region Parks	NRCA Information Manager	Develop management overlays and literature search

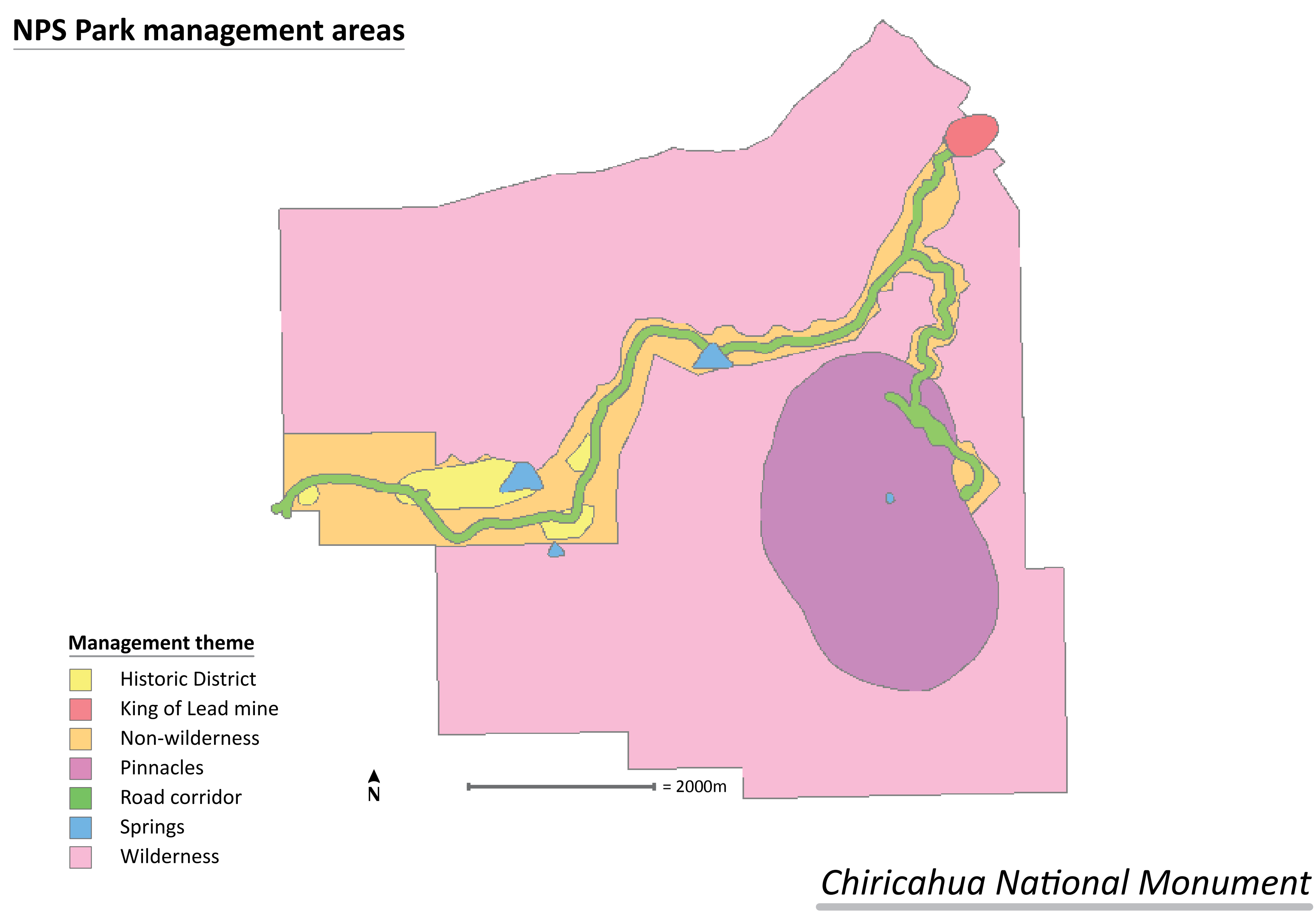

Figure 3.1. Management/Thematic overlays for Chiricahua NM

Table 3.2. Chiricahua NM Management Areas and Associated Primary Management Themes

Management Area	Primary Management Themes
All Areas	Safety
Historic District (173 acres)	Cultural resource protection Cultural/Civilian Conservation Corps/Mission 66 structures Visitor experience Visitor facilities Vegetation management for cultural landscape Vegetation management for visitor use Exotic plant management Fire – fuel reduction Integrated pest management issues Park operations Housing Flooding Wildlife habitat Utility related vegetation management Water supply
King of Lead Mine (48 acres)	Actual and potential effects of past and future mining Access concerns for mine, law enforcement, visitors Top of watershed Red Horse Extension – mine restoration
Pinnacles (1615 acres)	Rock formations (pinnacles and hoodoos) Influence of geology on ecology (microenvironments) Viewshed
Road Corridor (372 acres)	Park operations High visitor use Viewshed Vegetation management Fire & fuels Cultural resources/Civilian Conservation Corps Riparian system Wildlife corridor Implications of road kill Poaching Exotic species - grasslands Cultural resources Wildlife: deer, wild turkey Flooding
Springs (48 acres)	Water quantity and quality Aquatic and wildlife habitat Cultural significance
Wilderness (8931 acres)	Wilderness values Scattered archaeological sites (prehistoric and historic) Civilian Conservation Corps built trails Horseback use and high visitor use Wildlife habitat: Mexican spotted owls Biodiversity Fire Rock formations Influence of geology on ecology Recharge for water Cattle trespass Poaching Border issues Minimum Requiremens Decision Guide

proportion of the park's trails, many of which wind through the Pinnacles. The area also includes all or portions of Echo Canyon and Rhyolite Canyon.

- Road Corridor – The road corridor area includes buffers around the Entrance Road and Bonita Canyon Road. The numerous management themes for the road corridor are listed in Table 3.2.

- Springs – Springs at Chiricahua NM possess both cultural and natural significance. Primary management themes for the springs include water quantity, wildlife and aquatic habitat, and cultural significance.

- Wilderness – Eighty-seven percent (87%) of the monument is designated as wilderness (10,290 acres). Designation of the Chiricahua NM Wilderness was made on October 20, 1976 (Public Law 94-567). As wilderness, management of this area is guided by NPS Director's Order No. 41. Archeological sites are scattered through the Chiricahua NM Wilderness, which is accessed by CCC built trails. The area receives high visitor use and faces challenges from concentrated visitor use, cattle trespass and border issues. Additional management themes are found in Table 3.2.

The management areas for Coronado NMem (Figure 3.2) are:

- Administrative – The administrative area contains current administrative buildings, a lookout, a picnic area, and the Coronado Cave. Management themes for the area include interpretive programs and visitor facilities, caves, park operations and the Montezuma Pass viewshed (Table 3.3).

- Canyon – The canyon area covers most of Montezuma Canyon as it descends from northwest to southeast across the park. Riparian habitat, hydrologic processes including flooding, wildlife movement, and road infrastructure impacts are some of the management themes for the area (Table 3.3).

- Grassland – The southeastern portion of the park consists of grassland and is an important feeding area for the lesser long-nosed bat. The area was once home to cattle operations and is bordered on the southern boundary by the U.S./Mexico boundary pedestrian fence. The primary management themes for this area center on its former use, proximity to the border, and natural resources (Table 3.3).

- Road Corridor – A winding mountain road bisects the park and takes visitors from the park entrance to the top of Montezuma Pass. In addition, two roads lead from the main road to the U.S./Mexico border. Management themes for the road area include migration, cultural resources, and border interdiction (Table 3.3).

- Uplands – The uplands area covers the majority of the park, is home to a myriad of wildlife, and is important for groundwater recharge. Since the memorial's trails cross through the uplands area, this management area receives significant visitor use and faces additional challenges resulting from its proximity to the border. Table 3.3 describes additional management themes for the area.

The management areas for Fort Bowie NHS (Figure 3.3) are:

- Administrative – The administrative area contains current administrative buildings on the western boundary of the park. Management themes include park operations and encroachment by adjacent landowner.

- Apache Spring – Apache Spring provides reliable surface water and is located near the ruins of the first and second forts. As such, the spring has both natural and cultural resource significance and the management themes listed in Table 3.4 reflect the springs' significance.

- Fort – The fort area contains the ruins of the First Fort Bowie and the Second Fort Bowie and receives significant visitation. The primary management themes

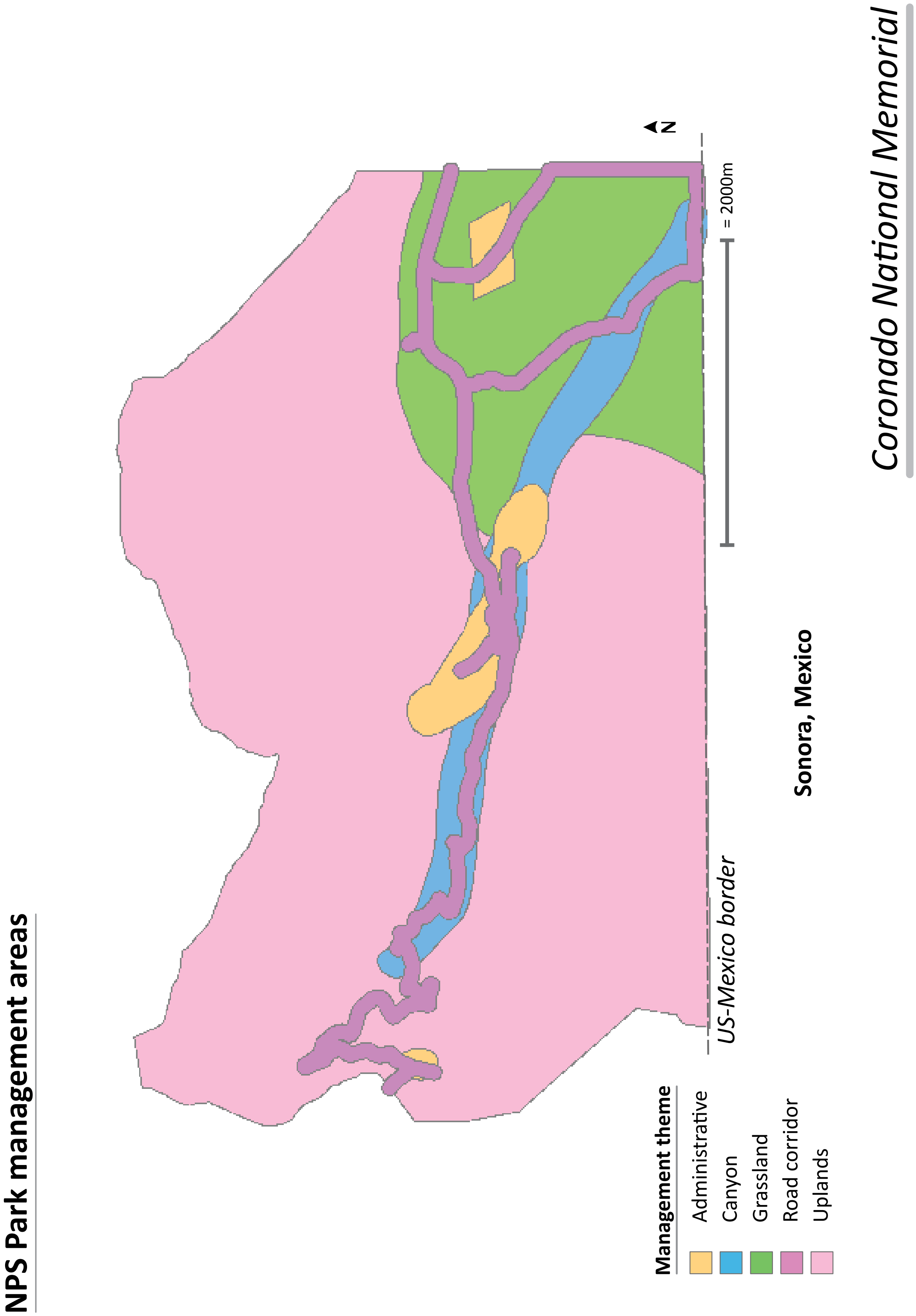

Figure 3.2. Management/Thematic overlays for Coronado NMem

Table 3.3. Coronado NMem Management Areas and Associated Primary Management Themes

Management Area	Primary Management Themes
All Areas	Safety
Administrative (121 acres)	High visitation – majority of visitor use within park Visitor facilities Caves Interpretive programs Fuel concerns - fire Montezuma Pass viewshed Park operations Water supply
Canyon (190 acres)	Riparian habitat Hydrologic processes Flooding and debris flows Impact of pedestrian fence on hydrologic processes and erosion Rolling debris Road infrastructure impacts Wildlife habitat and corridor Water supply
Grassland (648 acres)	Open grassland Viewshed Lesser long-nosed bat habitat/T&E species feeding area High exotics population (Lehmann lovegrass) Cemetery Grazing infrastructure (remaining corral and buildings) Inholdings Accessible grassland trail planned Fire Pedestrian fence & border tower Homeland Security issues – border interdiction Through travel/migration/smuggling Some cultural resources
Road Corridor (350 acres)	Dirt section of main road – eligible for & submitted to National Historic Register Visitor use Flooding Transportation/access to & beyond Montezuma Pass Homeland Security issues – border interdiction Through travel/migration/smuggling Access to border road Poaching Cultural resources Windmill Road

Table 3.3. Coronado NMem Management Areas and Associated Primary Management Themes

Management Area	Primary Management Themes
Uplands (3563 acres)	Viewshed Wildlife habitat Threatened & endangered species habitat Mines (historic) Homeland Security issues – border interdiction Through travel/migration/smuggling Border impacts Recreational use – Crest, Joe's Canyon, Cave trails Visitor/UDA interactions – Crest/Joe's Canyon/Cave trails Springs & seeps Groundwater recharge Fire Erosion – debris flow Limestone Cultural significance - State of Texas mine Blue waterfalls (Comprehensive Environmental Response, Compensation, and Liability Act site)

include cultural resources, the cultural landscape, the viewshed and visitation. Table 3.4 lists additional management themes for the fort area.

- Grassland – The grassland area covers Triangle Valley as well as a portion of grassland on the western boundary.

- Other Springs – In addition to Apache Spring, several other springs dot the landscape. Primary management themes for this area are water rights and water quantity.

- Proposed Expansion – The proposed expansion area to the south and north of the park contain cultural sites and will provide continuous habitat.

- Siphon Canyon – Siphon Canyon flows south to north through the park and borders the Triangle Valley. Management themes for the canyon include riparian habitat, border activity, wildlife, and guzzler maintenance.

- Trail Network – Most park visitors arrive at the historic fort site by walking the park's trails. However, the trail network extends beyond the trail from the parking area to the fort area and passes numerous cultural sites. Table 3.4 lists additional management themes for the trail network area.

- Uplands – The uplands area covers the majority of the park, contains scattered cultural sites, and is an important viewshed. Additional management themes and concerns include mines and mining access, border activity, and poaching.

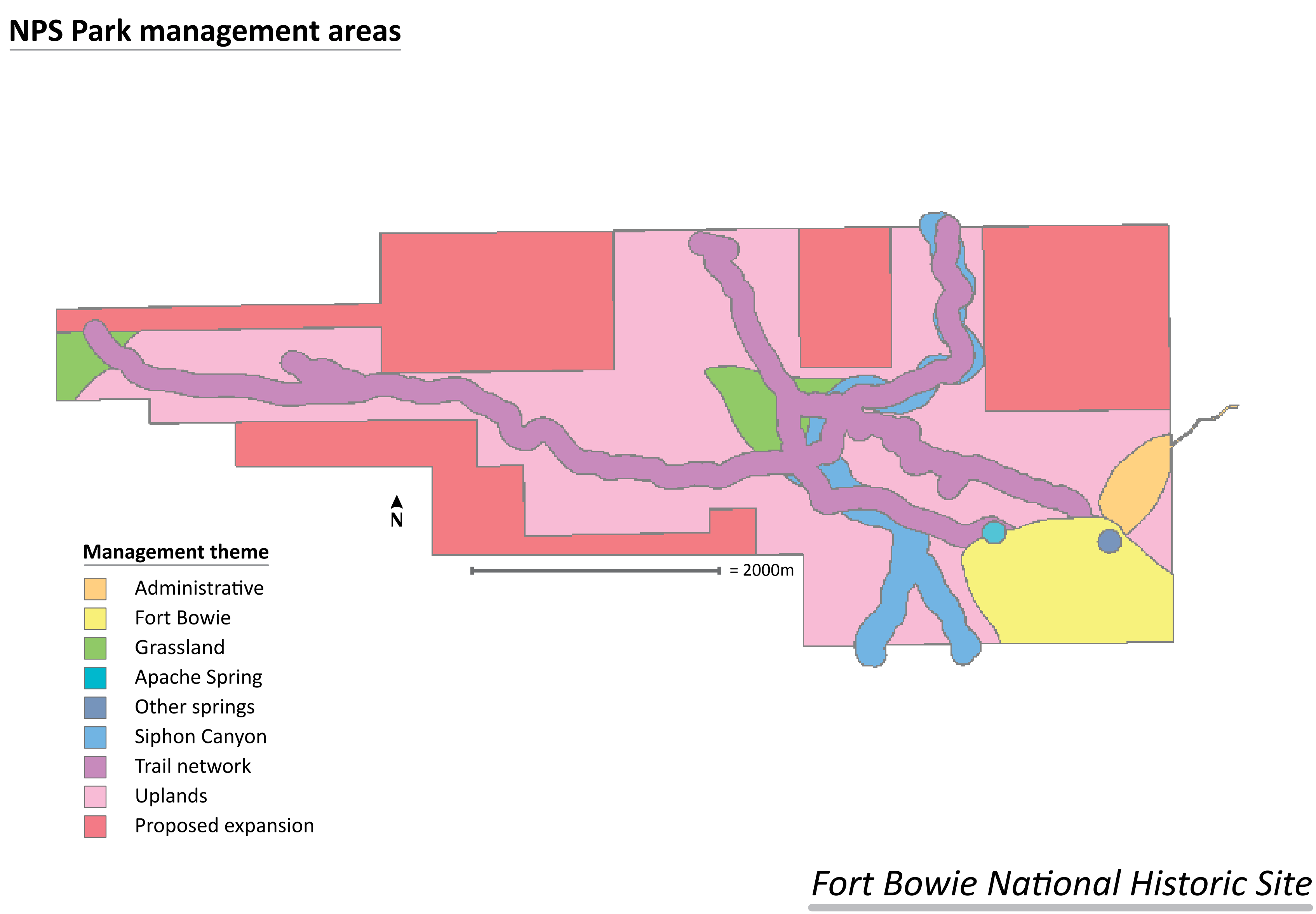

Figure 3.3. Management/Thematic overlays for Fort Bowie NHS

Table 3.4. Fort Bowie NHS Management Areas and Associated Primary Management Themes

Management Area	Primary Management Themes
All Areas	Safety
Administrative (21 acres)	Park operations Handicapped access Encroachment by adjacent land owner Water supply
Apache Spring (2 acres)	Riparian system Water quantity – declining flows Water rights – share with former owner Water supply to drinker – important bat water source Wildlife habitat Cultural significance Visitor use Spring box Erosion throughout the watershed
Fort (99 acres)	Cultural resources/landscape Viewshed Visitor use/Visitor facilities Vegetation control-restoration of cultural landscape Bat maternity roost Wildlife habitat Recharge to aquifer and Apache Spring Erosion and soil loss Poaching Archeological Resources Protection Act Trails
Grassland (34 acres)	Grassland Visitor experience Trails Fire-fuels Mesquite treatment Cultural sites/cemetery/Butterfield stage trail/ruins/other Wildlife habitat
Other Springs (2 acres)	Water rights (share with former owner) Water quantity Wildlife habitat
Proposed Expansion (518 acres)	Protect cultural sites Continuous protected habitat
Siphon Canyon (55 acres)	Riparian habitat Through travel/migration/smuggling Wildlife Guzzler maintenance Debris flows Trails
Uplands (574 acres)	Viewshed Cultural sites (prehistoric and historic) Wildlife habitat Trails Mines and mining access Erosion and debris flows Through travel/migration/smuggling Poaching Archeological Resources Protection Act

3.3 Selection of Resources and Indicators

3.3.1 Assessment Framework Used in the Study

The usefulness, consistency, and interpretation of the Natural Resource Condition Assessment is facilitated by a framework that:

- Employs indicators and reference conditions/values
- Rolls up indicator findings to report conditions by ecosystem characteristics
- Rolls up indicator findings to report conditions by park areas

There are several such frameworks that meet these criteria, most of which overlap considerably, but differ slightly in how they group and split categories. For this assessment, we modified a framework developed by the Heinz Center (Figure 3.4; The Heinz Center 2008) which fits well with the resources at the parks and includes a category (specialized themes/topics) that facilitates incorporation of cultural resource values and other priority themes and topics.

3.3.2 Consideration of Park Fundamental Resources and Values

We identified fundamental and important resources to be included in this assessment during the scoping process. Where applicable, we incorporated them directly from park planning documents. However, we did not limit inclusion to those resources directly identified in planning documents and additional important resources were identified as part of the scoping process. Resources

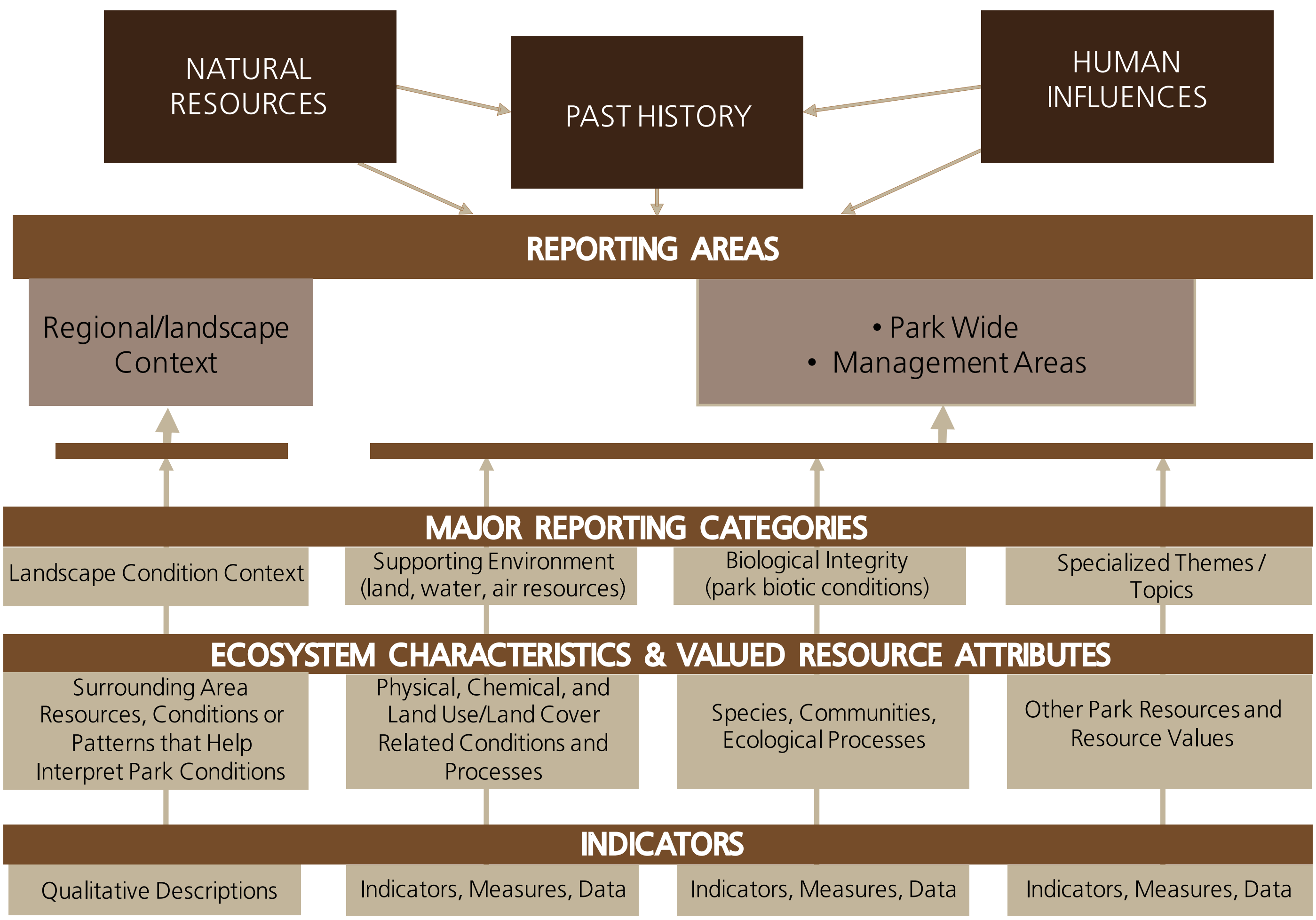

Figure 3.4. The hierarchical assessment framework used in this assessment. Adapted from The Heinz Center (2008).

identified during the scoping included rare, endangered, threatened or candidate species, keystone species, sensitive species, U.S. Forest Service species assigned to "guide management decisions" and "species that require special management consideration," invasive species, major vegetation communities, ecological processes, surface water, groundwater, air quality, soil, geology, and climate.

3.3.3 Study Priorities – Resources and Indicators

Unfortunately, we were not able to conduct a condition assessment for all resources of interest to the parks. Budget limitations and associated time constraints necessitated limiting the assessment to resources of high priority. However, it was not feasible to conduct the assessment even for all of the high priority resources since few of them had data from which to base an assessment of current condition. As such, we selected the resources to include assessment from the list of potential resources identified during the scoping process by a sequence of criteria. First, we determined whether the resource was considered a high priority by the park. We also considered resources with high ecological significance, even if the resource was not considered a priority by the park. For each resource that met the park or ecological significance criteria, we determined if sufficient data existed for an assessment. We also determined if a reference condition existed or if there was sufficient context to compare the current condition of the resource. For resources that lack sufficient data or context, we provide a descriptive narrative and/or identify important data gaps.

3.4 Forms of Reference Conditions / Reference Values Used in the Study

Reference conditions provide the point(s) of reference against which current conditions are measured, interpreted, and reported. They are sometimes identified as benchmarks, standards, norms, or thresholds (among other terms). Source data and methods can involve historic or comparison-site data, best professional judgment, quantitative models, regulatory standards, etc. They do not have to represent pristine natural conditions or be highly quantitative, precise and statistically repeatable—though all of these qualities are desirable.

NRCAs do not establish a park's desired conditions or management targets. These are determined through separate park management and planning activities. However, through use of appropriate reference conditions and values, NRCAs can assist park managers as they consider what their park's desired conditions and management targets should be. In cases where park management has already quantified these conditions or targets, they can be introduced as such and used as reference conditions/values within an NRCA.

The general idea of reference conditions centers around the comparison of a given site with some other site or condition being used as a "reference." These references may be actual sites in another location or time, or they may be some hypothetical or assessed condition (desired condition, natural range of variability, etc). Reference conditions may take on different forms depending on how they are being used but in this assessment, we use reference conditions in the context of condition reporting. In this context reference conditions take on a form analogous to a standard or benchmark. The benchmark can also have several forms such as a desired condition, legal standard, range of acceptable variability, etc. The current condition is compared to such a benchmark to derive an assessment about the quality of the resource condition. For this assessment, we primarily use ecological reference conditions (values developed via historic data, modeling site comparisons, best professional judgment, etc.) and values based on natural resource management priorities and context. In some cases, we utilize reference conditions based on legal/regulatory standards. In the text, where reference conditions are utilized, the basis or context for developing the benchmark is identified.

While reference conditions, baselines, or expected trends of indicators are important for monitoring programs to be able to make a determination about the current state of an ecosystem or variable or to assess the effectiveness of management practices, estimating reference conditions is difficult and imprecise. A lack of undisturbed ecosystems makes it difficult to collect measurements at so-called reference locations. In addition, an incomplete understanding of the relationship between an indicator and an ecosystem and of the variability of an indicator or ecosystem makes estimating reference conditions difficult. Furthermore, the potential for non-linear relationships between an indicator and an ecosystem clouds reference conditions. Therefore, we recognize that the reference conditions proposed within this assessment are imperfect, although we believe them to be the best informed opinions possible at this time and benchmarks for park resource management goal setting

3.5 Study Methodologies

Much of the data used in this assessment are Geographical Information System (GIS) data. ArcMap version 9.3 GIS software was used to store, edit, and display data. A regional project area was created by drawing a bounding box around much of the Madrean Archipelago (Figure 3.5). A 3 kilometer (km) buffer was delineated for each park (Figures 3.6-3.8). General base map layers and specific topical layers were developed for the full region and for the 3km boundary around each park. Accurate and useful data were re-projected into the North American Datum 1983 (NAD83) datum and the Universal Transverse Mercator (UTM) zone 12 projection. Metadata was generated for each layer following the Federal Geographic Data Committee (FGDC) compliant format. All GIS data layers were imported into an ArcGIS File Geodatabase using ArcCatalog version 9.3. The geodatabase and project map file were populated with GIS data obtained through an extensive search of NPS sources as well as local, state, and federal sources. The map project file was populated with GIS data through an extensive search of NPS sources. See Appendix A for additional information about the GIS product.

Additional non-GIS data for biological and physical resources were acquired from the NPS, including the NPS Sonoran Desert Inventory and Monitoring Network, which covers all three parks. In addition, we acquired data and information from literature searches, and directly from universities, non-profits, local, federal, and state agencies.

In addition to compiling existing data, ASDM staff made several field trips to the parks to refresh our familiarity with the region and to discuss the concept of ecosystem health in situ. The ASDM team has a combined several decades of experience working in the Sky Islands Archipelago, on which our professional opinions are based. Richard Brusca is part of a University of Arizona research team that is investigating soil invertebrates throughout the Sky Island Archipelago, and his group has spent considerable time in the Chiricahua and Huachuca Mountains. The Sonoran Institute made several trips to the parks to compile and scan existing data and reports. In addition, Sonoran Institute staff made two field trips to the parks to investigate the physical resources. The Sonoran Institute team has a combined decade of experience working in the Sky Islands Archipelago and five years of experience on ecological assessments, on which our professional opinions are based.

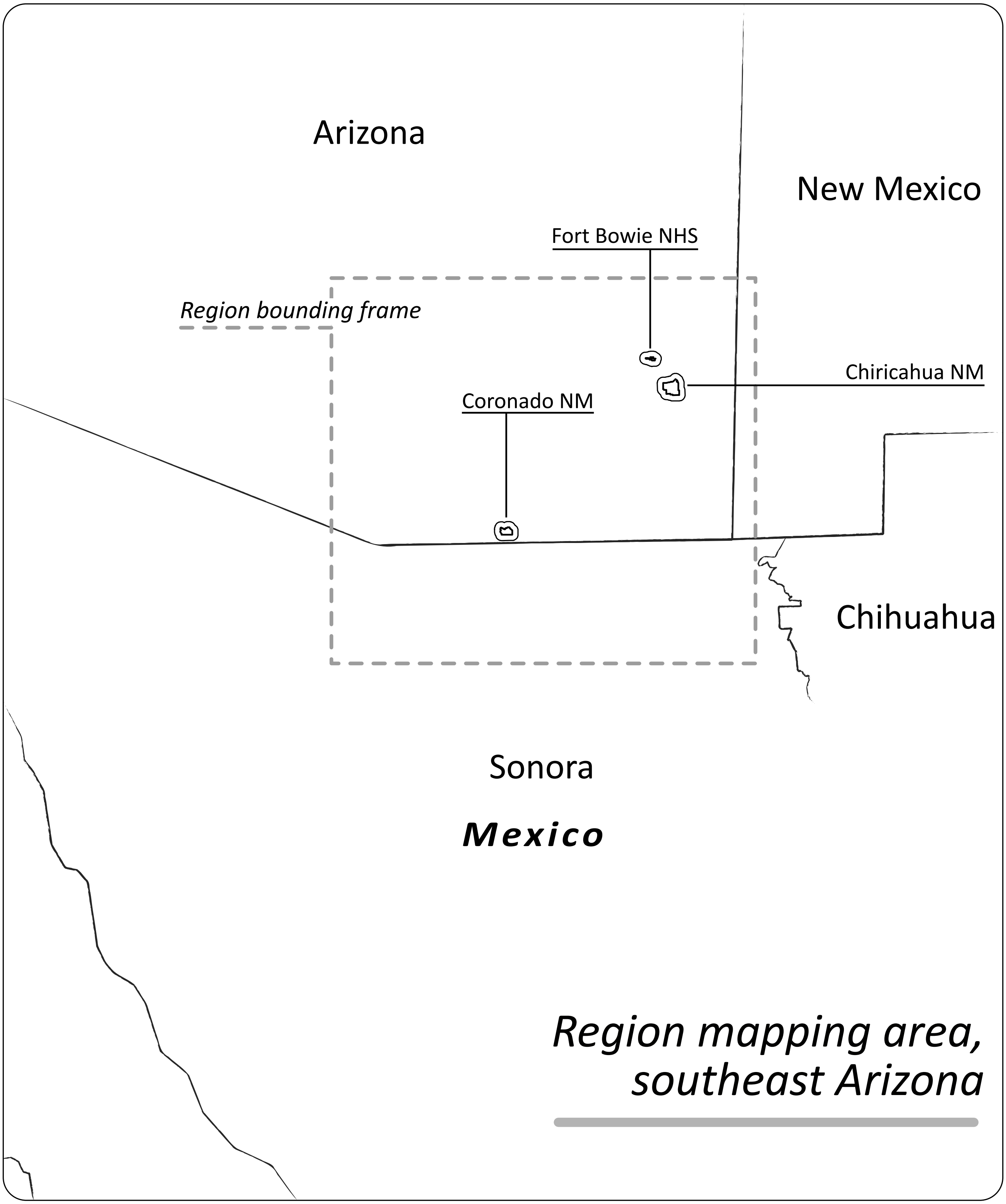

Figure 3.5. Regional mapping area, southeast Arizona.

General features & elevation

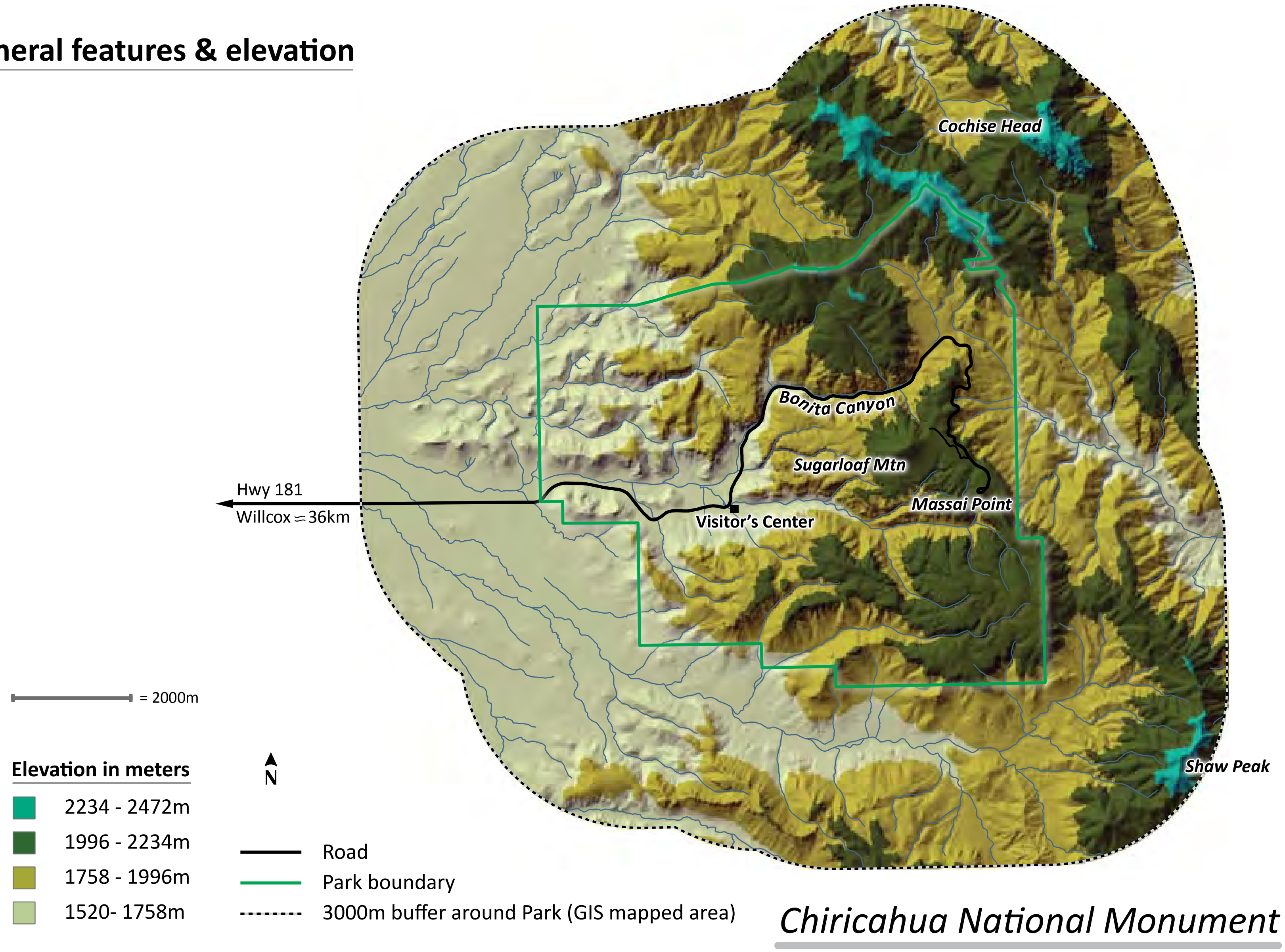

Figure 3.6. General features, elevation, and 3 kilometer mapping buffer at Chiricahua NM.

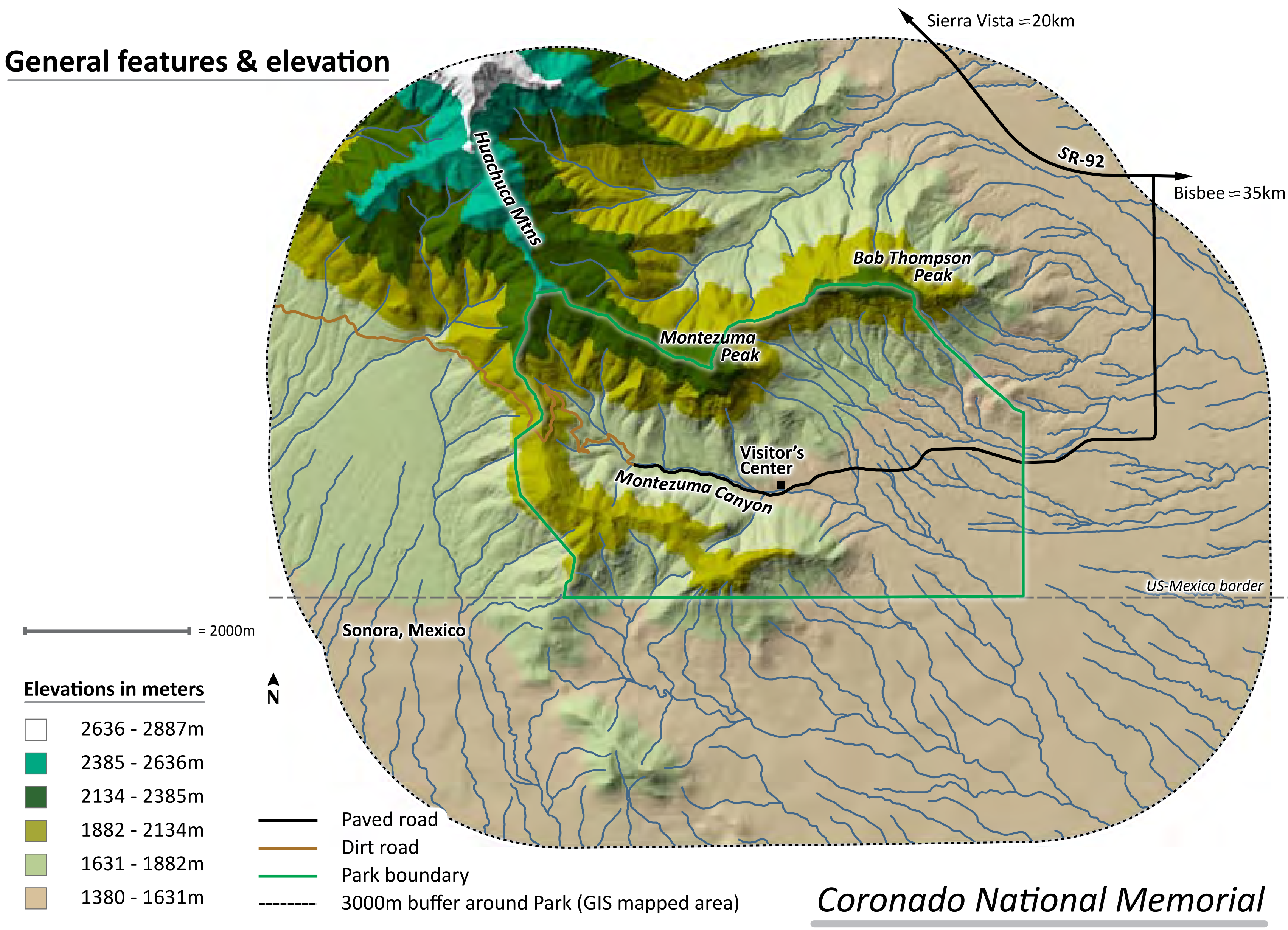

Figure 3.7. General features, elevation, and 3 kilometer mapping buffer at Coronado NMem.

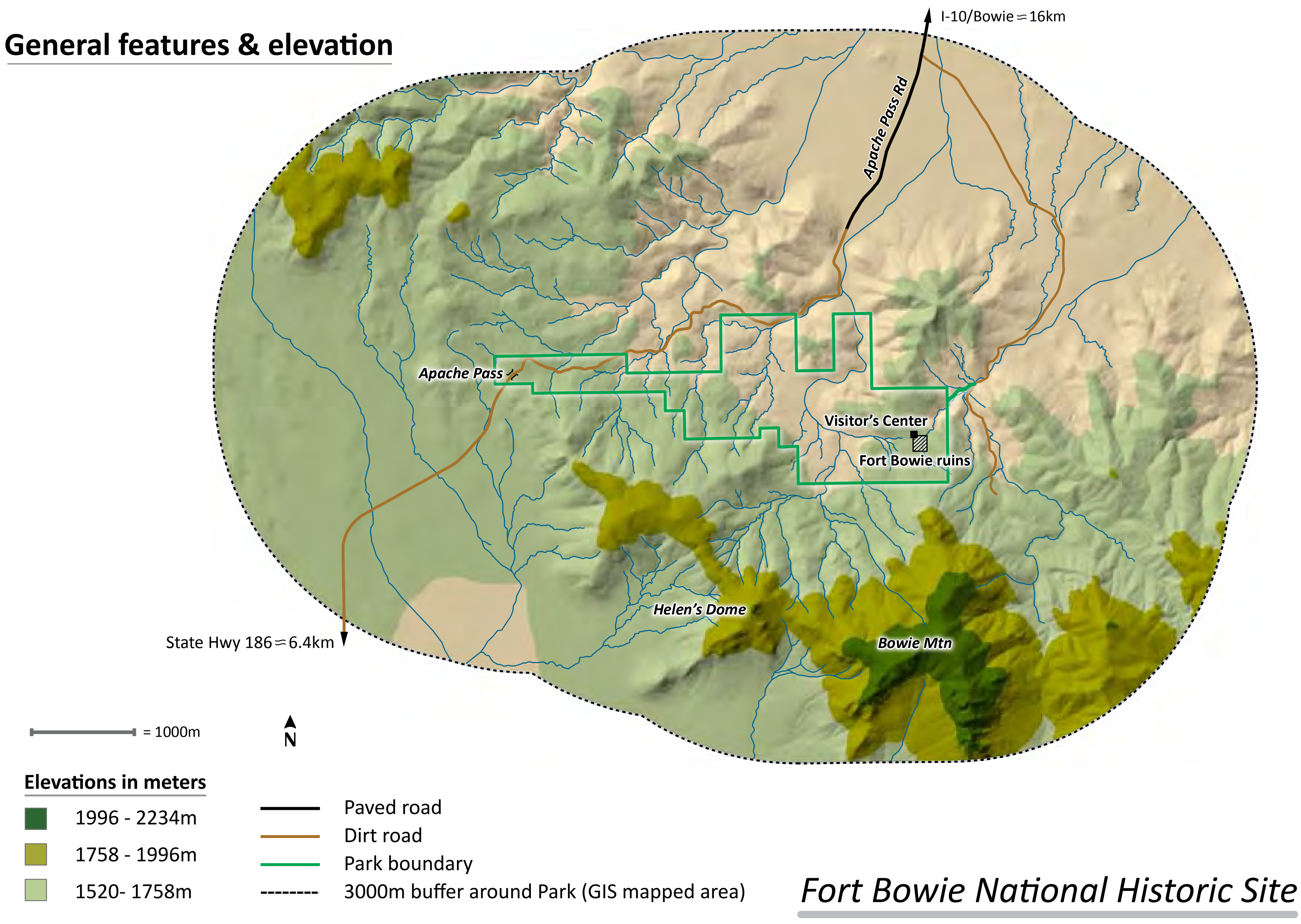

Figure 3.8. General features, elevation, and 3 kilometer mapping buffer at Fort Bowie NHS.

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4.1 Regional/Landscape Context

The southwestern United States and northwestern Mexico abound in unique and interesting geographic names of Spanish, English, and various indigenous language origins, reflecting a rich cultural heritage. The numerous overlapping and sometimes conflicting terms for the region between the northern end of the Sierra Madre Occidental in Sonora and the Mogollon Rim in Central Arizona can cause confusion.

On the second United States-Mexico Boundary Survey in 1892-93, Lieutenant David Gaillard took detailed notes on the natural history of the borderlands including the Sierra San Luis and Cajón Bonito (Mearns 1907). He described the region as “bare, jagged mountains rising out of the plains like islands from the sea”. Weldon Heald, a resident of the Chiricahua Mountains, named the ranges in southeastern Arizona sky islands (Heald 1951), evoking the image of continental islands emergent from inland seas of desert grassland or desertscrub. Marshall (1957) studied the birds and dominant plants in pine-oak woodland in mountain ranges in southeastern Arizona and northeastern Sonora, and in the northern Sierra Madre Occidental in Chihuahua. This was the first comprehensive study in the region, but he did not use the term “sky island” (lower case or capitalized, with or without hyphen). Variants include Sky Island Region (McLaughlin 1995, Gottfried et al. 2005, Skroch 2008), sky-island ranges (Felger and Wilson 1995, Fishbein et al. 1995), and sky island bioregion (Fishbein et al. 1995, Skroch 2008). The Sky Island Alliance is a volunteer, non-profit organization dedicated to the protection and restoration of native species and habitats in the Sky Island Region.

“Sky islands” are ecological or regional phenomena restricted to isolated mountain ranges crowned with woodlands and forests. Marshall (1957) and Lowe (1964) discussed the distributions of biotic communities on mountain ranges in response to climatic gradients. At higher elevations, rainfall increases as temperature and area decrease. More mesic (wetter) vegetation occurs above more xeric (drier) vegetation in all mountainous areas, not just in the sky islands. For example in the Sonoran Desert, Arizona Upland desertscrub is surrounded by Lower Colorado River Valley desertscrub in the Sierra Estrella near Phoenix, and Foothills Thornscrub is above Plains of Sonora desertscrub in the Sierra Espinazo Prieto north of Hermosillo. Considering that species richness generally increases in biotic communities above desert grassland, Chihuahuan and Sonoran desertscrub, and foothills thornscrub, the Madrean Sky Islands have higher species diversity than lowland areas. The analogy to oceanic islands (Warshall 1995) is limited because sky islands differ from true insular areas in having high species diversity, low local and regional endemism, and low percentages of non-native species (McLaughlin 1995). While any isolated area is a potential area for speciation in small populations, there are relatively few species restricted to the sky island mountains.

The term **Madrean** comes from the Sierra Madre. The Mexican Plateau is a vast area of grasslands and desertscrub between the Rocky Mountains in New Mexico and the Trans-Mexican Volcanic Belt in south-central Mexico about 1,300 km (800 mi) to the south. Although the Plateau is open to incursions of frigid Arctic air from the north, the Sierra Madre Oriental on the east and the Sierra Madre Occidental on the west create a double rain shadow, drying the mid-continent. Madrean is a general term used to describe things in or from the two Sierra Madres.

Another recent term that aptly expands the sky island image is **Madrean Archipelago**, which is often used interchangeably with **Sky Island Region**, was first used by Lowe (1992) in a biogeographical analysis of the herpetofauna of Saguaro National Monument (now a Park; McCord 1995). Bennett and Kunzmann (1992) used the term the same year in a paper on factors affecting plant species richness at the Chiricahua Mountains Research Symposium (Bennett and Kunzmann 1992), crediting Lowe (1992) as the source.

It was quickly accepted and widely used at the 1994 *Biodiversity and Management of the Madrean Archipelago. The Sky Islands of Southwestern United States and Northwestern Mexico* symposium (Debano and Ffolliott 1995).

The Nature Conservancy's **Apache Highlands Ecoregion** includes most of the mountain ranges in the Madrean Archipelago, with the exception of the Baboquivari Mountains in Arizona and a few ranges south and west of Moctezuma in Sonora (Marshall 2004, Turner et al. 2005). The Apache Highlands also includes a large area of Mediterranean interior chaparral below the Mogollon Rim in Central Arizona northwest of the Madrean Archipelago.

Other phytogeographic terms have been used for this region as well. McLaughlin (1995) considered the Sky-Island Region as equivalent to his **Apachean district of the Madrean floristic province**. Felger and Wilson (1995) write about the **Apachean-Madrean region** of northern Mexico, an area that included the Apachean district and some Sky-Island ranges, but extended southward along the Chihuahua-Sonora border to Sinaloa in the Sierra Madre Occidental.

Throughout this report, we primarily refer to the region as the **Madrean Archipelago** but also use the terms **Sky Islands Region** and **Sky Islands Archipelago**.

4.1.1 Physical Resources and Setting

4.1.1.1 Geology, Topography, and Landforms

The Madrean Archipelago lies within the Basin and Range geologic province, which spans from southern Idaho and Oregon to northern Mexico. Within the Basin and Range province, broad alluvial valleys separate approximately 400 roughly parallel mountain regions that trend from northwest to southeast (Kiver and Harris 1999). Large faults were created roughly 20 million years ago when the Earth's crust stretched, thinned and cracked (USGS 2000). Mountains were uplifted and valleys down-dropped along the faults (Nations and Stump 1996). In some areas, the vertical relief between the valley and mountain top is 10,000 feet (USGS 2004). Mountains in the Basin and Range province continue to erode into the adjacent valleys through the forces of water, ice, and wind (USGS 2000; USGS 2004; Kiver and Harris 1999).

Limestone outcrops, found in the higher mountains (e.g. Huachuca and Chiricahua), are significant contributors to biodiversity and groundwater resources in the Madrean Archipelago. Water moves relatively easily through the fractured and porous limestone to recharge aquifers. In southeastern Arizona, most limestone was deposited 200 to 400 million years ago, when a shallow marine environment covered much of central and western North America.

In addition to the mountain ranges, landforms within the Madrean Archipelago include alluvial fans, bajadas, pediments, stream cuts, and playas. The sediment carried by mountain stream channels during rare, heavy rain events forms alluvial fans. As the stream channel enters the relatively flat valley floor, it spreads out, streamflow decreases dramatically, the water loses its ability to suspend sediments, and the stream deposits sand, gravel and silt. Sediment from the stream channel forms a delta-shaped pile of roughly stratified particles, known as an alluvial fan. When several alluvial fans combine to form a sloping surface along a mountain front, the surface is known as a bajada (Nations and Stump 1996). Pediments stretch from the edge of the mountain towards the large fault and adjacent valley and are formed as the stream channels wear the mountain front away. Subsequently, the shoulders are buried by a thin layer of gravel (Scarborough 2000). Basins without an outlet (closed basin) drain into nearly level playas. Playas can be temporarily covered by water but are typically dry most of the time (ADWR 2009).

Chiricahua NM lies within the northwest portion of the Chiricahua Mountains, a range of inactive volcanoes with peaks approaching 10,000 ft. The mountain range is roughly 20 miles wide and 40 miles long. The geologic history of the area includes volcanic events and tectonic compression and stretching. The thrust faulting found in the

Chiricahua and Dos Cabezas mountains was the result of convergence of the plates during the Late Cretaceous to middle-Tertiary time periods (Graham 2009). The area underwent the crustal thinning and stretching which resulted in the topography of the Basin and Range province.

The geology of most of Chiricahua NM (Figure 4.1) is influenced by the eruption of the volcano associated with what is now known as the Turkey Creek caldera. The volcano erupted approximately 27 million years ago and produced volcanic material that was one thousand times greater, by volume, than that produced by the 1980 eruption of Mount St. Helens (Graham 2009). The amount of material was so large that the ground surface collapsed into the void left by the material; creating the Turkey Creek caldera (Pallister et al. 1997). The Chiricahua Mountains and nearby areas are the only areas that contain the volcanic rocks that resulted from the Turkey Creek volcano eruption (Graham 2009). The eruption filled the paleobasin in the central part of the monument with Rhyolite Canyon Tuff, an ash-flow tuff that has eroded into the dramatic cliffs and pinnacles in and near Bonita and Rhyolite Canyons (NPS et al. 2005). Fault blocks in the northeast corner of the monument expose the monument's oldest rocks: late Paleozoic, Permian limestones, which are around 280 million years old. Erosion and weathering over the past two million years carved the volcanic deposits into the configuration that characterizes Chiricahua NM. Weathering and chemical processes continue to alter the landscape (Graham 2009).

The complicated geology of the area containing Coronado NMem (Figure 4.2) resulted from the eruption of the Montezuma caldera volcano and subsequent volcanic events. Some areas of the memorial exhibit a juxtaposition of age in the rock layers. For example, sandstone and red shale are overthrust onto younger granite in the northeastern portion of the memorial (Denney and Peacock 2000b). In addition, the memorial contains limestone laid down by a shallow sea around 270 million years ago. Water seeping through cracks in the limestone likely formed the caves at the Memorial.

The Apache Pass fault, Pennsylvanian and Cretaceous limestone on Precambrian granite, characterize Fort Bowie NHS (Figure 4.3). Numerous small drainages dissect a homogenous area of Precambrian granite. Exposed granite emerges in the western portion of the park typically as very steep to vertical outcroppings. The northeastern portion of the park is a complex of metamorphic and sedimentary limestone and calcareous rock in folded layers. In some areas, granite alluvium deposited by stream channels has formed stable fan terraces (Denney and Peacock 2000c).

4.1.1.2 Soils

Soil, a thin layer of mineral and organic material, supports living plants, microbes, and vertebrate and invertebrate soil fauna and plays a central role in the cycling of nutrients, water, and energy in terrestrial ecosystems (Strahler and Strahler 1984). Soils form relatively slowly and are the result of climate, biological processes, underlying geology, and topographic position. Compared to most biological processes and land-management cycles, soil development is imperceptibly slow (Brady and Weil 2002). It takes 100,000 years of Ice Age climate to regenerate a foot of soil.

Soil scientists classify soils based on measurable properties such as texture, soil depth, structure, and clay mineralogy, characteristics that are relatively static compared to land management cycles. The highest and most generalized level of the hierarchical soil classification is order. According to the Arizona General Soil Map, there are five soil orders in the Arizona portion of the Madrean Archipelago: Alfisols, Aridisols, Entisols, Mollisols, and Vertisols (Hendricks 1985). As its name implies, the General Soil Map is a broad inventory of soils in Arizona and is based on more detailed soil surveys, when possible. Alfisols tend to occur at higher elevations and have light-colored surface layers with clayey subsurface layers. Aridisols also have light-colored surface layers and typically have calcium carbonate in at least some of the soil. In many cases, Entisols (relatively young soils that lack subsurface horizons) formed in alluvium in

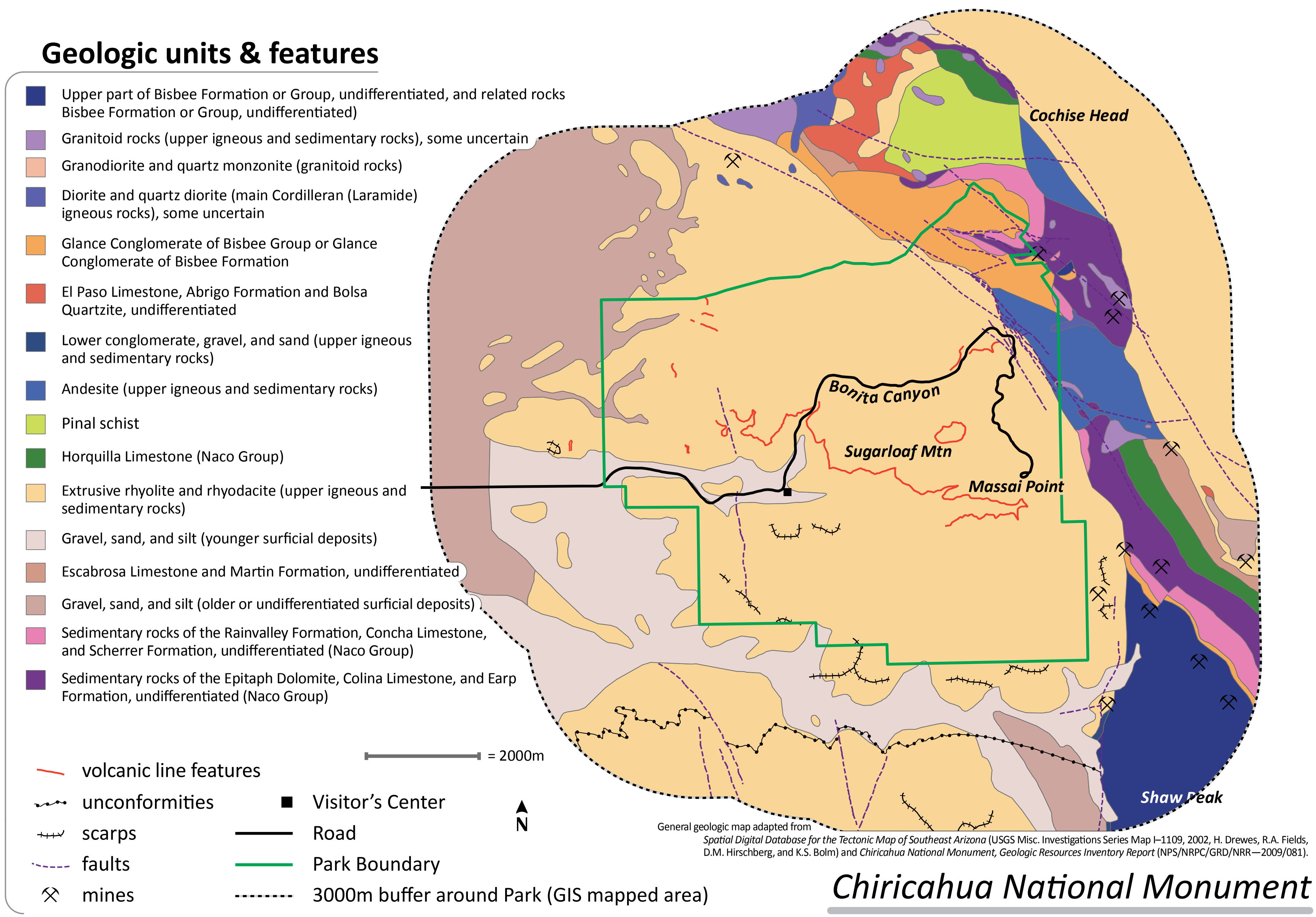


Figure 4.1. Surface geology at Chiricahua NM.

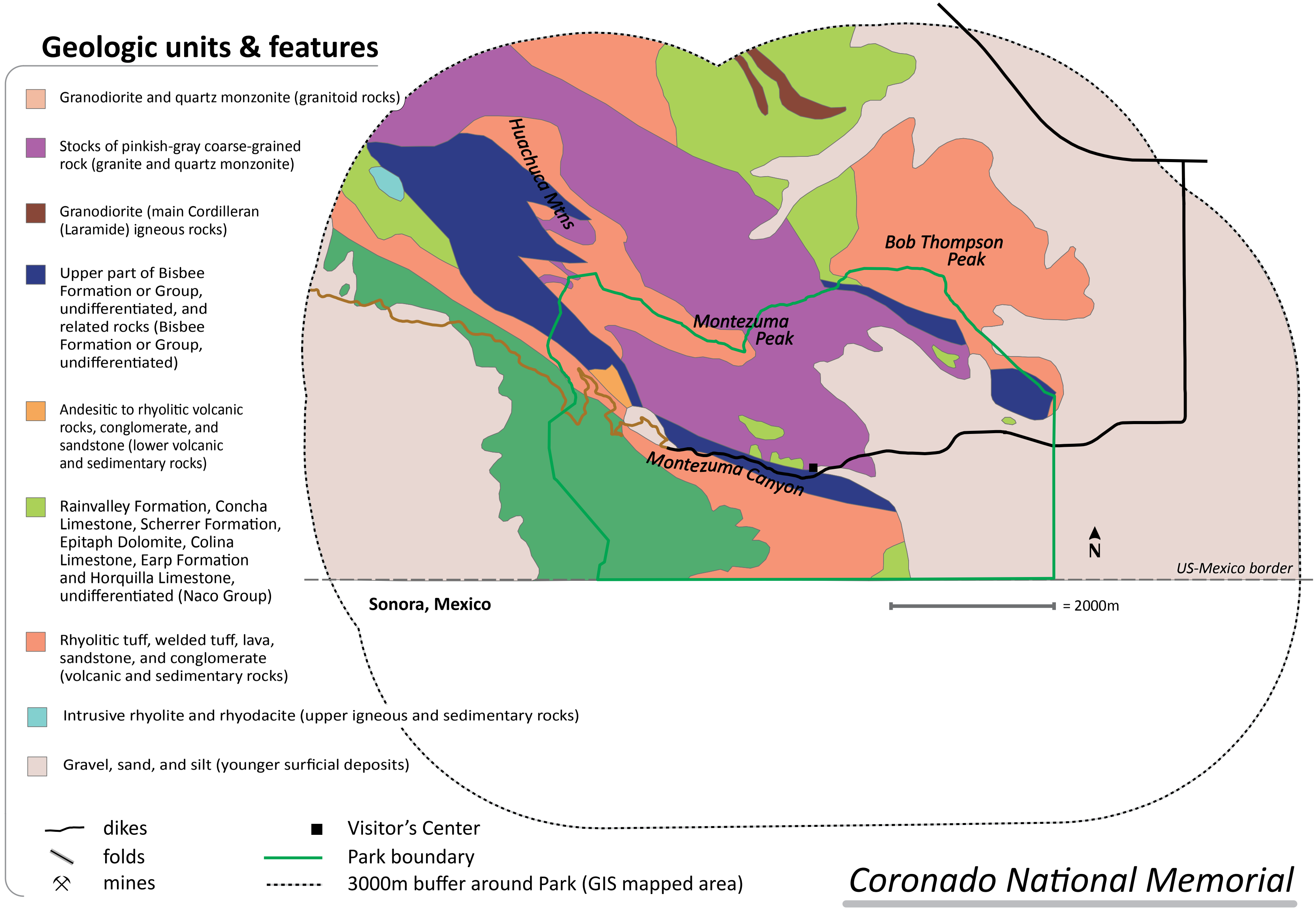


Figure 4.2. Surface geology at Coronado NMem.

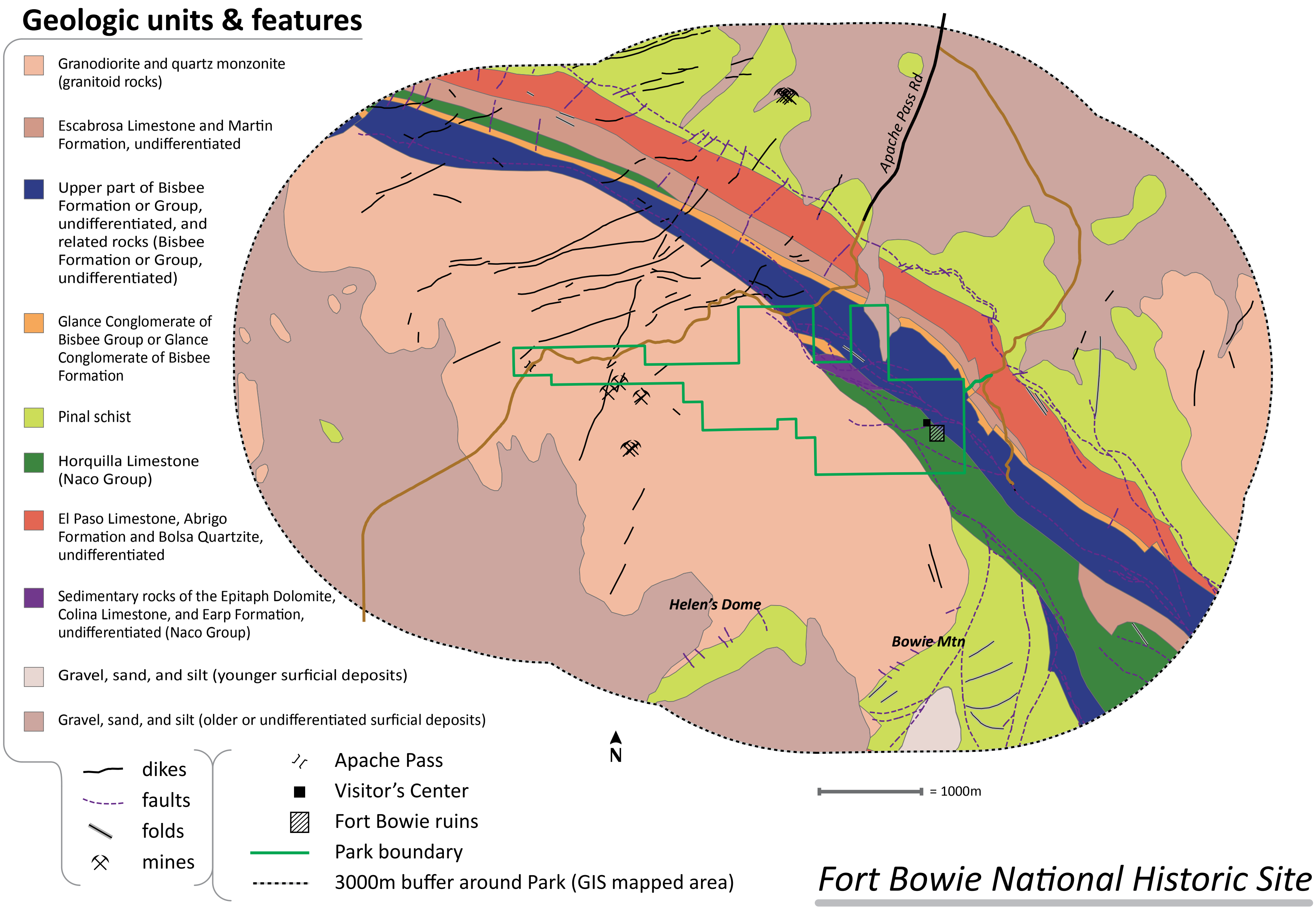


Figure 4.3. Surface geology at Fort Bowie NHS.

floodplains or on alluvial fans (Hendricks 1985). Mollisols have dark-colored, thick surface horizons and are found in grass and tree landscapes at higher elevations (DeBano et al. 2008). The relatively rare Vertisols occur in Cochise County's San Bernardino Valley (Hendricks 1985). Vertisols are clayey soils dominated by montmorillonite. Weak bonds bind Montmorillonite clay crystals together and the distance between the crystals depends on the amount of water in the soil. As the amount of water increase, the water pushes the crystals farther apart and the clay swells. When the amount of water decreases, the crystals move closer together and the soil shrinks (Hendricks 1985).

Soil texture describes the relative proportions of sand, silt, and clay particles in the soil and is an important determinant of soil-water relationships. The amount of rock-fragments characterizes the size of large particles in the soil. The higher the proportions of rock fragments, the fewer pores there are for water movement and storage. However, rock fragments also protect the soil from disturbance and decrease soil erosion. Soil organic matter helps bind together soil aggregates, helps retain nutrients and water in the soil matrix and tends to increase infiltration rates. Permeability rates describe the range of rates at which a saturated soil transmits water (Brady and Weil 2002).

The cataclysmic eruption of the Turkey Creek Caldera and subsequent volcanic eruptions resulted in complex geology and soils at Chiricahua NM. Soils at the monument were derived from numerous parent materials, including residuum, aeolian material, alluvium and colluvium (Denny and Peacock 2000a). Denny and Peacock (2000a) identified thirteen soil types and twenty-four soil map units within the monument (Table 4.1 and Figure 4.4). Most map units are "complexes," which consist of two or more soil types that are too intricately mixed to be separated into independent map units. Table 4.1 identifies key properties of the thirteen soil types.

Coronado NMem is an area of complex geology within an area known as the Montezuma caldera. The geologic variation, and resulting differences in parent material, results in twenty-one major soil types combined into twenty soil map units, within Coronado NMem (Figure 4.5; Denney and Peacock 2000b). Table 4.1 identifies key properties of the twenty-one soil types. Soils are deep on the lower slopes but shallow soils with high rock fragment content tend to dominate the steep slopes.

The geologic variation at Fort Bowie NHS, and resulting differences in parent material, combined with the diverse effects of pedogenic processes, results in seven major soil types combined into eight soil map units, within Fort Bowie NHS (Figure 4.6; Denney and Peacock 2000c). Table 4.1 identifies key properties of the seven soil types.

In addition to the relatively static soil characteristics that feed into soil classification, dynamic soil characteristics and soil biota can change over relatively short periods of time and are directly influenced by management actions. The dynamic soil properties, such as soil aggregate stability, soil surface cover, and biological soil crusts, can help provide a functional assessment of critical ecosystem processes, such as soil erosion, infiltration, nutrient cycling, and site fertility. Soil erosion can cause dramatic changes in vegetation. For instance, soil erosion from the foothills and bajadas of the Sky Island Archipelago can cause drastic and permanent changes in the vegetation. The presence of desert grassland or Chihuahuan desertscrub depends on whether the substrate is soil or rock.

The amount of soil surface cover is the most important dynamic characteristic affecting water erosion. Most soil erosion occurs in "unprotected" areas (bare patches). In general, as exposed bare ground increases, the erosion rate increases (Herrick et al. 2005; Davenport et al. 1998). Soil cover, such as plants, biological soil crusts, litter, gravel and rock, slow the flow of water by forcing the water to go over and around obstacles. Decreasing the surface-water flow rate decreases the erosive force of the water and allows the water has more time to soak into the soil (Herrick et al. 2005). Similarly, wind erosion is decrease by plant cover as plants protect the soil surface beneath it as well as reduce soil surface wind velocity (Herrick et al. 2005).

Table 4.1. Key characteristics of soil types at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Denney and Peacock 2000a)

Soil Type	Order	Rock Fragment Content	Organic Matter Content	Clay Content	Permeability Rate	Depth
Chiricahua NM						
Aridic Ustorthents	Entisols	< 10%	< 1%	35-45%	0.2-0.6 in/hr	60 in
Atascosa	Mollisols	35-65%, up to 85%	1-3%	18-35%	0.6-2 in/hr	4-20 in
Augustine family	Alfisols	<35%	< 1%	18-35%	0.2-6 in/hr	> 60 in
Canpicket	Entisols	> 25%	n/a	8-18%	6-20 in/hr	5-20 in
Gardencan	Alfisols	<35%, up to 55%	< 1%	18-35%	0.2-0.6 in/hr	60 in
Hailstone	Entisols	> 30%		8-18%	6-20 in/hr	5-20 in
Hogris	Entisols	35-85%	< 1%	< 18%	2-6 in/hr	> 40 in
Huachuca	Mollisols	> 35%	1-3%	5-18%	0.6-2 in/hr	5-20 in
Massai	Entisols	25-85%	n/a	8-18%	6-20 in/hr	> 40 in
Montcan	Mollisols	50-60%, up to 80%		< 8%, up to 12%	6-20 in/hr	
Otroizo	Entisols	45-60%	0.1-0.5%	4-8%	6-20 in/hr	
Whitebuck	Alfisols	35-60%		25-35%	0.6-2 in/hr	14-20 in
Yaquican	Mollisols	35-60%	1-5%	18-25%	0.6-2 in/hr	10-20 in

Table 4.1. Key characteristics of soil types at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Denney and Peacock 2000a)

Soil Type	Order	Rock Fragment Content	Organic Matter Content	Clay Content	Permeability Rate	Depth
Coronado NM						
Amuzet	Entisols	45-60%, up to 80%		<5%, up to 12%	6-20 in/hr	> 60 in
Aridic Ustifluvents	Entisols	15-80%	~ 1%	0-12%	> 20 in/hr	> 60 in
Bothompeek	Mollisols	40-60%, up to 70%		18-27%	0.6-2 in/hr	20-40 in
Budlamp	Mollisols	> 35%	1-3%	5-18%	2-6 in/hr	5-20 in
Canquya	Mollisols	45-60%	1-5%	18-27%	2-6 in/hr	10-20 in
Coppercan	Mollisols	15-35%		35-50%	0.06-0.2 in/hr	20-30 in
Costavar	Mollisols	35-60%	1-3%	28-35%	0.6-2 in/hr	6-18 in
Gardencan	Alfisols	<35%, up to 55%	< 1%	18-35%	0.2-0.6 in/hr	> 60 in
Guaynaka	Mollisols	35-50%	1-5 %	18-27%	0.6-2 in/hr	6-14 in
Kinockity	Entisols	25-60%		<8%	> 20 in/hr	26-40 in
Lanque	Mollisols	<35%, up to 55%	1-3%	3-15%	2-6 in/hr	> 60 in
Lutzcan	Mollisols	40-60%	1-3%	28-35%	0.2-0.6 in/hr	14-20 in
Montcan	Mollisols	50-60%, up to 80%		< 8%, up to 14%	6-20 in/hr	> 60 in
Morgamine	Mollisols	45-60%	3-5%	20-27%	0.6-2 in/hr	20-30 in
Morimount	Entisols	60-80%		18-27%	0.6-2 in/hr	12-18 in
Terrarossa	Alfisols	<35%, up to 50%		> 35%	0.06-0.2 in/hr	> 60 in
Tomarizo	Alfisols	35-60%	1-3%	18-27 %	0.6-2 in/hr	7-16 in
Yabamar	Mollisols	35-60%	1-3%	35-60%	2-6 in/hr	20-40 in
Yaquican	Mollisols	35-50%	1-5%	20-25%	0.6-2 in/hr	10-20 in
Yarbam	Mollisols	35-70%	1-3%	5-18%	2-6 in/hr	6-20 in
Zaleska	Alfisols	<15%		40-60%	0.06-6 in/hr	14-20 in
Fort Bowie NHS						
Amuzet	Entisols	35-60%, up to 80%		< 5%, up to 16%	6-20 in/hr	> 60 in
Budlamp	Mollisols	> 35%	1-3%	5-18%	2-6 in/hr	5-20 in
Overlook	Mollisols	> 35%		18-35%	0.6-2 in/hr	
Quillian	Alfisols	15-35%	< 1%	18-27%	0.6-2 in/hr	20-40 in
Silverstrike	Alfisols	> 40%	< 1%	35-50%	0.2-0.6 in/hr	20-40 in
Siphoncan	Mollisols	> 35%	1-3%	> 35%	0.6-2 in/hr	8-20 in
Yarbam	Mollisols	35-70%	1-3%	5-18%	2-6 in/hr	6-20 in

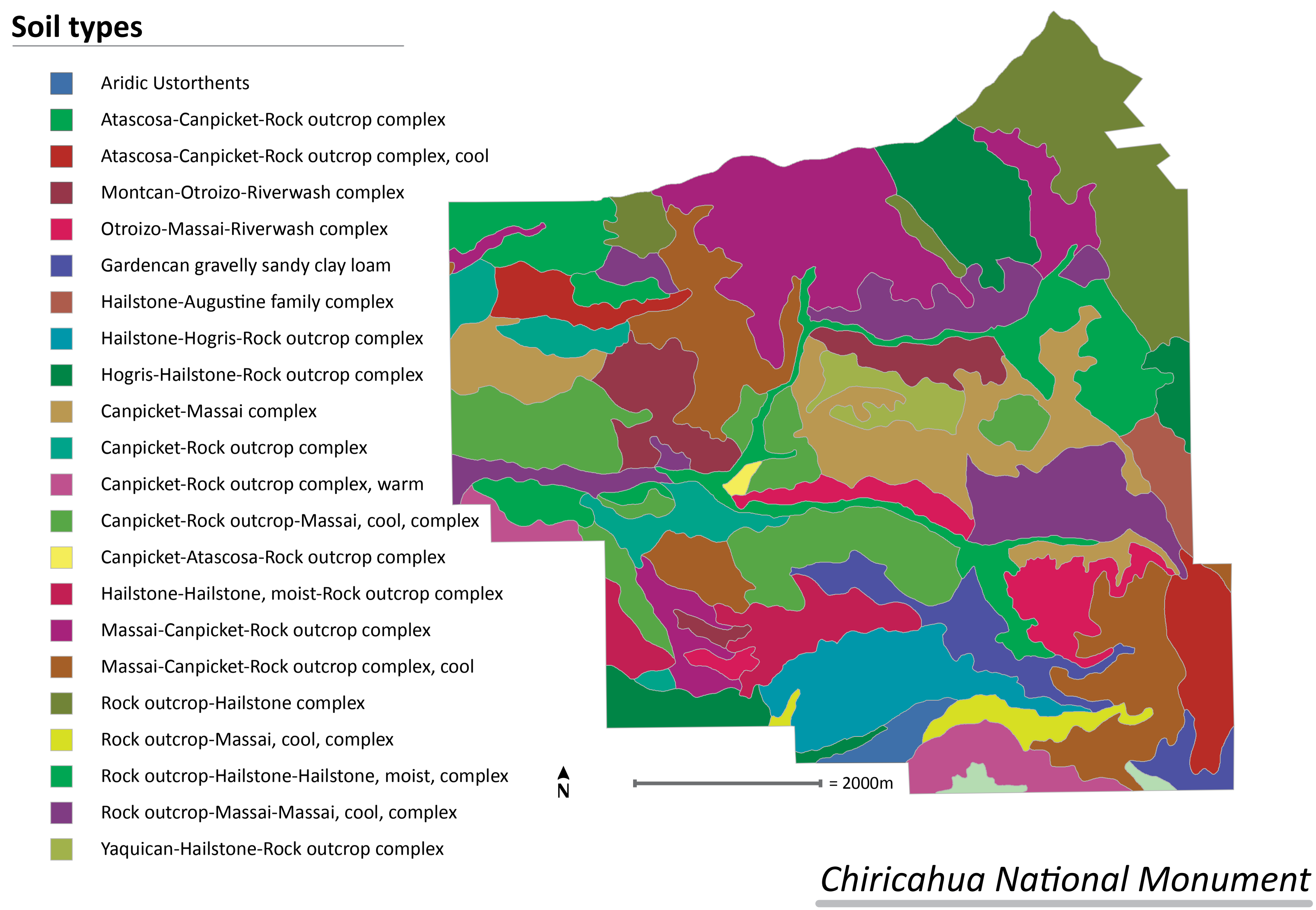
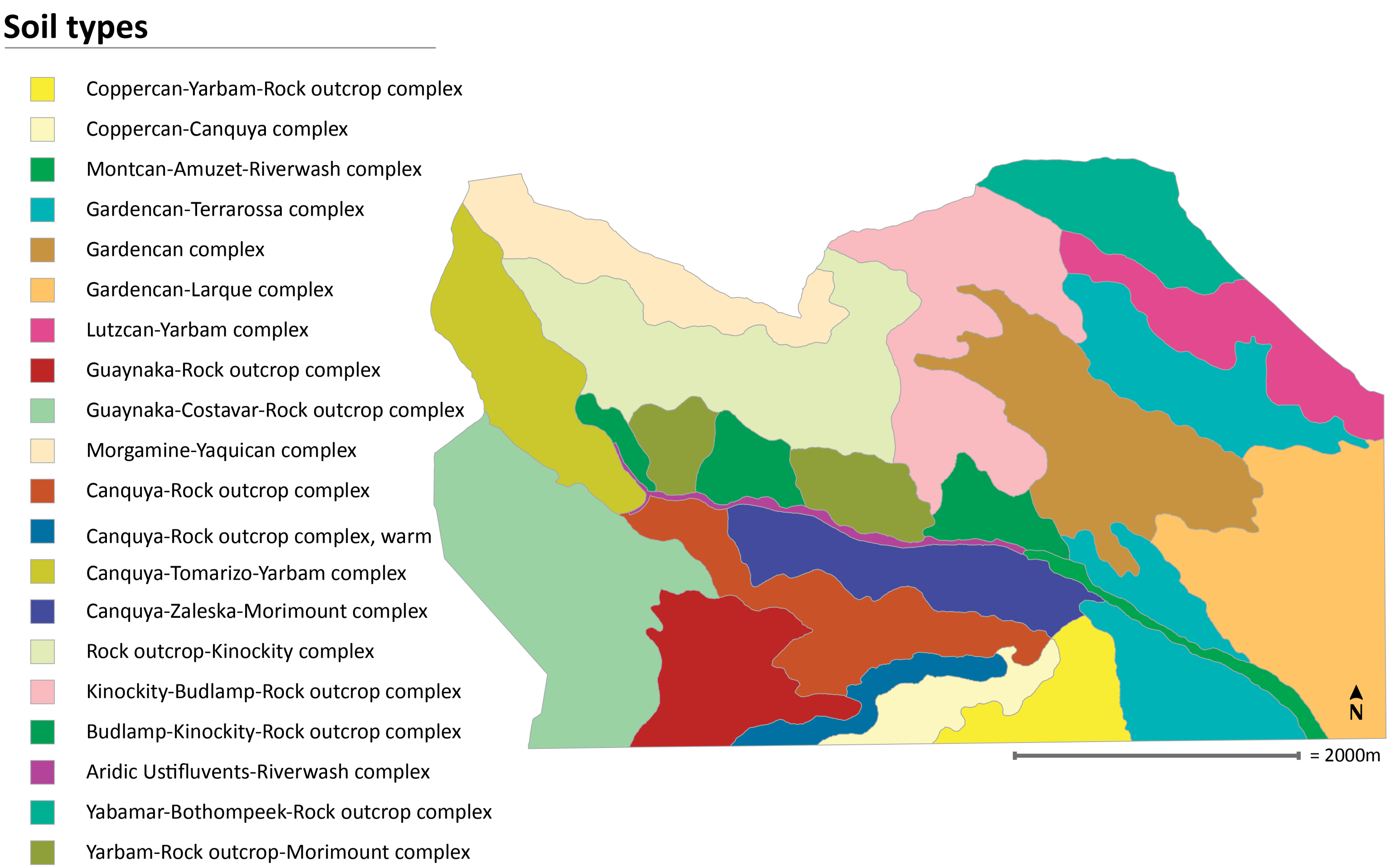


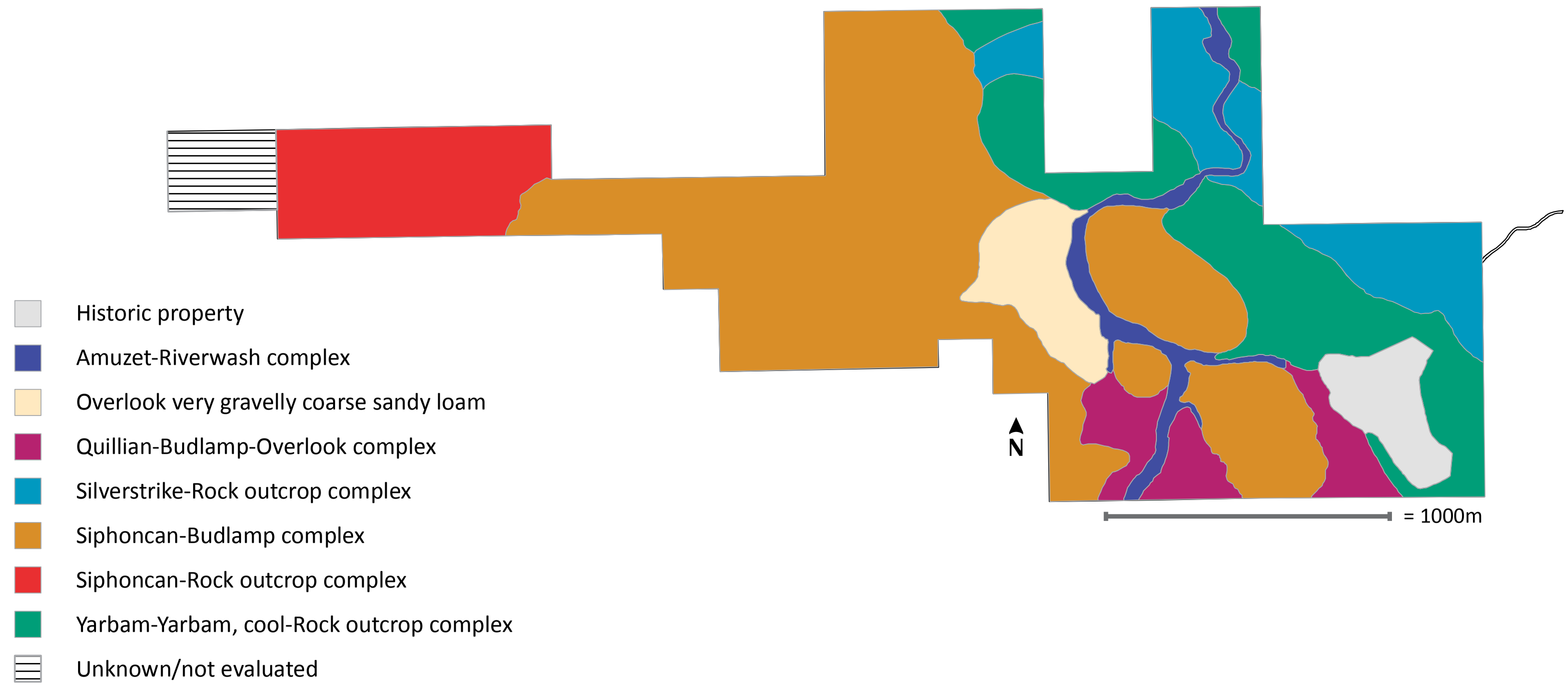
Figure 4.4. Soil types at Chiricahua NM (Denney and Peacock 2000a).



Coronado National Memorial

Figure 4.5. Soil types at Chiricahua NM (Denney and Peacock 2000a).

Soil types



Fort Bowie National Historic Site

Figure 4.6. Soil types at Fort Bowie NHS (Denney and Peacock 2000c).

Soil aggregates are the product of physical, chemical, and biological processes and affect the movement of water, nutrients, and gases through the soil–atmosphere interface. In addition, surface soil aggregates are critical in resisting wind and water erosion (Herrick et al. 2005). The material that binds together soil aggregates is typically live and dead soil organic matter, which degrade rapidly. Therefore, the presence of stable soil aggregates indicates that the soil-biotic system is functioning (Herrick et al. 2005).

Biological soil crusts, a highly specialized community of cyanobacteria ("blue-green algae"), algae, microfungi, lichens, and bryophytes, typically cover undisturbed open spaces in arid and semiarid regions (Figure 4.7). They contribute to soil and site stability and function by increasing erosion resistance, generally increasing infiltration, contributing organic matter, and fixing atmospheric nitrogen. In the Madrean Archipelago, biological soil crusts do not contribute as much to the above ecosystem services as they do in the Sonoran Desert or Colorado Plateau due to the greater amount of vegetation in the Madrean Archipelago (Rosentreter and Belnap 2003). Unfortunately, there is limited information on the distribution and abundance of biological soil crusts in the Madrean Archipelago. The description of biological soil crusts below applies to crusts in North America.

Cyanobacteria weave through the top few millimeters of soil secreting polysaccharides, providing stability and fixing nitrogen. The polysaccharides bind together soil particles and help reduce erosion. In addition, the polysaccharides also contribute to soil aggregate structure, which is directly correlated with soil erosion resistance (Belnap et al. 2003; Herrick et al. 2005). Lichens (a composite, symbiotic organism comprised of a fungus and either a cyanobacteria or a green alga) and bryophytes (small, non-vascular plants, including mosses and liverworts) occur on the surfaces of soil and have small anchoring structures that help them protect the soil surface (Belnap 2003). Bryophytes are typically indicators of moist habitats. Biological soil crusts are metabolically active only when wet and, thus, favor moister habitats, such as under a plant canopy or a northern exposure (Belnap et al. 2003). While biological soil crusts can be found on almost all soil types, their distribution is influenced by soil chemistry, elevation, timing of precipitation, vascular plant community structure, and disturbance (Belnap et al. 2001).

On most soils, biological soil crusts increase infiltration. However, on soils with more than 80% sand-sized particles, biological soil crusts tend to reduce infiltration rates (Warren 2003). Biological soil crusts contribute fixed carbon to soil through decaying and leaching processes (Lange 2003). Cyanobacteria and cyanolichens have the ability to fix atmospheric nitrogen. This process reduces atmospheric nitrogen (N_2) to ammonia (NH_4^+), which is usable by vascular plants (Belnap 2003).

Soil surface disturbance affects the cover, function, and species composition of biological soil crusts. The type, timing, and severity of disturbance influence the impact of a given disturbance (Belnap and Eldridge 2003). Disturbed crusts recover slowly in areas with high annual temperature and low annual precipitation (Belnap and Eldridge 2003). Following disturbance, biological soil crusts typically follow a recovery sequence in which cyanobacteria first colonize a site,

Figure 4.7. Biological soil crust community at Chiricahua NM

followed by cyanolichens, other lichens, and then bryophytes (Belnap et al. 2001).

4.1.1.3 Climate

The Madrean Archipelago's location between the mid-latitude and subtropical atmospheric circulation regimes strongly influences the region's climate and results in relatively low annual precipitation, warm temperatures and clear skies (Sheppard et al. 2002). While temperatures tend to be warm, there can also be a considerable range in daily and seasonal air temperature (Gori and Enquist 2003). Typically, precipitation increases dramatically with elevation due to the orographic effects of the sky islands (Davey et al. 2007). Under climatic conditions of the past 50 years, each 1000-foot increase in elevation results in a 3- to 4-inch increase in annual precipitation. While earlier studies suggested a rate of increase 4- to 5-inches per 1000-foot increase in elevation, those studies utilized data from the first half of the 20th Century, a generally wetter period in Arizona (Sellers 2008). Large differences in elevation — and associated differences in temperature and precipitation — results in a diverse vegetation community in the region (Sellers 2008).

Across the region, precipitation is highly variable and falls in a bimodal pattern. During the intervening months between the precipitation peaks, little rain falls. Typically, the spring dry period is more stressful than the fall dry period for plants because of the increasing temperatures in the spring (Sellers 2008). Approximately half of the annual precipitation falls from July through September in temporally and spatially variable monsoonal storms that derive their moisture primarily from the tropical Pacific Ocean and Gulf of California (Sheppard et al. 2002). During this time, maximum air temperatures can exceed 100°F, which can lead to locally violent thunderstorms (Gori and Enquist 2003) as well as less effective precipitation due to increased evaporation and run off (Ingram 2000). Annual monsoon strength varies and is the subject of continued research (Adams and Comrie 1997).

In contrast to the locally violent summer rains, the majority of the remaining annual precipitation falls in relatively gentle, widespread events from November through March. The winter storms, which originate in the north Pacific Ocean, cause widespread precipitation over a large geographical area (Sheppard et al. 2002). Pacific Ocean sea surface temperatures strongly affect the amount of winter precipitation in the region. During years when sea surface temperatures in the eastern Pacific Ocean near the equator are warmer than normal (El Niño years), the region tends to experience winters with higher than normal precipitation. The opposite occurs when the sea surface temperatures of the eastern Pacific Ocean near the equator are cooler than normal (La Niña years). In addition, sea surface temperatures in the northern Pacific Ocean influence winter precipitation. The Pacific Decadal Oscillation (PDO) is a decades-long pattern of warmer or cooler than normal sea surface temperatures in the northern Pacific Ocean that can last for several decades when the temperatures in the northern Pacific Ocean are warmer or cooler than usual. When the PDO is in the positive phase, with warmer than normal temperatures, the region experiences increased winter precipitation (Sheppard et al. 2002).

In addition to the summer monsoons and winter rains, tropical storms occasionally move into the region in early fall. While tropical storms are infrequent, they have produced some of the largest rainfall events recorded in the region. These events can result in widespread flooding and severe erosion (Ingram 2000).

While, the Parameter Regression on Independent Slopes Model (PRISM) can provide interpolated climate information, the region's small-scale and topographical variation causes researchers to approach the PRISM outputs with great caution (Gray 2008). Therefore, this assessment relies on weather station measurements.

Climate scientists suggest comparing seasonal or annual precipitation to the average precipitation received during a historic or "normal" period (Gray 2008). In order to compute a "normal" or historic average, data for a given weather station must meet standards set by the World Meteorological

Organization. In 1989, the WMO prescribed that "no more than three consecutive year-month values can be missing for a given month or no more than five overall values can be missing for a given month (out of 30 values)" (NOAA 2002). Twenty-six weather stations in the region met the WMO standard (Figure 4.8), including weather stations at Chiricahua NM and Coronado NMem, from elevations of 2330 ft and 5390 ft. The staff at Fort Bowie NHS maintains a National Weather Service (NWS) Cooperative Observer Program-style weather station. For four decades, since 1970, the staff has collected daily weather data but does not report the data to the Weather Service Office in Tucson. Therefore, the Fort Bowie NHS weather station is not included in the list of stations meeting the WMO standard. Based on the 26 WMO qualified weather stations, mean annual precipitation in the region ranged from just under 12 inches to just under 25 inches from 1971—2000 (Figure 4.8 and Table B.1; NOAA 2002). During the same historic period, mean summer monsoon precipitation ranged from 5.0 to 11.5 inches and mean winter precipitation ranged from 3.3 to 11.67 inches (Table B.1; NOAA 2002). Between 1971 and 2000, the summer monsoon contributed between 37% and 56% of the total annual rainfall. In general, the northern portion of the region had a smaller contribution from summer monsoon precipitation (Figure 4.8; NOAA 2002).

While 26 weather stations met the WMO standard for calculating the 1971-2000 historic average, many of the stations experienced long periods without data collection between 2000 and 2010 including the stations at Chiricahua NM and Coronado NMem. Data was consistently collected at the Fort Bowie NHS weather station but was not reported to the National Weather Service. In addition, the Douglas Bisbee International Airport station provides reliable climate information from 1949-2010. A comparison of five weather stations in the region (Bowie, Chiricahua NM, Coronado NMem, Douglas Bisbee International Airport, and Fort Bowie NHS) shows that precipitation varied dramatically over the past 20 years and that there is not a consistent relationship between the weather stations (Figure 4.9). For example, all five stations recorded approximately 10 inches in precipitation in 1989. This represented roughly average precipitation for the Bowie station but only half of the normal precipitation for the Coronado NMem and Chiricahua NM stations. However, maximum temperatures in June (Figure 4.10) and January minimum temperatures (Figure 4.11) show more correlation between the five weather stations but a consistent relationship is lacking. This underscores the need for site-specific data collection to understand local conditions.

4.1.1.4 Hydrology

The Arizona portion of the Madrean Archipelago includes drainages of the San Pedro River, Santa Cruz River, Gila River, Rio de Bavispe, and the Willcox Playa. The free-flowing San Pedro River flows north from Mexico east of Coronado NMem and the Huachuca Mountains and joins the Gila River near Winkelman, Arizona. Some tributaries to the San Pedro River begin on the slopes of Coronado NMem and drain into Mexico. Major tributaries to the San Pedro River include Babocomari River and Arivaipa Creek (ADWR 2009). The San Pedro River is perennial near the U.S./Mexico border due to groundwater discharge. Perennial flow continues north to near St. David, depending on the season (Webb et al. 2007).

Each summer since 1998, volunteers, conservation scientists, and agency personnel map the presence of surface water in the San Pedro River and its tributaries. Within the Upper San Pedro basin, beginning in Mexico and continuing north of Benson, the collaborative effort mapped 90% of the nearly 77-mile stretch of the San Pedro River in 2010. Approximately 40% of the surveyed river had surface water on June 18-19, 2010 the Upper San Pedro (TNC 2010). These results were identical to those in 2008 but less than the surface water present in 2007 and 2009. During 2007 and 2009, 52% of the surveyed stretch within the upper basin had surface water present (TNC 2010). Annual streamflow of the San Pedro River has decreased by more than 50%, as measured at Charleston, Arizona (Thomas and Pool 2006). A recent study by the USGS showed that seasonal

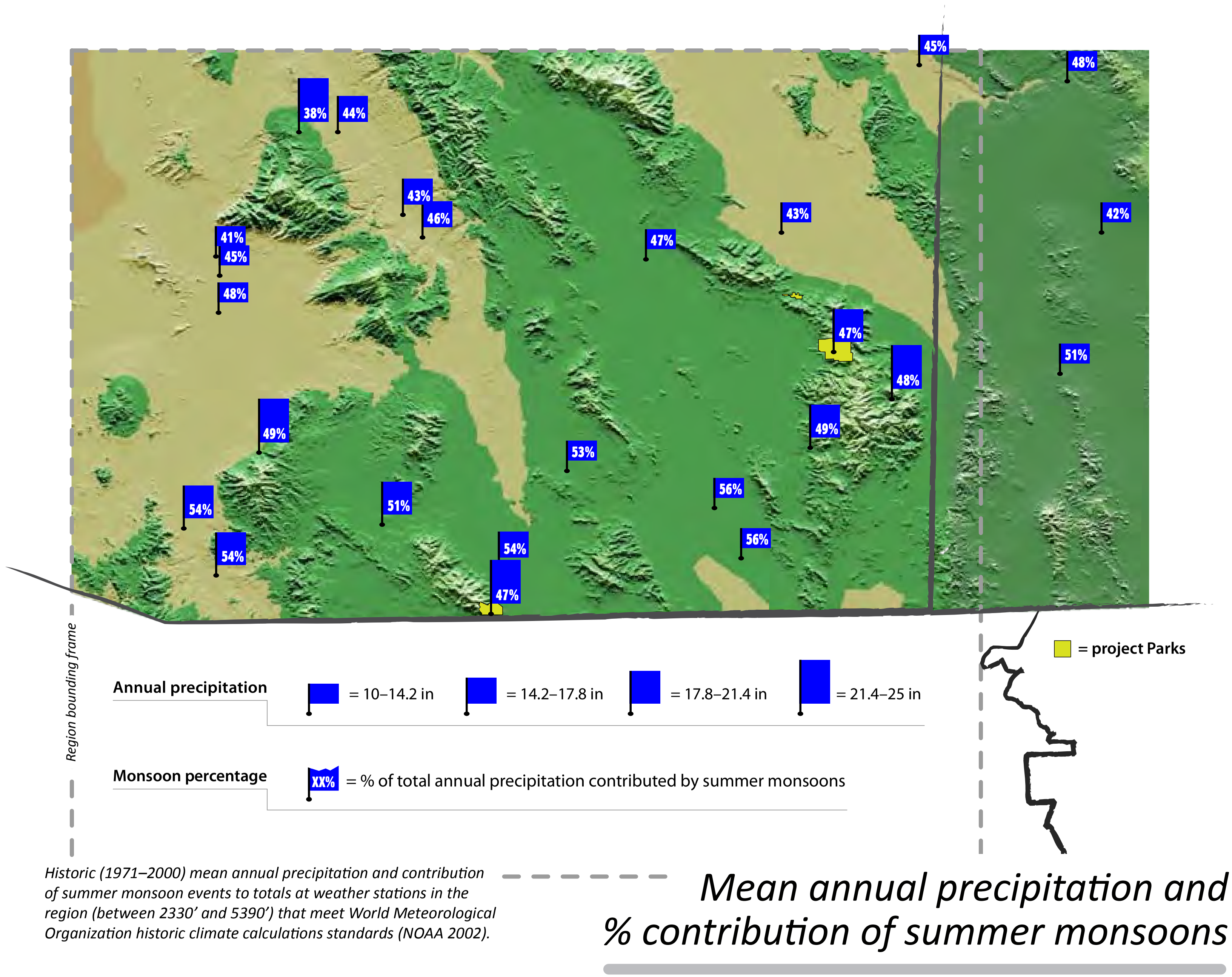
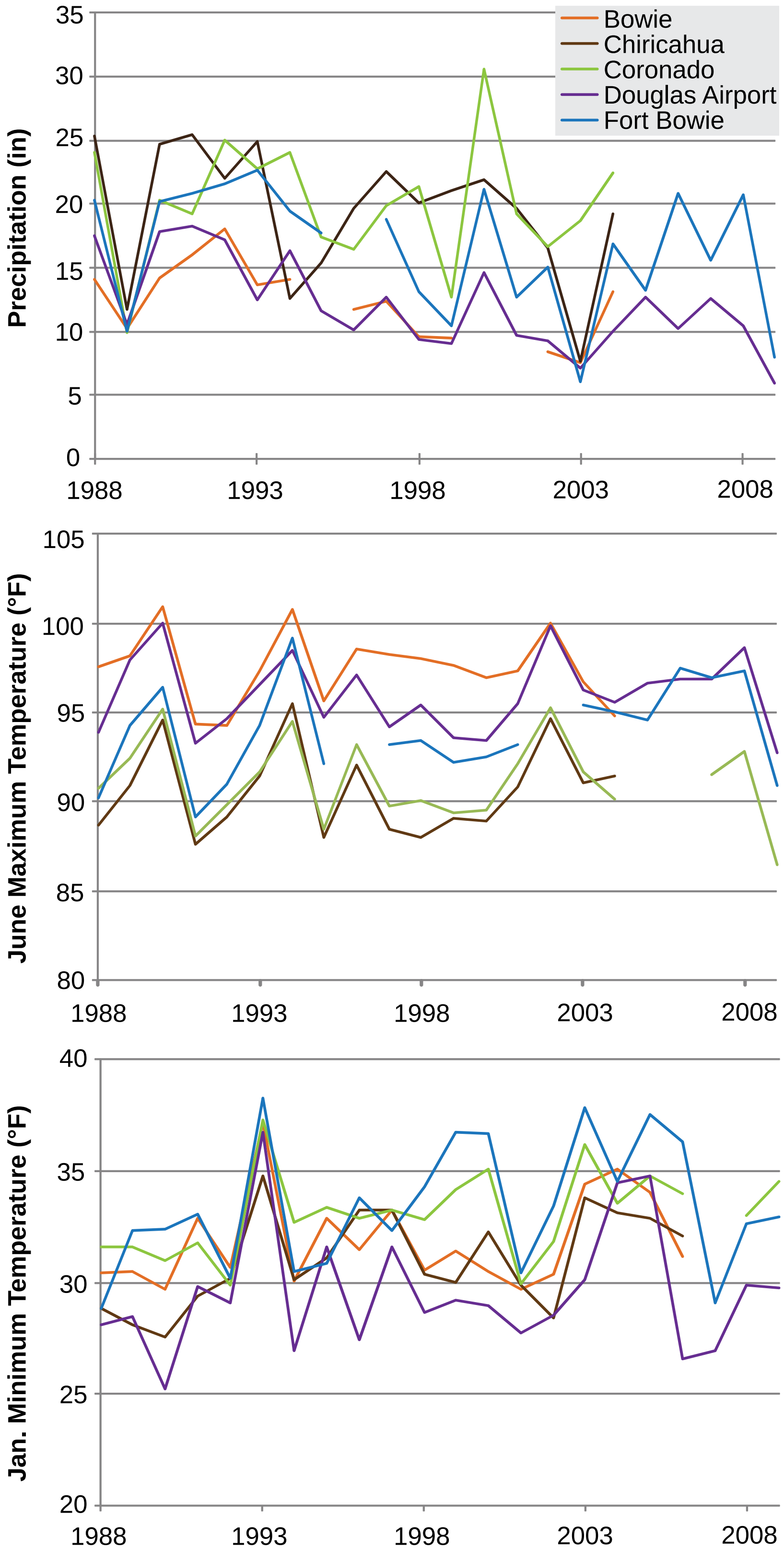


Figure 4.8. Historic averages (1971-2000) of mean annual precipitation and contribution of summer monsoon precipitation to total annual precipitation at weather stations in region that meet the World Meteorological Organization's standard for historic climate calculations (NOAA 2002).



Figures 4.9, 4.10, and 4.11 (top to bottom). Annual precipitation (top), average June maximum temperatures (middle), and average January minimum temperatures (bottom) for Bowie, Chiricahua NM, Coronado NMem, Douglas International Airport, and Fort Bowie NHS weather stations, 1988-2010 (WRCC 2010a, WRCC 2010b, WRCC 2010c, WRCC 2010d, and NPS 2010)

flows, except winter flows, for the San Pedro River had significant decreasing trends from 1913 to 2002. The decreasing streamflow trends were not the result of precipitation fluctuations but instead are likely due to other factors such as fluctuations in air temperature, changes in watershed characteristics, changes in bank storage, or human activities (Thomas and Pool 2006).

The Santa Cruz River originates in the San Rafael Valley, flows south into Mexico, where it makes a U-turn and flows north into the United States east of Nogales and continues to the north through Tucson to the Gila River. Major tributaries to the Santa Cruz River include Sonoita Creek and Cienega Creek. Historically, the Santa Cruz River was ephemeral with local areas of perennial flow, and streamflows were maintained by surface runoff and groundwater discharge (Webb et al. 2007). The increasing use of groundwater pumps throughout the 20th Century resulted in a dewatering of the river and reduction of the riparian corridor along its length. Beginning in 1972, flow was restored to the upper portion of the river by the introduction of discharge from the Nogales International Wastewater Treatment Plant in Rio Rico, Arizona, to the stream channel. The plant discharges roughly 15 million gallons of effluent a day into the Santa Cruz River, with two-thirds of the wastewater generated in Mexico (IBWC 2005). Additional wastewater treatment plants in Tucson also discharge into the river.

Whitewater Draw, which flows by Douglas, Arizona and Black Draw in the San Bernardino Valley are tributaries to Rio de Bavispe in Mexico. Eventually, the Rio De Bavispe joins the Rio Yaqui and flows to the Gulf of California (ADWR 2009). The main portion of Whitewater Draw originates in Rucker Canyon in the southern Chiricahua Mountains. Whitewater Draw has experienced a history of arroyo cutting and filling stretching back roughly 8,000 years resulting in a maximum depth of 25 feet near Douglas in the 1950s (Webb et al. 2007). The major tributary in the San Bernardino Valley, Black Draw, becomes perennial just before flowing south into Mexico. The Willcox Playa, a remnant of the Pleistocene-age Lake Cochise, occupies about 50 square miles in the center of the Willcox Basin. Within the closed Willcox Basin, surface water drains from the Pinaleno and Chiricahua Mountains and the outer edges of the basin to the Willcox Playa (ADWR 2009).

Within the region, the groundwater basins consist of sediments deposited before the Basin and Range province formed and a layer of basin fill (up to 1,000 feet thick) of material eroded from the mountains. Typically, groundwater discharge occurs near the center of the basin as groundwater flows from the edges of the basin towards the center of the basin. Groundwater discharge includes pumpage, evapotranspiration, and discharge to streams and springs. When the water table in the aquifer is above the level of the stream, groundwater will emerge or discharge from the aquifer into the stream channel and augment flow (known as a gaining stream/reach). The major components of groundwater inflow to the aquifers are mountain front recharge and stream infiltration. Mountain front recharge describes the contribution of infiltration of rain and snowmelt originating at high elevation to groundwater recharge to basins adjacent to the mountain front (ADWR 2009). Stream infiltration occurs when the water table is below the level of the stream. Water from the stream infiltrates through the streambed to the groundwater basin, consequently lessening flow in the stream (known as a losing stream/reach).

Seeps and springs are critical surface water sources in the semi-arid Madrean Archipelago. They are important sources of water for plants and animals and apart from streams, represent the primary interface between groundwater and surface water.

Groundwater basins in the the Arizona portion of the region include the Tucson, Upper Santa Cruz, San Rafael, Cienega Creek, Upper San Pedro, Douglas, Willcox, San Bernardino Valley, and Safford. In some cases, the boundaries of the groundwater basins do not match up exactly with the surface watershed boundaries that share the same name (ADWR 2009). The Safford basin contains almost all of Fort Bowie NHS and the western portion of Chiricahua NM. The Safford Basin is a large, alluvial filled depression. In the San Simon Valley, east of Fort Bowie NHS, groundwater levels tend to be deep. Groundwater levels in the San Simon sub-basin declined by more than 30 feet between 1990-1991 and 2003-2004 (ADWR 2009). Within the Safford basin, approximately 98% of the groundwater demand is used for agriculture (ADWR 2009).

The Willcox basin includes most of Chiricahua NM and a small portion of Fort Bowie NHS, the town of Willcox and the Willcox Playa. Groundwater pumping for agriculture has altered recent groundwater flow regimes, resulting in large cones of depression southeast of the Willcox Playa and north of the town of Willcox (ADWR 2009). In 2003, depth to groundwater in the Willcox basin ranged from 30 feet to greater than 400 ft (USGS 2006). Five hundred and forty-nine wells, out of 578, showed a decline in groundwater levels between November/December 1999 and November/December 2006 with most wells experiencing a 0.5-20.4 foot decline (ADWR 2009). According to the Arizona Department of Water Resources (2009), agriculture accounts for over 90% of water use and groundwater supplies approximately 90% of the municipal water supply in the Willcox basin.

The Douglas and San Bernardino Valley basins are south of the Willcox basin. Minimal groundwater level information is available for the San Bernardino Valley basin (ADWR 2009). The main aquifer in the Douglas basin occurs in a long alluvial valley. In 1980, most of the Douglas basin was designated as an Irrigation Non-Expansion Area, which limits irrigated land to any land that was irrigated between 1975 and 1980 (USGS 2006). Overall, groundwater levels in the basin declined between 1990-1991 and 2003-2004 (ADWR 2006). Agriculture accounts for approximately 75% of the water use (all groundwater) in the basin.

The Upper San Pedro basin contains the majority of Coronado NMem as well as Sierra Vista, Fort Huachuca, Kartchner Caverns and the Bureau of Land Management's San Pedro Riparian National Conservation Area. Groundwater recharge occurs through mountain front recharge, underflow from Mexico, streambed infiltration, and effluent recharge projects (ADWR 2009). Depth to groundwater ranges from 10 feet near the U.S./Mexico border to nearly 600 feet near Sierra Vista (ADWR 2009). In most parts of the basin, groundwater levels declined between 1990-1991 and 2003-2004. However, some areas saw groundwater levels increase up to 15 feet (ADWR 2009).

The San Rafael basin contains the headwaters of the Santa Cruz River. There is limited groundwater level information for the San Rafael basin and groundwater pumping has remained fairly constant at less than 300 acre-feet per year (ADWR 2009). The Cienega Creek basin sits north of the San Rafael basin and west of the Upper San Pedro basin. Groundwater levels tend to be stable in the Cienega Creek basin (ADWR 2009).

Chiricahua NM Groundwater

Due to limited hydrologic data from Chiricahua NM, the following discussion is based almost entirely on the personal observations of park staff, combined with interpretation of geologic maps as structure and lithology would reasonably be expected to control hydrologic processes at the monument. Further study of hydrologic processes at the monument, particularly regarding timing and duration of surface flows in Bonita Canyon, is needed.

As described in Section 4.1.1.1, Chiricahua NM is situated just north of the Turkey Creek caldera. The eruption which created this caldera is responsible for the extensive thick volcanic ash deposit, known as the Rhyolite Canyon Tuff, that blankets most of the park and has weathered to form the unique pinnacles and formations for which the park is famous. The southwest strand of the Apache Pass fault passes into the park's northeast boundary following a northwest-southeast strike, then curves 90° to the southwest along what is now the upper reaches of Bonita Canyon (Drewes 1982). This fault may be a primary reason why the park's most reliable surface water, Shake Spring, is located in the middle reaches of Bonita Canyon.

Hydrologic properties of volcanic tuff vary depending on the conditions under which deposition takes place. Slow cooling at depth results in greater degrees of welding, producing less permeable deposits that are more resistant to erosion, while rocks formed under rapid-cooling conditions show lesser degrees of welding and tend to be characterized by higher permeabilities and greater friability (more easily eroded). Usually, these properties occur gradationally depending on eruption timing and volume, thickness of the ash and location relative to the source. The ash flow tuffs at the monument remain in place as they originated in a layered configuration, with more recent deposits overlying older ones. Across the landscape at and around Chiricahua NM, younger, more poorly-welded tuff facies are lost to erosion except where preserved along the flanks of Sugarloaf Mountain. The tuffs remaining on the surface today cooled more slowly deep within the ash deposit. Due to the weight of the overlying ash and the slow rate of cooling, these layers are moderately to densely welded. The vertical joints that formed in this welded tuff as it cooled provide entry to infiltrating water, facilitating chemical and physical weathering and leading to the formation of the hoodoos and spires that awe and inspire visitors.

Rain and snowmelt high within the monument flow across rock surfaces and down steep canyons, infiltrate rapidly into joints and fractures in the rocks and the coarse alluvium of canyon bottoms, and less rapidly into the rock matrix. Surface flows are ephemeral in the higher reaches of the steep canyons, but are intermittent in the lower reaches of Bonita and Rhyolite creeks where rapid surface runoff events are followed by more extended periods of discharge of waters percolating within tuff layers from higher in the watershed. The volume and duration of intermittent flows in these canyons are directly related to environmental factors including amount of snowpack, rate of snowmelt, and frequency, duration and intensity of rainfall events (E. Cluff, personal communication 2011). Percolation of infiltrated waters is controlled by the structure and physical properties of the tuff layers encountered on the journey from the mountains to the valley below. Repeated ash flow events within short time intervals resulted in the formation of layers within the tuff beds, some of the layers more densely welded than others. Within the rock matrix, the less permeable densely welded layers will slow infiltration rates, but water perched on these layers will move laterally until joints are encountered, facilitating deeper percolation. Where perched groundwater flows to the surface, springs are found. Approximately nine springs have been identified in the park. Groundwater resources in Bonita Canyon have been essential to inhabitants of this area, beginning with the settlement at Faraway Ranch, where hand-dug wells were used to obtain a year-round water supply.

Coronado NMem Groundwater

Coronado NMem is situated at the southern end of the Huachuca Mountains and occupies a portion of the Sierra Vista subwatershed of the Upper San Pedro Basin watershed, including portions of three drainages, all of which flow to Mexico and eventually back into the United States within the Upper San Pedro Basin (Montezuma Canyon [HUC 150502020302], Copper Canyon Agua Dulce [HUC 150502020104], and Yaqui Canyon [HUC 150502020301]). The Huachuca Mountains are an important recharge area for groundwater in the San Pedro Basin.

The primary drainage in the park is Montezuma Canyon, an ephemeral tributary of the upper San Pedro River. All drainages within the park are within the San Pedro watershed, but flowing surface waters infiltrate to the Upper San Pedro groundwater basin aquifer before reaching the San Pedro River. Both surface flows and groundwater within the park discharge toward the Mexican border to the south, but ultimately return to the U.S. either as surface flows in the San Pedro River or as groundwater if not captured in Mexico.

Groundwater at Coronado NMem is a vital resource, providing potable water for park operations and sustaining numerous springs situated throughout the park. Storage of groundwater reserves is likely minimal on mountain slopes, where soils are coarse and thin and fractured granitic rocks have limited porosity. Alluvium in Montezuma Canyon transmits surface and subsurface drainage toward the valley below. Recharge from the

Huachuca Mountains percolates toward the center of the basin within the permeable deposits and rocks of the fan terrace.

The southeastern quadrant of the park is occupied by a gently to moderately sloping fan terrace composed of terrace gravel deposits, alluvium and residuum at depth. The southwest, northwest and north-central parts of the Memorial are characterized by steep slopes with shallow, rocky, loose soils formed as residuum or colluvium from a range of parent rock types. Rainfall events on these slopes produces significant runoff, including flash floods, which carry substantial alluvial loads, and less frequently, debris flows such as those observed in 2006 and 2008 when precipitation intensity is especially high (Youberg 2008).

Fort Bowie NHS Groundwater

Fort Bowie NHS occupies the mid to upper reaches of Siphon Canyon and its tributaries, as well as parts of Cutoff and Willow Canyons, all of which are included in the greater San Simon watershed (Happy Camp Wash subwatershed HUC 1504000603). Surface flows in the subwatershed do not reach the San Simon River, and infiltrated waters recharge the Safford groundwater basin. Precipitation and evapotranspiration are the key drivers of hydrologic processes at Fort Bowie NHS. As described in Section 4.1.1.1, the Apache Pass fault is the primary geologic structure in the area, juxtaposing impermeable granites and semipermeable siltstones with a wedge of fractured limestone, upon which the second fort was situated. The limestone receives infiltrated runoff from the surrounding uplands and transmits the water to a small number of springs in the area. The springs were a valuable resource to the Native Americans that made their home in this region, and were the focus of the clash of cultures that set the stage for the establishment of the fort in the 1862. Today, Apache Spring is an important focal point of the visitor experience at Fort Bowie NHS and is the sole source of reliable surface water sustaining wildlife at the park. Another important spring in the area but outside the park boundaries is Bear Spring, which is believed to be undergoing development at this time. In addition to discharge from storage in the fractured limestone aquifer, about 50% of the water daylighting at springs originates seasonally as seepage within the thin soil veneer that is present in varying degrees throughout the area (Filippone 2009).

Ephemeral surface water flows occur following precipitation events in Siphon Canyon and the many smaller drainages throughout the park. Intense precipitation events result in rapid runoff and erosion of the thin and poorly developed soils on the slopes surrounding and including the fort itself. Soil losses within the Apache spring watershed have been identified as key to significant decreases in spring discharge in recent decades (Filippone 2009). Decades of human use concentrated in the second fort area have taken its toll on the natural vegetation and soils that were once present. As soils are lost, reduced infiltration and storage of precipitation within the upper reaches of the watershed occurs, surface runoff increases, soil losses are accelerated, and a cycle of ever-diminishing water availability occurs.

Water quality characteristics of groundwater and spring waters are determined by a number of environmental variables, beginning with the composition of the precipitation, as rain or snow, when it reaches the ground surface. Sources of solutes found in natural waters include atmospheric gases and aerosols, chemical breakdown of rocks and soils by weathering, and reactions occurring in the subsurface (Hem 1985). In the subsurface, water quality is influenced by the chemical makeup of the rocks and soils along the flow path, i.e., mineral availability, and the solubility of available minerals in the water solution as it comes into contact with the solid phase (Freeze and Cherry 1979).

Each of the southeast Arizona parks is located at or near the top of its respective watershed(s). Recent water samples are all relatively low in dissolved solids and, except for those affected by mining at Coronado NMem, the waters sampled are dominantly calcium bicarbonate waters. Recent data for Chiricahua NM, Coronado NMem, and Fort Bowie NHS are presented in Sections 4.2.1.1, 4.2.2.1, and 4.2.3.1 respectively. Additional water quality data not reviewed here are presented and reviewed in the NPS Baseline

Water Quality Data Inventory and Analysis series. As listed in the references accompanying this report, Baseline Water Quality reports have been completed for each of the southeast Arizona parks and are available for downloading on the internet by selecting the park of interest at http://www.nature.nps.gov/water/horizon.cfm.

4.1.1.5 Air Resources

Air quality affects vegetation, wildlife, and water as well as scenery, vistas, and viewsheds. The Clean Air Act includes programs to protect air quality in wilderness areas and some national parks. Additionally, the NPS Organic Act protects air resources in national parks. Chiricahua NM is designated as a Class I airshed and has visibility standards set by the Clean Air Act (Mau-Crimmins and Porter 2007). Chiricahua NM contains air monitoring stations to measure atmospheric deposition, visibility, and ozone. In addition to the station at Chiricahua NM (Cochise County), there are three stations near Douglas (Cochise County), one in Agua Prieta, one in Nogales, Arizona (Santa Cruz County), one in Nogales, Sonora and numerous stations in Tucson (Pima County).

Fires, wood smoke, wind-eroded soil, and the burning of fossil fuels contribute particulates to the air, which can reduce visibility. Particulate matter is measured near Douglas, Agua Prieta, Nogales, Sonora, and Nogales, Arizona. In 2008, two stations near Douglas, Arizona exceeded the EPA standard for the 24-hour average of particles less than 10 microns in diameter. None of the other regional stations had exceedances for particulate matter in 2008. While there were exceedances, all of the sites were in compliance because the exceedance rate was less than one per year measured over three years (ADEQ 2009). In general, visibility shows signs of improvement at Chiricahua NM over the past 20 years. While visibility is monitored at Saguaro National Park (NP), there is insufficient data for long-term trend analysis (NPS ARD 2010a). Recent visibility data for Chiricahua NM, Coronado NMem, and Fort Bowie NHS are presented in Sections 4.2.1.1, 4.2.2.1, and 4.2.3.1 respectively.

Ozone (O_3) is a component of the atmosphere that is produced through the reaction of water and oxygen with lightning and with anthropogenic pollutants. In the stratosphere, ozone blocks ultraviolet radiation but in lower levels of the atmosphere ozone can be toxic to humans and plants. A national standard for ozone was set by the Environmental Protection Agency to protect the environment and human health (Mau-Crimmins and Porter 2007). Within the region, ozone is monitored at Chiricahua NM and in Tucson. Since 1990, the ozone level at Chiricahua NM has not exceeded the EPA standard. In general, there are no long-term trends in ozone levels at Chiricahua NM or Saguaro NP (NPS ARD 2010a). Recent ozone data for Chiricahua NM, Coronado NMem, and Fort Bowie NHS are presented in Sections 4.2.1.1, 4.2.21., and 4.2.3.1 respectively.

Atmospheric deposition has two mechanisms: wet deposition and dry deposition. Dry deposition occurs through a series of complex processes. Wet deposition occurs when gases and particles of transformed air pollutants are deposited via rain and snow. Air pollutants such as sulfur dioxide (SO_2), ammonia (NH_3), and nitrogen oxides (NO_X) are transformed in the atmosphere into compounds such as sulfate (SO_4^{2-}), ammonium (NH_4^+), and nitrate (NO_3^-). Acidification, eutrophication, toxin accumulation, and fertilization can result from atmospheric deposition and can affect water, soil, plants, and animals. Some plants are better able to use nitrogen than others and atmospheric deposition of nitrogen can affect species composition and biomass, with resulting changes in fire frequency (Mau-Crimmins and Porter 2007). By county, total nitrogen emissions in the region average less than 5 tons per square mile per year (Sullivan et al. 2011) and total nitrogen deposition (wet and dry) in the region averages less than 5 kilograms per hectare per year (Sullivan et al. 2011). Deposition is monitored at Chiricahua NM but there is not sufficient data for long-term trend analysis (NPS ARD 2010a). Recent deposition data for Chiricahua NM, Coronado NMem, and Fort Bowie NHS are presented in Sections 4.2.1.1, 4.2.2.1, and 4.2.3.1 respectively.

4.1.2 Biological Resources and Setting

4.1.2.1 Description of the Madrean Archipelago

Warshall (1995) discussed sky islands and mountain archipelagos in a global context. By his definition, there are 20 sky island complexes on the planet. The Great Basin and Madrean Sky Island Archipelagos are unusual among these because they consist of large numbers of isolated ranges that serve as stepping stones between two larger mountain areas. Warshall also pointed out that the northwest-southeast orientation of the Basin-and-Range mountains and valleys provides dispersal opportunities and mixing of species along latitudinal climatic gradients, especially in the transition from tropical to temperate climates. For plants and animals restricted to upland biotic communities, valleys may be formidable barriers to dispersal between ranges. The Madrean Archipelago has a more diverse geological composition than sky island complexes in other parts of the world.

Warshall's Madrean Archipelago discussion included series of sky island ranges connecting both Sierra Madre ranges to the Rocky Mountains, although his map and estimate of the number of sky islands ranges was only for the Sierra Madre Occidental. Here we are also concerned with this western area and will use Madrean Archipelago and Sky Island Region for the ranges that occur between the Sierra Madre Occidental and the Mogollon Rim of Central Arizona (Marshall 1957, McLaughlin 1995, Warshall 1995).

The Sierra Madre Occidental extends up western Mexico from Zacatecas and Jalisco north to Chihuahua and Sonora, Mexico (Rzedowski 1978). Highest elevations for much of this cordillera exceed 9100 feet (2800 m), and its continuity provides an important route for fauna and flora dispersing between tropical and temperate pine forests, and between tropical forests and northern grasslands. The continental divide follows the Sierra Madre northward to the upper Río Gavilán-Sierra Huachinera on the Chihuahua-Sonora border, and then through the isolated Sierra Púlpito and Sierra San Luis in Sonora and the Animas Mountains in New Mexico.

Warshall (1995) estimated that there were about 40 sky island ranges in the Madrean Archipelago, a number that has been often repeated (Skroch 2008, Turner et al. 2005). McLaughlin's (1995) map included the sky island mountain ranges from the Santa Teresa Mountains in the north, Baboquivari Mountains in the west, and Animas Mountains in the east, southeastward to the Sierra Aconchi and Sierra de las Guijas in the south. Fishbein et al. (1995) included the 24 largest ranges in their map of the Sky Island Bioregion of the northwestern Mexico and southwestern United States. The Sky Island Alliance also includes the Mazatzal and Pinal Mountains of sub-Mogollon Arizona and the Cedar Mountains of New Mexico in their sky island inventory.

Use of the adjective "Madrean" may seem a bit misleading. The term refers to flora and fauna having their origins in the Sierra Madre Occidental of Mexico. Although much of the biota of the Sky Islands is montane Sierra Madre in origin, especially the oaks, not all of the flora originated from the south (and the Madrean component decreases moving northward, and higher in elevation). For example, most of the Sky Island oaks are southern species, but some are northern in distribution (e.g., Gambel oak, gray oak); and, while many of the conifers are southern in origin (e.g., Apache pine, Chihuahuan pine), most are temperate species (e.g. blue spruce, Englemann spruce, subalpine fir, corkbark fir, white fir, limber pine, ponderosa pine). The term "Petran" refers to the flora of the Rocky Mountains. Plant inventories suggest that, among the Sky Islands of Arizona, 57% of the plant species are Madrean (Sierra Madre Occidental), 17% Cordilleran (Petran+Cascade range), 15% Sonoran, 6% Californian, and 5% "intermountain" (Great Basin, Columbia Plateau, Colorado Plateau) (McLaughlin 1994). The biogeographic mix depends on latitude and altitude; in the Pinaleños, above 9000 ft (2745 m) for example, the flora is mostly Cordilleran. The Madrean species reach their northern limits in southeastern Arizona's Sky Islands. These mixed vegetative origins were documented by Shreve in the early 1900s. Of all the National Park Service parks and monuments in the region, only three contain significant Madrean biota: Chiricahua NM, Coronado NMem, and Guadalupe Mountains National Park (NP).

Using the existing definition of a sky island as an isolated mountain with woodland or forest on the summit and surrounded by drier biocommunities, we identified 52 sky islands within the broad Madrean Archipelago on the Brown and Lowe vegetation map (1980; Figure 4.12 and Table 4.2). This region (Figure 4.12) covers about 10 million hectares (nearly 25 million acres), with elevations ranging from 975-10,500 ft (300 to 3240 m). In this compilation of sky islands, ranges were both added and combined into larger contiguous areas. This is a useful, complicated, and important regional biogeographical concept that warrants discussion, definition, and revision in a binational workshop. There are 16 sky islands in Arizona, and 36 in Sonora that have oak woodland above about 3600 ft (1100 m) elevation. This includes 20 ranges on the Brown and Lowe map that were too small to be individually named. The Sierra El Humo and the Sierra Mezquital-San Juan in Sonora south of Sásabe, Arizona (Flesch and Hahn 2005), Sierra los Locos north of Rayón, Sonora, Sierra los Pajaritos, Sierra Santo Niño, the Sierra de Mazatán (Flesch and Hahn 2005, Sánchez-E. et al. 2005), eight small outlier ranges between Sierra las Guijas and Hermosillo, and Sierra San Javier were not included on McLaughlin's (1995) map. (The Sierra el Cobre northwest of the Sierra el Humo rises above 4220 ft [1300 m] and has a 100-square-meter patch of Mexican blue oak [*Quercus oblongifolia*]. It was not judged sufficient to call it a sky island. Similarly, the Sierra el Durazno WNW of the Sierra el Humo has patches of shrub live oak [*Q. dumosa*], which is as indicative of chaparral as it is of Madrean Woodland; it was also excluded.)

Many of the 52 sky islands consist of two or more mountain ranges connected by oak woodland. These include the Dos Cabezas-Chiricahua-Pedregosa-Swisshelm complex and the Huachuca-Canelo Hills-Patagonia sky islands in Arizona. The Atascosa-Pajarito-Las Guijas-Avispas-Cíbuta sky island straddles the Arizona-Sonora border west of Nogales. Brown and Lowe (1980) and McLaughlin (1995) mapped this area as continuous with the Sierra Pinitos based on elevation, but the area along MEX 15 south of Nogales is desert grassland instead of oak woodland. The Sierras Elenita-Mariquita-Púrica-Bueno Aires-Manzanal-Azul-la Madera (near Imuris)-Cucurpe sky island is another large contiguous area from the Cananea area southward. Brown and Lowe (1980) and McLaughlin (1995) mapped this area as continuous with the Sierra Pinitos based on elevation, but the road from Santa Cruz south to San Antonio on MEX 2 passes through desert grassland. Across the Río Sonora Valley to the east, the Sierra de los Ajos merges southward into the Sierra Bacoachi and Sierra de la Madera (= Oposura). These last two areas are the largest sky islands in the Madrean Archipelago. Two important complexes in northeastern most Sonora are the Sierras San Luis-Embudos-Minitas-Pan Duro-Cabellera-Las Cuevas and Sierras Cabullona-Fronteras-Basomari-los Fresnos-Cerro Corbata sky islands.

Inland Seas

The theme of the 2004 symposium on the *Biodiversity and Management of the Madrean Archipelago II* was *Connecting Mountain Islands and Desert Seas* (Gottfried et al. 2005). The lowland biotic communities are an integral part of the vegetation of the sky islands, forming skirts below the woodland crowns. Gehlbach's 1981 book *Mountain Islands and Desert Seas. A Natural History of the U.S.-Mexican Borderlands* is an important regional overview and source of information. His use of "desert seas" was rhetorical and included non-desert arid communities. Desert grassland is the most widespread vegetation in the valleys of southeastern Arizona and adjacent New Mexico and Sonora. In the lower reaches of the Gila, San Pedro, and Santa Cruz Rivers, Arizona Upland Sonoran desertscrub flanks the Pinaleño, Galiuro, Santa Catalina, and Rincon Mountains. Chihuahuan desertscrub is in upstream areas of the Gila and San Pedro Rivers as well as on limestone in southeastern Arizona and northeastern Sonora. In

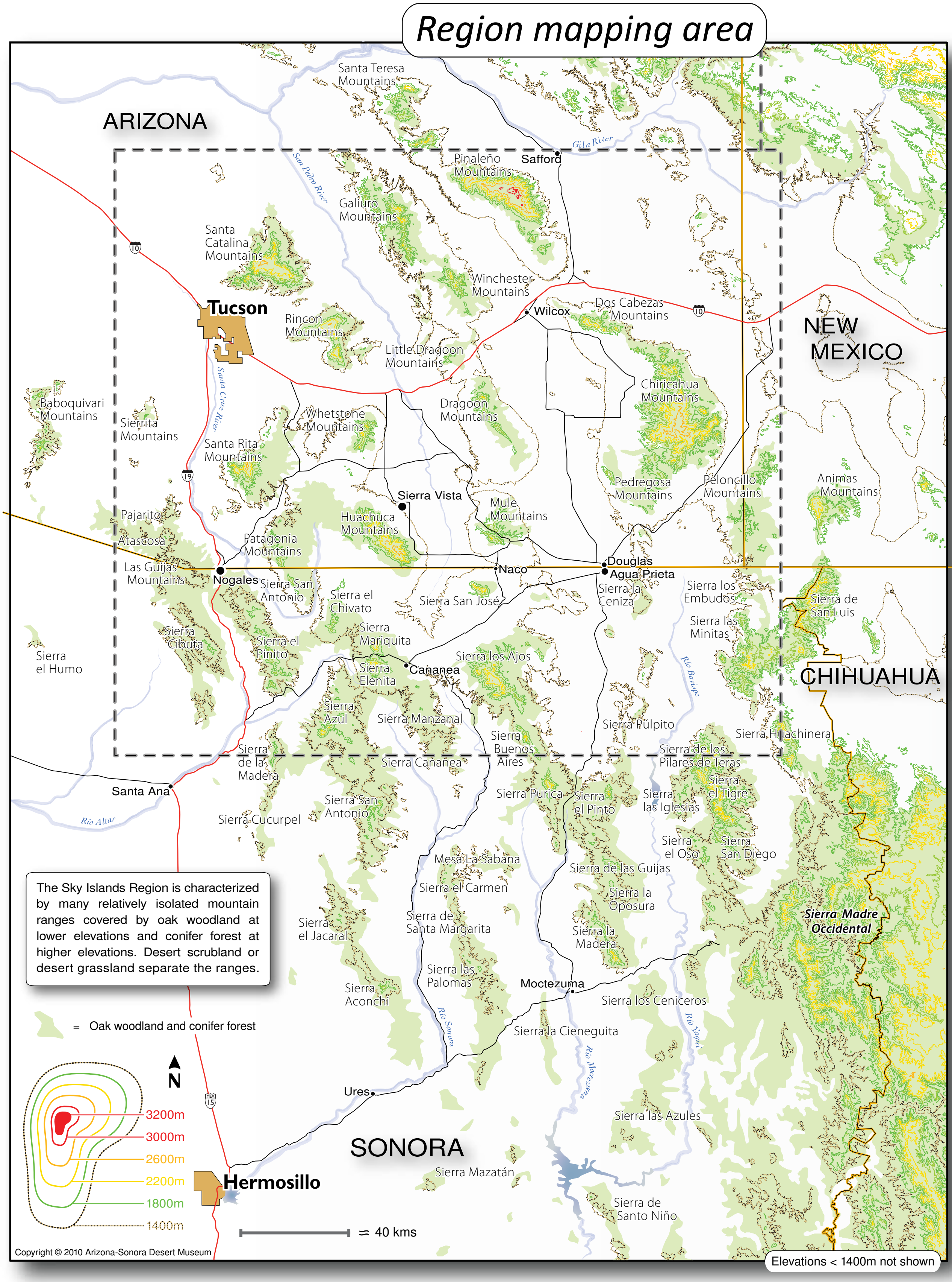


Figure 4.12. The Sky Islands Archipelago. ©Arizona-Sonora Desert Museum.

Table 4.2. Sky island mountains and mountain complexes in the Madrean Archipelago based on the Brown and Lowe (1980) map and names from the INEGI 1:50,000 topographic maps. (The largest range in each group is listed first.)

Arizona	1. Santa Teresa
	2. Pinaleño Mountains
	3. Santa Catalina Mountains
	4. Rincon Mountains
	5. Sierrita Mountains
	6. Baboquivari-Pozo Verde Mountains
	7. Santa Rita
	8. Galiuro-Winter Mountains
	9. Chiricahua-Dos Cabezas-Pedrogosa-Swisshelm Mountains
	10. Little Dragoon Mountains
	11. Dragoon Mountains
	12. Mule Mountains
	13. Huachuca-Canelo Hills-Patagonia Mountains
	14. Pajarito-Atascosa-Las Guijas mountains-Sierras Las Avispas-Cíbuta)
	15. Whetstone Mountains
	16. Peloncillo Mountains (in part)
New Mexico	-- (Peloncillo Mountains, in part – see #16)
	17. Animas Mountains
Sonora-Chihuahua	-- (Sierras Cíbuta-Las Avispas- Atascosa-Pajarito-Las Guijas Mountains, in part – see #14)
	18. Sierra Pinitos
	19. Sierra San Antonio
	20. Sierras Azul-Elenita-Mariquita-Púrica-Buenos Aires-Manzanal-la Madera (Imuris)- Cucurpe
	21. Sierras San José-la Muela (SW of Naco)
	22. Sierra las Cenizas (SE of Agua Prieta)
	23. Sierras San Luis-Embudos-Minitas-Pan Duro-Cabellera-Las Cuevas
	24. Sierras Cabullona-Fronteras-Basomari-los Fresnos-Cerro Corbata
	25. Sierras los Ajos-Bacoachi-Madera
	26. Sierra el Tigre
	27. Sierra Aconchi
	28. Sierra Santa Margaritas
	29. Sierra las Guijas (SE of Moctezuma)
	30. Sierra el Púlpito
	31. Sierras Cieneguita-Huerta (SE of Moctezuma)
	32. Sierra El Carrizo (NE of Bacanora)
	33. Cerro Varal (near La Madera [Oposura])
	34. Cerros Blanco (NW of Ojo de Agua)
	35. Mesa la Sabana (east of Arizpe)

Table 4.2. Sky island mountains and mountain complexes in the Madrean Archipelago based on the Brown and Lowe (1980) map and names from the INEGI 1:50,000 topographic maps. (The largest range in each group is listed first.)

Outside McLaughlin's (1995) map	36. Sierra el Humo (Sonora, westernmost island)
	37. Sierras el Mezquital-San Juan
	38. Sierra los Locos (near Rayón)
	39. Sierra Pajaritos (E of Ures)
	40. Sierra El Batamote
	41. Cerro el Repecho
	42. Sierra Agua Verde (= Las Calabazas, W of San Pedro de la Cueva)
	43. Sierra Santo Niño
	46. unnamed?, west of El Novillo (3; map H12 D34)
	47. Sierra San José de Carrizo
	48. Sierra Mazatán
	49. Cerro Cobachi
	50. Sierra Martínez
	51. Sierra el Aliso
	52. Sierra San Javier

Sonora, foothills thornscrub covers a larger area in the sky islands region than desert grassland. South of the Sierra el Tigre in the Río Bavispe drainage, thornscrub surrounds all of the ranges including the Sierra Aconchi, Sierra Las Margaritas, Sierra Cieneguita-la Huerta, Sierra las Guijas, Sierra Santo Niño, and Sierra de Mazatán. The southernmost sky island in Sonora is the Sierra San Javier 130 km (80 mi) east-southeast of Hermosillo (Varela-Espinosa 2005); it also has the northernmost tropical deciduous forest in Sonora (Van Devender et al. 2010).

4.1.2.2 Major Ecoregions and Biomes

We use the Brown-Lowe-Pase (BLP) hierarchical classification system (Brown 1982; Brown et al. 1979) for the regional vegetation (Figure 4.13), because the National Vegetation Classification Standard maps have not been sufficiently developed for the Madrean Archipelago. It ranks vegetation first by broad vegetation types, formations, and climates, and then more regionally-specific biomes, biotic communities (= series), and the associations. The classification is dynamic and completely open to the addition of other associations with different dominants. Some modifications have been published. Desert Grassland is used instead of Semidesert Grassland. As knowledge of tropical vegetation in northwestern Mexico increased, the term Sinaloan has fallen out of use for tropical vegetation units such as Thornscrub, Tropical Deciduous Forest, and others (Yetman et al. 1998). Most important, Madrean Evergreen Woodland has been split into Madrean Oak Woodland and Madrean Pine-Oak Forest (Van Devender and Reina-G 2005). Our recommendations for reference sites are indicated for the biocommunities that are well represented within the parks.

The parks are mapped according to the National Vegetation Classification Standard (NVCS). The BLP classification is not easily converted to the NVCS, especially at the lower levels of Alliance and Association. The three parks in this study have been or are being mapped at the Association level. The Southwest has not been completely mapped at this level, and numerous new Associations were defined during the park surveys. Moreover, different agencies are mapping their lands without sufficient coordination to assure consistent classification within the guidelines of the NVCS (Todd Esque, USGS, pers. comm. 2010). Direct comparison of vegetation communities within and outside

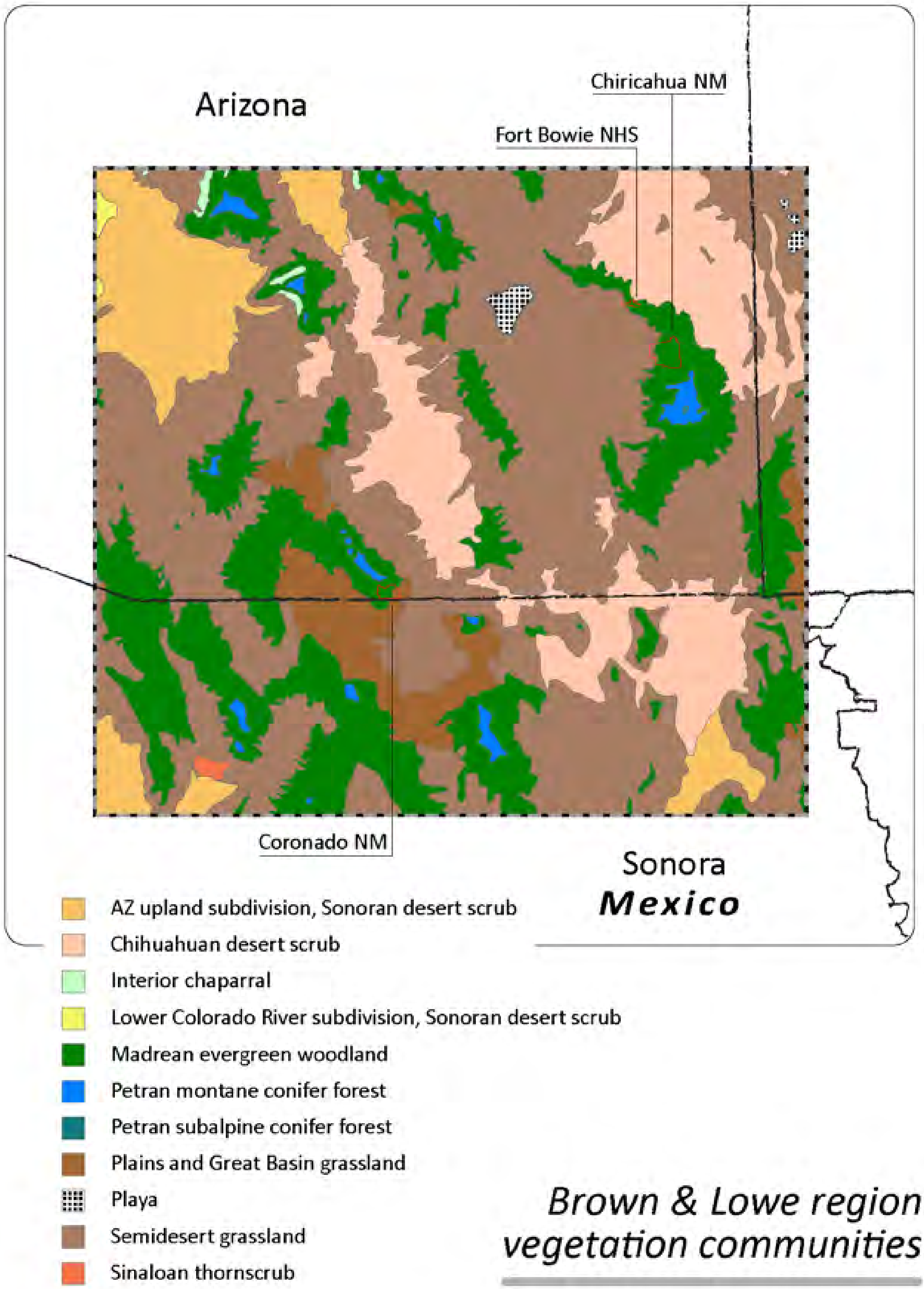


Figure 4.13. Major vegetation of the Madrean Archipelago. Modified from Brown, Lowe, and Pase 1981.

the parks is therefore difficult. We were unable to determine whether associations defined within the parks are rare or common elsewhere in the Madrean Archipelago. Table C.1 is our rough attempt to cross-walk BLP with NVCS at the formation level.

Tropical Deciduous Forest

Tropical Deciduous Forest (TDF) is a semiarid tropical community, most of which never experiences freezing temperatures. In Sonora the dry season lasts about nine months, but the summer rainy season is dependably wet. At Alamos in southern Sonora, summer rainfall averages about 760 mm (30 inches) and comprises about 90% of total rainfall. TDF occurs on the Sierra San Javier, the southernmost sky island in the Madrean Archipelago. TDF is of minor importance to the sky islands in the focus area of this NRCA.

Thornscrub

Thornscrub is semiarid, seasonally dry tropical vegetation that extends from Sinaloa to north-central Sonora. Coastal Thornscrub is on the coastal plain in southern Sonora; it gradually merges into Sonoran Desertscrub to the north and TDF to the south. Foothills Thornscrub forms broad transitions with tropical deciduous forest in southern Sonora, oak woodland in the Sierra Madre Occidental in eastern Sonora, Sonoran Desertscrub in central Sonora, and Desert Grassland and Chihuahuan Desertscrub in northeastern Sonora. Thornscrub in Sonora experiences occasional frost; nonetheless it contains many more frost-sensitive species than the Sonoran Desert, the biota of which is largely derived from thornscrub. The rainy season is in summer. Rainfall is considerably less than in TDF, but still usually ample to produce lush summer growth. This is an important distinction from desertscrub communities, in which water is often limiting even during the rainy season(s). The vegetation consists mostly of woody trees and shrubs with a significant component of succulents including arborescent cacti. Foothills Thornscrub surrounds the bases of the southernmost ranges of the Madrean Archipelago in Sonora. The community does not reach the United States, but it makes a significant contribution to the biodiversity of the focus area. The geographical ranges of a number of its tropical species extend into the Desert Grassland and Madrean Oak Woodland communities of the three parks.

Sonoran Desertscrub

The Sonoran Desert is the lowest elevation desert in North America. (However, Death Valley, part of the Mohave Desert, is lower.) Most of its area is nearly frost free and therefore tropical in the biological sense. The vegetation is characterized by legume trees and columnar cacti (the only North American Desert with these lifeforms), and includes many shrubs, succulents, and annuals. About half of the species in its flora and fauna are of tropical origin. Their ancestors occur in Thornscrub that merges with the southern limit of the Sonoran Desert, and to a lesser extent in Tropical Deciduous Forest farther south.

Sonoran Desertscrub occupies two valleys in the northern half of the Madrean Sky Islands Region: the lower San Pedro River Valley southward to about Redington, and the Gila/San Simon River Valley south to about halfway between Safford and San Simon. The vegetation in these valleys is Arizona Upland Sonoran Desertscrub; this subdivision is the wettest and coldest subdivision of the Sonoran Desert. It experiences substantial frost, and 10 to 14 inches of annual precipitation split between winter and summer rainy seasons. The southeastern reaches of these valleys are occupied by Chihuahuan Desertscrub and Desert Grassland.

Chihuahuan Desertscrub

The Chihuahuan Desert on the Mexican Plateau in north-central Mexico and adjacent United States is the southernmost North American desert. Its high elevation and incursions of arctic air masses result in cold winters with frequent hard freezes. The dominant vegetation is a great diversity of woody shrubs and small succulent plants. There are no trees except in riparian corridors, and no arborescent cacti. Chihuahuan Desertscrub occupies the upper San Pedro and San Simon River valleys. Limestone sedimentary rocks characterize most of the

Chihuahuan Desert in New Mexico, Texas, Coahuila and Chihuahua. Chihuahuan Desertscrub is also present on limestone substrates in northeastern Sonora in the Agua Prieta area, and in the Mule and Swisshelm Mountains, and other ranges in southeastern Arizona. None of the three parks has any Chihuahuan Desertscrub, but a number of species typical of this community occur on calcareous substrates in the focus area, especially in Fort Bowie NHS.

Plains Grassland

Plains Grassland is the vegetation of the Midwestern prairies. In the Madrean Archipelago, Plains Grassland is limited to isolated patches in the Sonoita and San Rafael valleys. These areas receive between 11 and 18 inches of annual precipitation. Temperate grassland also occurs in the Animas Valley in southwestern New Mexico and adjacent northeastern Sonora.

Reference area: San Rafael Valley, Arizona; Ladder Ranch, New Mexico. These areas have been carefully managed for decades, and are regarded to be in good health.

Desert Grassland

Desert Grassland (= Semidesert Grassland of Brown and Lowe) is drier and warmer than Plains Grassland, and is much more common in our region. It is distinguished from Plains Grassland by its largely different, typically shorter growing, species of grasses, and a greater admixture of woody and succulent plants. Characteristic nongrass species in Desert Grassland include mesquites (*Prosopis glandulosa*, *P. velutina*), littleleaf sumac (*Rhus microphylla*), wait-a-minute bush (*Mimosa biuncifera*), sotol (*Dasylrion wheeleri*), soaptree yucca (*Yucca elata*), and beargrass (*Nolina microcarpa*). Desert Grassland is a major community in the area of the three parks, where it typically occurs between 4000 and 5000 feet elevation. It is the primary "sea" that surrounds the mountain islands in southeastern Arizona. Average annual rainfall is 12 to 15 inches. The majority of desert grassland in the Madrean Archipelago is degraded, classified as dominated by nonnative grasses, shrub-invaded, or converted to shrubland.

Reference area: Ranches in the Malpai Borderlands Group in southeastern Arizona and southwestern New Mexico. These ranches have been carefully managed for several decades. The areas designated as grass reserves have been very lightly grazed by livestock during most of that time. The grass cover is almost all native species, and there is little shrub invasion.

Chaparral

Chaparral is a vegetation type that occurs in Mediterranean climates, which are those with mild wet winters and hot, dry summers. In North America this biome is mostly restricted to the Pacific coast from northern Baja California to southern Oregon. The California Chaparral community is composed of many species of woody shrubs, with few other lifeforms in mature stands.

The Interior Chaparral biotic community is a depauperate chaparral in mountainous areas east of the Colorado River. In Arizona, Interior Chaparral is best developed in a broad band below the Mogollon Rim in central Arizona, where it is dominated by shrub live oak (*Quercus turbinella*) and pointleaf manzanita (*Arctostaphylos pungens*). This association occurs as far southeast as the foothills of the Pinaleño Mountains and into the Fort Bowie NHS area. Other association dominants include mountain mahogany (*Cercocarpus montanus*), buckbrush (*Ceanothus pauciflorus = C. greggii*), and Wright's silktassel (*Garrya wrightii*). It occurs between 4000 and 7000 feet elevation, and receives 13 to 23 inches average annual rainfall. The rainfall in central Arizona is biseasonal, but receives about the same amount of winter rain as chaparral in California. The only Interior Chaparral in northeastern Sonora is a pointleaf manzanita-Emory oak (*Q. emoryi*)-Toumey oak association in the Sierra San Luis.

There are significant patches of what may be Interior Chaparral in Chiricahua NM, where it is unusually rich and its species composition is anomalous for this community. Silverleaf and Toumey oaks (*Q. hypoleucoides*, *Q. toumeyi*) are codominants with pointleaf manzanita. Other forest trees such as border pinyon (*P. discolor*) are also present. All of the tree species are dwarfed. The vegetation looks like a combination of chaparral and krummholz (treeline stunted forest). The elevation is much too low for the latter vegetation. Its short stature may be an edaphic effect.

Reference area: Upper slopes around Massai Point, Chiricahua NM. The area near the parking lot is heavily trampled. More distant sites (e.g., around the weather station) that have not burned in several decades are representative of undisturbed local chaparral, or whatever this odd vegetation is.

Great Basin Conifer Woodland

Great Basin Conifer Woodland is centered in the colder, drier areas of the Great Basin highlands. The pinyon-juniper biotic communities include various pinyon-juniper and juniper woodland associations dominated by Colorado pinyon (*Pinus edulis*) or singleleaf pinyon (*P. monophylla*) in association with several species of junipers (*Juniperus* spp.). Below the Mogollon Rim and in most of southeastern Arizona, these woodlands are replaced by Interior Chaparral or Madrean Oak Woodland. In the Madrean Archipelago, there is only a small area of Pinyon-juniper Woodland in the northernmost reach between the Galiuro and Santa Teresa mountains. Some of the characteristic species of this community such as singleleaf pinyon range southward into the three parks. Areas in Chiricahua NM where border pinyon (*P. discolor*) is common are reminiscent of these woodlands.

Madrean Oak Woodland

Madrean Oak Woodland is part of BLP's Madrean Evergreen Woodland. Yetman et al. (1998) split it in two, and used the term Madrean Oak Woodland as equivalent to the Encinal (Oak) biotic community. It is characterized by open stands of several species of oaks, with an understory of grasses and shrubs, herbs, and grasses. The most characteristic species are Emory oak (*Quercus emoryi*) Arizona white oak (*Q. arizonica*), and Mexican blue oak (*Q. oblongifolia*). It is the common community of the middle elevations of the Sierra Madre Occidental in Mexico. It covers a large part of the Madrean Archipelago at elevations between 4000 and 5500 feet, including substantial portions of all three parks. It extends as far north as the southern slopes of the Mogollon Rim, where it is presumably limited from more northerly distribution by winter cold at the elevation where rainfall is sufficient.

Reference area: The lower slopes of the southern end of the Huachuca Mountains. This area has not been heavily grazed or burned in several decades. It was cited as a reference area by Ffolliott and Gottfried (2010) for oak savannah.

Madrean Pine-oak Forest

Madrean Pine-oak Forest is the other term used by Yetman et al. (1998) for the Oak-Pine biotic community in BLP's Madrean Evergreen Forest and Woodland. It occurs on mountain slopes above oak woodland at elevations of 5500 to 6500 feet on the peaks of the Madrean Archipelago, and replaces the Ponderosa Pine Forest found at these elevations above the Mogollon Rim. It differs from oak woodland in having taller trees in a denser canopy dominated by both pines and oaks. Most of the higher ranges in the Madrean Archipelago are occupied by this community, including significant stands in Chiricahua NM and Coronado NMem. Common trees include Apache pine (*Pinus engelmannii*), Arizona pine (*P. arizonica*), Ponderosa pine (*P. ponderosa* var. *scopulorum*), and silverleaf oak (*Q. hypoleucoides*). Biogeographic affinities with the Sierra Madre Occidental are strong in Madrean Pine-Oak Forest. Above 6500 feet it is replaced by Rocky Mountain conifer communities that are more cold tolerant. Several key species of this community are actually Rocky Mountain plants, so it should more accurately be called simply Pine-oak Forest.

Reference area: The middle elevation slopes of the Chiricahua Mountains, Cave Creek drainage.

Petran (Rocky Mountain) Conifer Forest

Petran (Rocky Mountain) Conifer Forest, including the Ponderosa Pine Forest and Mixed-Conifer Forest communities, is the dominant vegetation of the Rocky Mountains. It is more cold adapted than Madrean communities, and mostly occurs at higher elevations than Madrean forests. In the Madrean Archipelago, areas dominated by pines without oaks are very limited. Common trees are Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*). In northeastern Sonora, this community is restricted to elevations mostly above 7,000 feet in the Sierras de los Ajos, San José, San Luis, and el Tigre. This community does not occur in any of the three parks.

Petran Subalpine Conifer Forest

Petran Subalpine Conifer Forest is represented by Spruce-fir Forest in Arizona. South of the Mogollon Rim, it is restricted to small areas in the Chiricahua, Pinaleño, and Santa Catalina Mountains above about 8500 feet where the average annual precipitation is 30-35 inches. Common trees are Engelmann spruce (*Picea engelmannii*; Chiricahua and Pinaleño Mountains), [above Mogollon Rim] corkbark fir (*Abies lasiocarpa arizonica*; Pinaleño and Santa Catalina Mountains), and southwestern white pine (*Pinus strobiformis*). This community does not occur in any of the three parks.

Riparian

Riparian communities can occur in any biome. Each type of wetland and riparian habitat supports vegetation that is different from the nearby drylands. The classification of wetland and riparian vegetation is cumbersome because many types are found within most upland vegetation types, and are often repeated as biotic communities in multiple biomes; e.g., Cottonwood-Willow Riparian Forest biotic communities are present in seven different biomes in the greater Southwest. In this report we will use more general terms to describe these habitats (Brown et al. 1979).

Along arroyos and rivers in the lowlands and in canyons in the uplands, riparian vegetation forms linear bands that pass through drier communities. In lower, drier drainages, riparian vegetation can be dominated by desert willow (*Chilopsis linearis*), netleaf hackberry (*Celtis reticulata*), velvet mesquite (*Prosopis velutina*), and shrubs. West of Chiricahua NM, Arizona oak (*Quercus arizonica*) and alligator juniper (*Juniperus deppeana*) in lower Pinery Canyon extend well into the grasslands of the Sulphur Springs Valley.

Riparian forests with Fremont cottonwoods (*Populus deltoides* var. *fremontii*), willows (*Salix bonplandiana*, *S. gooddingii*), sycamore (*Platanus wrightii*), velvet ash (*Fraxinus velutina*), and Arizona walnut (*Juglans major*) are important wildlife habitat along canyon streams and rivers from southeastern Sonora south to central Sonora, with Cajón Bonito in northeastern Sonora an outstanding example. Fremont cottonwood-willow gallery forests are present at elevations of 3500-5500 feet. At higher elevations in Mixed-Conifer Forest, riparian trees include bigtooth maple (*Acer grandidentatum*), boxelder (*A. negundo*), narrowleaf cottonwood (*Populus angustifolia*), Gambel oak (*Quercus gambelii*), and white fir. In Chiricahua NM, Arizona cypress (*Cupressus arizonica*) is a common riparian tree. At all three parks, sycamores (*Platanus wrightii*) are very common and cottonwoods are less common.

The Babocomari Ciénega on the north end of the Huachuca Mountains, Arizona, the Cloverdale Ciénega in the Animas Valley, New Mexico, and the Saracachi Ciénega east of Cucurpe, Sonora are examples of an important wetland in the Madrean Archipelago region. However, water sources in the three parks are limited to a few springs.

Reference areas: Riparian communities are extremely variable depending upon elevation, average flow volume, and time since the last scouring flood. Selection of reference areas for a given subtype requires detailed analysis that is beyond the scope of this report. In addition to the general criteria for assessing ecosystem health, a riparian community that is within protected habitat and has not been subject to substantial negative human impact for at least several decades is probably healthy.

4.1.2.3 Biological Diversity

Southeastern Arizona has long been recognized as a center of high biodiversity. Several factors combine to support this diversity.

1. The primary reason for the great biodiversity of southeastern Arizona is that it is greatly enhanced by the merging of five biotic provinces.

a. The Sonoran Desert lies to the west of the Madrean Archipelago. Some of its species reach their easternmost distributions in Foothills Thornscrub in northeastern Sonora and Desert Grassland in southeastern Arizona.

b. The Great Plains/Chihuahuan province is to the east. In western Texas, the Great Plains meets the Chihuahuan Desert, which mostly occurs on the Mexican Plateau in Chihuahua and Coahuila. From Texas to southeastern Arizona, Chihuahuan Desertscrub and Desert Grassland occur in a mosaic pattern, with desertscrub on limestone slopes and grassland on adjacent deeper valley soils. Plants and animals from the Great Plains, Desert Grassland, and Chihuahuan Desertscrub reach their westernmost distributions in the sky islands region.

c. The forests of the Rocky Mountains occur in massive stands as far south as the Mogollon Rim. Rocky Mountain plants occur in the Madrean Archipelago in Pine-oak Forests (the equivalent of Ponderosa Pine Forest) and isolated patches of Mixed-conifer and Subalpine Forest communities.

d. The extensive, continuous Madrean Pine-oak Forest and Oak Woodlands of the Sierra Madre Occidental of northwestern Mexico extend northward to about 50 miles south of the U.S.-Mexican border. Isolated patches of these communities and a great many Madrean species occur at intermediate elevations in the mountains in the Madrean Archipelago to the base of the Mogollon Rim.

e. New World tropical vegetation reaches its northernmost limit in North America in eastern Sonora. Between the Sierra Madre Occidental and the Sonoran Desert in eastern Sonora, Tropical Deciduous Forest extends to 28°35'N in the Sierra San Javier and Foothills Thornscrub extends to 30°30'N in the Río Bavispe drainage. The most cold-tolerant species of these communities extend into warm-temperate habitats in southeastern Arizona.

2. The mountains are composed of various rock types, especially rhyolite, granite, and limestone, as well as textural diversity ranging from steep cliff faces in mountains to fine clay soils in the valleys. Slope exposures create still more microclimates. This topographic and geological diversity creates many microenvironments that in turn provide many ecological niches for plants and animals to occupy.

3. The region has a biseasonal precipitation pattern. This creates the opportunity for temporal niche separation. Many plants and animals respond only to either the summer or winter rains, while other opportunistic ones respond at any season. Furthermore, it is rare for both rainy seasons to fail in a given time period, which moderates the severity of droughts.

4. Elevations ranging from 300 to 3200 meters (975 to 10,390 ft) create a bioclimatic gradient of increasing moisture and decreasing temperatures. The climates change from tropical in Thornscrub to temperate in Desert Grassland, Chihuahuan Desertscrub, Oak Woodland, and Madrean Pine-oak Forest, and to boreal in Mixed-conifer and Spruce-fir Forests.

Flowering patterns change with elevation. Sonoran Desertscrub, Foothills Thornscrub, Interior Chaparral, and other lowland communities have five seasons: winter, spring, arid foresummer, monsoon summer, and fall. The region's two rainy seasons produce two distinct flowering seasons, spring and late summer. Many lowland species flower in response to only one of the rainy seasons, but some opportunists flower whenever there is sufficient soil moisture. The beginning of spring is delayed by cooler temperatures at higher elevations. Spring wildflowers in the Lower Colorado River Valley subdivision of the Sonoran Desert below 1,800 feet often peak in February (and sometimes as early as November) compared to March in Arizona Upland Sonoran Desertscrub near Tucson at 2,400 feet. Spring flowering is delayed until late April or May in Desert Grassland at 4,000 to 5,000 feet. At the highest elevations spring is delayed so long that it merges with summer in one warm season activity period.

Although the Neotropics are usually thought of as the most diverse biotic communities, Rzedowski (1978) in his book Vegetación de México stated that the highest biodiversity was actually in pine-oak forest. A similar pattern was found along the elevational gradient in the Municipio de Yécora in the Sierra Madre Occidental in eastern Sonora during extensive floristic work from 1995 to 2008; i.e., 791 taxa in tropical deciduous forest, 808 taxa in oak woodland, and 1077 taxa in pine-oak forest (Reina-G. et al. 1999, Van Devender et al. 2005, Van Devender and A. L. Reina-G. unpubl. data). The flora is very diverse with 1767 taxa in 3,300 km^2, great species turnover, and shifts in the importance of different plant groups; i.e., species of Fabaceae dominate Tropical Deciduous Forest, while Asteraceae and Poaceae dominate higher Madrean temperate biotic communities. Colder winters in Arizona's pine-oak woodlands reduce biodiversity somewhat, but it is still very high.

5. Latitudinal changes in climate influence the composition and diversity of the biota. Oak Woodland and Pine-Oak Forest communities in the Sierra Madre Occidental in eastern Sonora are more diverse than similar habitats in southeastern Arizona, reflecting mixtures of montane species from the Rocky Mountain-southwestern United States and Sierra Madrean species that do not reach the United States (Reina-G. and Van Devender 2005). For example, there are 11 species of pines and 14 species of oaks in the Municipio de Yécora compared to 7 pines and 8 oaks in the Chiricahua Mountains (Powell et al. 2008). The presence of tropical elements in the pine-oak forests of eastern Sonora (e.g., three species of Begonia, Tigridia pavoniana, Dahlia coccinea, etc.) indicates that winter minimum temperatures are not as low as in the Madrean Archipelago ranges. This trend continues southward in the Sierra Madre Occidental until winters are mild enough that flowering continues through the cold season; e.g., Salvias flowering in December at 8,500 feet in fir forest in Michoacán.

The northernmost distribution limits of some tropical species such as coralbean (*Erythrina flabelliformis*) and the Neotropical vine snake (*Oxybelis aeneus*) are in southeastern Arizona at 4,000-5,000 feet elevation in Desert Grassland/Oak Woodland, where they are limited by cold at higher elevations and aridity at lower elevations (Van Devender et al. 1994).

6. Species diversity in many groups of organisms increases towards the tropics. Plant families with numbers of taxa increasing southward into the Neotropics include Euphorbiaceae, Malvaceae, Convolvulaceae, Apocynaceae, Rubiaceae, Orchidaceae, Acanthaceae, and Cucurbitaceae (Van Devender et al. 2010). Reina-G. and Van Devender (2005) compared the floras of the Huachuca Mountains with similar biotic communities in the Yécora area in the Sierra Madre in eastern Sonora. The families Cruciferae, Rosaceae, and Liliaceae are clearly more abundant in the Huachuca Mountains than in Yécora while the Pteridaceae are equally abundant. Another nine families, including Poaceae (31% more), Fabaceae (37% more), Convolvulaceae (38% more), Lamiaceae (51% more), and Malvaceae (61% more), are more abundant in the Sierra Madre. Although, muhlies (Muhlenbergia) are abundant in the Huachucas (20 taxa), Yécora is a major center of diversity for muhlies with 41% more taxa. In the Cyperaceae, there are 133% more Carex in the Huachucas while Yécora has 48% more Cyperus. Asclepias and Euphorbia (including Chamaesyce, Esula, and Poinsettia) are about equally abundant in the two floras while four other genera (Dalea, Erigeron, Ipomoea, and Salvia) are from 21% to 80% more abundant in Yécora.

Robert L. Minckley has studied bee diversity and pollination interactions on Rancho San Bernardino east of Agua Prieta, Sonora since 2000, where he has collected more than 400 bee species in a 15 km^2 area (Minckley 2008). The bee fauna in Desert Grassland/Chihuahuan Desertscrub in northeastern Sonora is one of the most diverse in the world.

4.1.2.4 Flora

Estimating the number of vascular plant species in a political and geographical region can be a difficult task. This is especially true in areas such as the Madrean Archipelago with diverse landscapes, habitats, and climates and where broad biogeographical provinces come together. Kearney and Peebles (1964) reported 3,370 species for Arizona, which NatureServe (2002) increased to 3,512. Currently, the Southwest Environmental Information Network (SEINet; http://swbiodiversity.org) online database for Arizona contains records for 4,252 species and 4,901 taxa. But due to taxonomic problems and misidentifications, the totals are probably closer to 4,000 species and 4,600 taxa (E. Gilbert pers. comm. 2009). Van Devender et al. (2010) report 3,659 taxa of vascular plants documented by collections from the state of Sonora, and estimate that the total is actually 4,000 or more. This plant diversity is comparable with the floras of Chihuahua (ca. 4,500 taxa, R. Corral-Díaz, pers. comm. 2009) and Durango (4,562 taxa, González-E. et al. 1991, Socorro González-E., pers. comm. 2009).

A comprehensive flora of the Sky Islands Region in Arizona has not been compiled. McLaughlin (1995) gave estimates for the number plants in 12 mountain ranges in southeastern Arizona, which averaged 627 species per flora. Larger ranges each hold 1/3 to 1/2 of the regional flora. The Huachuca and Rincon Mountains (994 and 959 taxa) have relatively rich floras for their areas, and the Pinaleño Mountains have a relatively depauperate flora (786 taxa). Extant literature estimates that the Chiricahua Mountains have about 1,200 taxa, of which 845 taxa are documented in Chiricahua NM (Bennett et al. 1996, Powell et al. 2008). The SEINet checklist for the Chiricahua Mountains contains over 1000 taxa, but not all are vouchered. The most current list for Chiricahua NM (Table C.2) contains 803 taxa. Fort Bowie NHS has 638 taxa (Table C.3, 621 after Van Devender's review; Bennett et al. 1996, Powell et al. 2006). Coronado NMem has 651 taxa (Table C.4, all three tables are Buckley unpublished data 2010).

Estimating the total number of plant taxa in the whole Madrean Archipelago is even more problematic because most of the sky island ranges in Mexico have not been inventoried. The Sky Island Region according to McLaughlin (1995) extends from the Santa Teresa Mountains in the north, Baboquivari Mountains in the west, and the Animas Mountains in the east, southeastward to the Sierra Aconchi-Sierra de las Guijas in the south. Stephen S. White led botanical expeditions from the University of Michigan to the Río Bavispe region of northeastern Sonora from 1938 to 1941. This broad region includes the Sierra El Tigre and most of the upper Río Yaqui drainage in northeastern Sonora. White and his associates made around 4,000 collections in about 1,200 plant taxa (ca. 980 currently accepted; White 1948).

The Sierra de Los Ajos east of Cananea in the Área Natural Protegida Sierras de los Ajos, Buenos Aires, y La Púrica stands out as the most temperate Sonoran sky island. Cerro Las Flores at 2,645 m (8,675 ft) is the highest elevation in Sonora, and supports pine-oak forest, and local areas of mixed-conifer forest. Fishbein et al. (1995) reported 376 plant taxa for the Sierra de Los Ajos, but estimated that over 1,000 occur in the range. An unsuccessful proposal to expand the reserve into Reserva de la Biosfera Mavavi (2000 CONANP Justification) estimated 1,234 plants for the broader proposed area.

Bowers and McLaughlin (1982) showed that the log-log plot of area versus number of species in southeastern Arizona floras was a straight line, although the elevational range of the floral area was a better predictor of species diversity. This was because of rapid temperature and precipitation changes over small areas and greater habitat diversity (= "roughness"; Bennett and Kunzmann 1992; McLaughlin 1995). This results in high species turnover and very high ecosystem level diversity. In the Madrean Archipelago, the area with the least elevational range is the Sierras Elenita and Mariquita near Cananea where base level is high and includes the headwaters of the Río San Pedro and Río Sonora. The greatest elevational ranges are 1,525 to 2,355 m (5,000 to 7,725 ft) in the Chiricahua, Huachuca, Santa Catalina, Pinaleño Mountains in Arizona and the Sierra de los

Ajos. Elevational ranges in other Sonoran sky islands are less (1,065 to 1,285 m [3,495 to 4,215 ft]). The 2,030 m (6,660 ft) elevational range from 170 m (560 ft) at Ónavas on the Río Yaqui to 2,200 m (7,215 ft) near Yécora in the Sierra Madre Occidental is similar to the elevational range for the Santa Catalina Mountains in Arizona (2,120 m [6,895 ft]).

Elevational range in mountains is related to their geographic positions in the major river drainages. Base level in the Madrean Archipelago is lowest in the lower reaches of the major rivers: i.e., 670 m (2,200 ft) on the Santa Cruz River in Tucson west of the Santa Catalina Mountains and on the Río Sonora east of the Sierra Aconchi. South of the Madrean Archipelago, base level decreases along the Río Yaqui to sea level in the Gulf of California. The maximum elevations of the larger ranges in the Madrean Archipelago decrease modestly to the south. Although the Sierra Madre Occidental in northwestern Chihuahua with elevations of 2,400-2,800 m (7,870 to 9,185 ft) is mostly higher than eastern Sonora, the highest peaks are not much higher than the sky island ranges in Sonora and Arizona. The most important difference is that the areas of upland oak woodland and pine-oak forest are much greater in the Sierra Madre Occidental than in the Madrean Archipelago.

In the Arizona sky islands, the maximum species diversity is in the middle elevations in oak woodland and lowest in the high elevation pine-oak forests. This is in contrast to the general Sierra Madre Occidental in Mexico (Rzedowski 1978) where the highest species diversity is in pine-oak forest. A similar pattern was found along the elevational gradient in the Municipio de Yécora in the Sierra Madre Occidental in eastern Sonora during extensive floristic work from 1995 to 2008. The flora is very diverse with 791 taxa in tropical deciduous forest, 808 taxa in oak woodland, and 1,077 taxa in pine-oak forest (Reina-G. et al. 1999, Van Devender et al. 2005, Van Devender and A. L. Reina-G. unpubl. data). Reina-G. and Van Devender (2005) compared the flora of upland woodlands and forests in the Yécora area with similar biotic communities in the Huachuca (Bowers and McLaughlin 1996). While a few temperate families such as Brassicaceae, Liliaceae, and Rosaceae are more abundant in the Huachucas, many more including Poaceae, Fabaceae, Convolvulaceae, Lamiaceae, and Malvaceae are more abundant in the Sierra Madre. The flora of the Municipio de Yécora (1,768 taxa in 1274 mi^2 [3,300 km^2], elevational range of 2,030 m [6,660 ft]) is much more diverse than the flora of the Huachucas (994 taxa in 122 mi^2 [316 km^2], elevational range of 1,362 m [4,465 ft]). This is a reflection of increasingly warmer winter temperatures in the Sierra Madre Occidental south to Durango and Zacatecas, and increases in temperature and warm season precipitation at low elevations in tropical foothills thornscrub.

McLaughlin (1995) estimated that 2,100 species (166 non-native = 7.9%) are found in the sky island region of southeastern Arizona. This is roughly equivalent to his Apachean District of the Madrean Floristic Province (McLaughlin 1992). Floras in the Apachean District have the highest species diversity in the western United States for both area and elevational range (McLaughlin 1995). The sky island floras differ from true insular floras in high species diversity, low local and regional endemism, and low percentages of non-native species. However, the flora of the Sierra Madre Occidental in eastern Sonora and western Chihuahua is much more diverse than any area in the Madrean Archipelago.

Southeastern Arizona with 1,940 native and 166 non-native plant taxa in 40,000 km^2 (15,440 mi^2) is about half of the Sky Island Region. Considering that there are 225 species in the Sierra El Tigre (White 1948) that are not in Arizona, McLaughlin (1995) estimated there should be 2,300 to 2,800 plant taxa in the entire Sky Island Region. We think that this estimate is probably too low because plant species diversity increases to the south in both lowland foothills thornscrub and montane pine-oak forests. Our estimate of 3,000 to 3,500 taxa for the Madrean Archipelago represents about 50% of the combined floras of Arizona and Sonora. Felger and Wilson (1995) estimated about 4,000 species for the Apachean-Madrean Region from southeastern Arizona southward into the Sierra Madre Occidental along the Sonora-Chihuahua border to northern Sinaloa. Using lists documented by herbarium specimens and updated to reflect ever-changing taxonomic names is the only way to document a more accurate number of plants in these regions. Such projects are in progress with the SEINet project online database, regional lists at the Arizona-Sonora Desert Museum (Ed Gilbert and Mark Dimmitt), and the flora of Sonora project (Van Devender et al. 2010). Steve Buckley is compiling the vouchered floras of the three parks (provisional lists are in Table C.2, Table C.3, and Table C.4.)

In McLaughlin's (1992) analyses of the floristic affinities, he included the Apachean, Chihuahuan, and Central Arizona Districts within the Madrean Floristic Province. The Chihuahuan District includes Great Plains grassland, desert grassland, and Chihuahuan Desert biotic communities from western Texas to southeastern Arizona and northeastern Sonora. The Central Arizona District includes Interior Chaparral below the Mogollon Rim. Inclusion of these biotic communities, greatly overestimates the actual affinities of sky island plants with the Sierra Madre Occidental. Madrean floristic affinities should be limited to species in the Apachean District or the Sierra Madre itself.

4.1.2.5 Invertebrates

Invertebrates of the Sky Islands Region/ Madrean Archipelago with Special Attention to Chiricahua NM, Coronado National MEM and Fort Bowie NHS

Neither a body of scientific research nor good inventories of invertebrates for Chiricahua NM, Coronado NMem, and Fort Bowie NHS exist. However, a fair amount of scattered, published work on invertebrates in the Chiricahua and Huachuca Mountains is available, and for the Sky Islands Region in general. From this work we have developed a general narrative about the invertebrate landscape of the region, and compiled a list/ table of "species of concern" for the three park units. Although there are no Endangered Species Act, ESA-listed Threatened or Endangered invertebrate species identified so far from these three park units, there are several of serious conservation concern (see Table C.5), including a number that are endemic or nearly so that deserve to be monitored and their habitats protected. The highest priorities for invertebrate habitat protection are: springs, seeps, ciénegas, ponds and riparian habitats; native grasslands, especially those with agave stands; and limestone (and other rock rubble) outcrops.

Background

Over 90% of all known animal species are invertebrates. About 1.3 million species of invertebrates have so-far been described, and estimates of undescribed species range from 5 to 200 million (R. C. Brusca believes the higher number is likely to be correct). Of the described invertebrate species, 1.14 million are arthropods – 85% of all animal species – about a million of which are insects (Brusca and Brusca 2003). Because of the sheer number of species involved, details of invertebrate diversity are notoriously difficult to document. The number of species reported from an area usually has more to do with how much attention the area has received from biologists, than it does with how many species actually occur there. Experience has shown that each new field study brings many new discoveries. It is not unusual for several of the species collected in virtually any invertebrate sample to represent undescribed species, while others will represent significant range extensions. Almost any careful observation of invertebrate natural history reveals information new to science.

There are so many unknown and poorly known invertebrate species in the Sky Islands Region that answers to fundamental questions such as how many and what species reside in the region, where they live, what they eat, how they reproduce, how they interact with each other and with other species, etc. remain unknown for all but a small percentage of the actual fauna of the region. Similarly, estimates of how management decisions might affect invertebrates in the region must often be based on generalizations or extrapolations from other, similar species.

Given the above (and in contrast to vertebrates) most invertebrate diversity discussions are based on predictions and estimates, or on a handful of well-known threatened or "signature" species; not even the best-studied parks in the nation claim to have a complete inventory of their invertebrate faunas. Species diversity predictions can be based on estimated correlations between taxa (e.g., between numbers of plant species and numbers of insects), or they can be based on equations that use the number of species that have been found only once or twice to predict how many have not yet been found at all. Most predictions do not include taxa such as mites or nematodes that are hyper-diverse but difficult to sample and identify and very poorly known. The smaller the size of taxon, the more accurate the estimates tend to be — e.g., predictions of butterfly diversity will be more accurate than predictions of beetle diversity, insect predictions will be more accurate than those of invertebrates as a whole. Information is better about "popular" groups (e.g., butterflies, beetles, dragonflies) than it is for less popular taxa. Some groups are very poorly known simply because there are so few (or no) taxonomists specializing on them, such as moths, centipedes, terrestrial isopods, and most soil invertebrates.

Invertebrates in the Sky Islands Region

Although few scientific studies on invertebrate diversity have been conducted within the bounds of the Sky Islands Region, particularly in montane and grassland environments, numerous sources of information suggest that this area represents one of the most diverse regions in North America for arthropods (e.g., insects, arachnids, etc.) – perhaps the most diverse region. Several factors contribute to this richness, including the area's tremendous plant diversity, extraordinary regional topography, and unique biogeographic location where multiple biotic provinces meet and co-mingle. The Sky Islands Region also is home to many species at or near the edges of their ranges. Here, for example, many predominantly tropical (Mexican) species can be found mixing with others from temperate regions of North America. There are numerous known endemics (many known from single mountain ranges) and certainly a great many more that remain undiscovered. Some "species clusters" (e.g., springsnails) are local radiations, with different forms on each nearby mountain range. Soil-dwelling nematodes, especially entomopathogenic (causing diseases in insects) species are a common but largely undescribed fauna in the Sky Islands (Stock and Gress 2006; Adams et al. 2006). A survey of oak-juniper habitat in four sky islands (in Arizona) collected 120 soil samples and found a quarter of them had entomopathogenic nematodes, including four undescribed species and two known species recorded for the first time from Arizona (Stock and Gress 2006).

Information on invertebrates in the Sky Islands Region is widely scattered, often embedded in taxonomic notes and monographs or broader ecological studies, frequently buried in unpublished agency reports, and not easily found. Efforts to database entomological collections are making this information easier to obtain, but most collections are still in the early stages of this process. One of the best collections for this region is the University of Arizona's Entomology Collection (UAIC), but it has not yet received specimen-level cataloging, which greatly limits its use. However, plans are under way to build a specimen-level database for the UAIC.

In addition to being species-rich, the invertebrate fauna of the Sky Islands Region is especially interesting. And, despite the fact that few biodiversity surveys have been attempted in the region, the biology of this invertebrate fauna is arguably better-known than in most comparably rich North American regions (except, perhaps, for the Great Smoky Mountains) due to: (1) the proximity of major universities, such as University of Arizona (UA), Arizona State University (ASU), University of New Mexico (UNM); (2) the long-standing Southwestern Research Station (SWRS) of the American Museum of Natural History in the Chiricahua Mountains; and (3) various long-studied federal "reserves" in the region, e.g., Jornada Experimental Range (JER), San Bernardino Natural Wildlife Refuge (SBNWR), and Buenos Aires National Wildlife Refuge (BANWR). Virtually all animal behavior and ecology textbooks published in the U.S. feature case studies discovered or developed in this region (e.g. Alcock 2009; Molles 2005).

SWRS has been one of the nation's most productive sites for invertebrate research since 1955, when the station was founded. SWRS-affiliated scientists have published research from throughout the Chiricahua Mountains, from the bajadas and bottomlands of the San Simon Valley, to mid-elevation pine-oak habitats, and to higher conifer biomes. This research has spawned over 400 scientific papers on insects alone, about half of these on ants, plus over 60 papers on spiders and scorpions (see SWRS bibliography: http://research.amnh.org/swrs/bibliography.htm). Unfortunately, taxonomic lists have been compiled for only a handful of the invertebrate groups studied in and around the Chiricahuas and the other Sky Island ranges; most of the lists that do exist are unpublished. Nevertheless, SWRS and Chiricahua-based invertebrate research is a rich source of information for the region.

JER lies some 150 miles northeast of the Peloncillos in southern New Mexico. This experimental range was designated in 1912 when a Presidential Executive Order deeded 193,000 acres (78,000 ha) of grasslands and Chihuahuan desertscrub to the U.S. Department of Agriculture, to be used for research on management and remediation of desert grasslands. The site was included in the National Science Foundation's Long-Term Ecological Research (LTER) network in 1982, which brought a renewed focus on understanding effects of climate change and other long-term processes on flora, fauna, hydrology, and soils. JER studies on invertebrates have focused largely on the roles of invertebrates in ecological dynamics such as herbivory and plant competition, nutrient recycling, and soil aeration and fertility.

When new collections of invertebrates are made in the Sky Islands, researchers commonly discover new (undescribed) species, extend species' known ranges by hundreds of miles, and add new names to lists for the state or for the nation. For example, the "eastern centipede" *Theatons posticus* was long considered rare in the Southwest (two known records, one from Arizona and one from Utah) until Shelly (1990) surveyed the region and discovered it to be widespread from California, Nevada, New Mexico, Arizona and northwestern Mexico. Almost 400 species of bees are known from the San Bernardino NWR alone, and some 1,000 are estimated to live within the Peloncillo region (Bodner et al. 2006). The southernmost U.S. Sky Islands, often with direct habitat connections or riparian corridors into Mexico, are home to many species of Neotropical butterflies. Bodner et al. (2006) estimated there are at least 5000 species of invertebrates living in the Peloncillo Mountains alone, "and perhaps many times this number."

General Patterns Of Invertebrate Diversity In The Sky Islands Region

Overview

The Sky Islands Region's high plant diversity is clearly responsible for the great diversity of herbivorous insects such as butterflies, moths, true bugs (hemipterans and homopterans), grasshoppers, many beetle groups, etc. Legumes (Fabaceae), oaks (Fagaceae), and pines (Pinaceae) are especially diverse in this region (Felger, et al. 2000; Oldfield and Eastwood 2007). As for other animal and plant groups, this region is a mixing ground for temperate and tropical invertebrate genera and families. Many tropical invertebrate species range no farther north than this region, and many temperate species range no farther south. Furthermore, the region includes many species typical of the westernmost reaches of the continent, as well as species typical of the Midwest and eastern U.S. Additionally, there are local endemics (especially in certain groups, e.g., talus snails, spring snails) for which this area, or a single mountain range, comprises all of their known range. The higher elevations (e.g., oaks woodlands, pine forest, mixed conifer forests) typically host very different invertebrate communities than do the lower elevations (i.e., grasslands and desertscrub), enhancing regional biodiversity. A high diversity of soil types also increases local diversity of many groups, especially soil arthropods and soil burrowers.

Overall Species Richness

Many tens of thousands of invertebrate species inhabit the Sky Islands Region – the majority remaining to be formally documented in the area. The Great Smoky Mountains National Park ATBI (All Taxon Biodiversity Inventory) has documented over 4,200 invertebrate species (mostly arthropods), and estimates that the total number may exceed 70,000 (Sharkey 2001). By virtue of its larger size, greater elevational range and more complex biogeographic location, the Sky Islands Region likely harbors far more species than the Smokies. Some researchers have made conservative predictions of insect diversity in other southwestern parks on the basis of a ratio of five insect species per plant species. Using a preliminary estimate of 3,500 plant species in the Madrean Archipelago, this ratio would predict 17,500 plant-associated insect species alone. Adding other (non-plant-inhabiting) insects, and arthropod groups such as spiders, scorpions, centipedes, soil-dwelling invertebrates, etc., would likely bring the total to well over 50,000 – this does not include hyper-diverse, difficult to survey taxa such as mites, nematodes, parasitoids (e.g., wasps, etc.), and the smaller soil fauna, which could double or triple that number for a total invertebrate fauna of 100,000 to 150,000 species. The University of Arizona Insect Collection (UAIC) contains over 1,000 beetle species from the Chiricahua Mountains alone. This collection represents mostly haphazard collecting rather than systematic attempts to inventory the range; so additional collecting would certainly greatly increase this number.

The family Cerambycidae (longhorn beetles) is one of the largest insect groups on earth. Linsley et al. (1961) reported 132 species of cerambycids from the Chiricahuas, including San Simon Valley localities. The UAIC collections lists another 30-35 species. The authors considered almost half of these to be endemic to the Sky Island Region. Most species reported from the Huachuca Mountains can also be found in the Chiricahuas.

Several beetle families—including longhorn beetles (Cerambycidae) and click beetles (Elateridae)—have species groups that are forest-fire adapted. These species tend to reproduce only in burned forests of various ages, some only in trees that are still warm from the fire and others in a successional series as the burnt trees age. Many of these species are rare in collections because of their ephemeral presence and unlikeliness to be collected soon after fires. Some of these fire-adapted species may be vulnerable to extinction through fire suppression practices of land managers. The return to a semi-natural fire regime is likely to be beneficial to these beetles, as well as to other fire-adapted species.

The UAIC collection reports 60 native bark beetle species (subfamily Scolytinae, family Curculionidae, though many scolytines do not attack trees) from the Chiricahuas, and we have observed significant pine and juniper damage due to these beetles in Chiricahua NM (Figures 4.14 and 4.15). Some, but not all, bark beetle species naturally experience large population fluctuations that are termed "outbreaks." Outbreaks of bark beetles have raised concern throughout the West. Most scolytine outbreaks are self-limiting as the beetles' natural predators (primarily parasitoid wasps but also birds and other insectivores) bring populations back down to levels that humans are comfortable with, or fail to notice. However, bark beetles can cause large local die-offs of certain tree species, which, in turn, can harm other forest-dependant wildlife. Tree die-offs are visually alarming to people and may increase fire risk. While such population fluctuations are a natural part of the dynamics of both beetles and forests, there is considerable evidence that recent fluctuations have become more severe and/or more widespread than they have been in the past. This change has attributed to drought, tree overcrowding, fire suppression, and climate warming (that allows the beetles to better survive winter conditions). Carefully thinning overcrowded trees may reduce beetle kills in future outbreaks, but harvesting infested trees has not been shown to be effective in slowing the spread or intensity of a scolytine beetle outbreak. Returning to natural fire regimes is probably the most effective and economical means to reduce severity of bark beetle outbreaks.

The exotic, introduced, Old World dung beetle *Onthophagus gazella* (Scarabaeidae) was first noticed in New Mexico several years ago, and has been gradually spreading since then. The UAIC collection houses 24 species of native dung beetles from the Chiricahuas. *Onthophagus gazella* has the potential to out-compete some natives, particularly congeners with similar habits and body sizes. This invasive has not yet been reported from Arizona.

Species richness of Hymenoptera, Diptera, and Lepidoptera in the Sky Islands Region can be expected to be on the same order of magnitude as seen in Coleoptera. Bees may take the prize for unusually high diversity in this area, with over 400 species known from the San Bernardino National Wildlife Refuge alone and some 1,000 estimated to live within the Peloncillo region (Bodner et al. 2006). This is far more than in a similar-sized plot of tropical rainforest. Ants and butterflies are also notably diverse in the Sky Islands Region, with an estimated 200-300 species each (McAlpine 1971, Wielgus et al. 1972, 1973, Gaspar and Werner 1976, Miller and Brown 1981, Tilden and Smith 1986, Bailowitz and Brock 1991, Bodner et al. 1996, Opler and Wright 1999, Walsh 2009). A checklist of the ants of Arizona indicates that 187 species have been found in the Chiricahua Mountains (Cover and Johnson 2005). In a four-day study of a small hill in the Chiricahuas Chew and Chew (1980) identified 30 ant species. Ants (and spiders, which are generally poorly known in most of the world) are major ecological components of almost all habitats worldwide, except the polar regions. It has been estimated that ant biomass exceeds vertebrate biomass in most ecosystems, and that ants make up some 10% of the Earth's total living biomass (Gordon 1999). In the Sonoran Desert region, studies have shown that ants have a major influence on soil chemistry, aeration and fertility, seed dispersal and survival, plant recruitment, rodent dynamics, composition of other arthropod communities, and overall arthropod herbivory (Chew 1977; Schaffer et al. 1983).

Biogeographic Patterns

As noted elsewhere in this report, the Sky Islands Region represents an overlap and

Figure 4.14. View from Massai Point, Chiricahua NM, October 2010. The yellowing pine trees are dying from infestations of bark beetles. Several dead trees are also visible.

Figure 4.15. The bark has peeled off this dead pine, revealing the trails of the bark beetles that killed it. Chiricahua NM, October 2010.

blending of several major biogeographic zones, spanning the transition from tropical to temperate and the saddle between the eastern and western slopes of North America's great mountain spine. Thus, the region hosts invertebrate species typical of the Chihuahuan Desert, Sonoran Desert, Rocky Mountains, Sierra Madre Occidental, and beyond. Butterflies exemplify this pattern. The desert hoary-edge skipper (*Achalarus casica*), for example, is predominantly a Sonoran Desert butterfly species, while the range of the Chiricahua white (*Neophasia terlootii*) largely tracks that of the Sierra Madre Occidental. Similarly, the eastern black swallowtail (*Papilio polyxenes asterius*) reaches its western-most U.S. distribution here, just where the western orangetip (*Anthocharis sara*) nears its eastern edge. The Sky Islands Region also lies at the southern end of the ranges for temperate and alpine butterfly species such as the western tiger swallowtail (*Papilio rutulus arizonensis*) and the western marble (*Euchloe hyantis*). Many more Mexican species find their northern limits here. The yellow brimstone (a.k.a. angled sulphur, *Anteos maerula*), for example, ranges from here to Peru. The black-tipped (a.k.a. yellow mimosa sulphur, *Eurema nise*) ranges from here south to Argentina.

In some cases, regional mixing takes the form of annual immigrations. A dozen or so tropical and semitropical butterfly species have (one-way) immigrations into the U.S. portion of the Sky Islands Region every summer, a phenomenon that is still not clearly understood by biologists. But, perhaps the best-known, true migrant is the monarch butterfly (*Danaus plexippus*). Each spring and fall, 100-500 million monarchs make the migration between central and eastern North America and the oyamel fir tree forest (*Abies religiosa*) in Michoacán (Mexico). Monarchs are seen in the Sky Islands Region, but it is not clear what their origin and destiny are. Tagging studies show that monarchs east of the Rockies migrate to Michoacán, whereas those west of the Rockies tend to migrate to the California coast; but the movements of those found south of the Rockies in Arizona, and in the Sky Islands Region, remain a mystery. Recent tagging efforts by the Southwest Monarch Project have tracked southern monarchs California and to Michoacan. There is also some evidence of overwintering sites in the Phoenix area, but the origins of these populations have not been identified.

Certain groups of invertebrates have radiated as species clusters in the Sky Islands Region, some of the most notorious being the talus snails and spring snails. These pulmonate gastropods show exceptionally high endemicity and clearly tell wonderful biogeographic stories, but neither group has yet enjoyed broad phylogenetic analyses so their geographic histories remain elusive. Both groups have highly restricted distributions and thus are candidates for habitat protection and monitoring. A recent mitochondrial DNA analysis of talus snails (Guralnick 2008) showed that specimens from four mountain ranges (Chiricahuas, Pinaleños, Huachucas, Santa Catalinas) comprised distinct monophyletic clades.

The Influence of Habitat on Invertebrate Diversity

The Sky Islands Region includes a wide range of habitat types. The diversity of ants and tiger beetles provides good examples of how habitat diversity positively affects species diversity. Soil microhabitat strongly influences the distribution of desert seed-harvester ants in this region, and these species segregate out along variables of soil texture, moisture and topographic relief (Gaspar and Werner 1976; Johnson 1992, 2000). Several of the region's tiger beetles are specialists on alkaline salt flat habitats that periodically fill with water (known locally as *playas*), including *Cicindela willistoni*, *C. haemoragica*, and *C. nevadica*. Grassland tiger beetle species tend to be restricted to grasslands, and these include *Cicindela pulchra*, *C. horni*, *C. debilis*, and *C. obsoleta*. The last of these is so particular that it is considered a possible habitat quality indicator for healthy native bunchgrass habitat. Another tiger beetle species, *Amblycheila baroni* apparently lives only at the bases of large granite boulders. Although the direct effects of fires on tiger beetles is not well understood, fire suppression has been implicated in the decline of rare species (Knisley and Hill 1996). Numerous studies report tiger beetles becoming more abundant in an area following fires that open up ground vegetation (Bess et al. 2002). For saltpan and water-edge species, any activity that changes hydrologic patterns is highly likely to affect the species.

Riparian habitats are critical to many, if not most animal species in the Sky Islands region, and countless examples could be given (Table C.5). For example, *Limenitis archippus obsoleta*, the Arizona, or obsolete viceroy butterfly, is the only subspecies of *L. archippus* known from Arizona (Brock and Prchal 2001). So far as is known, the larvae of this butterfly feed solely on Gooding (black) willow, *Salix gooddingii*, and they are thus found along waterways where this plant flourishes (Arizona Game and Fish 2001). Elimination of willow stands by cattle tramping, falling water tables, or replacement by tamarix or other nonnative plants is thus a direct threat to the survival of this butterfly.

Many other invertebrates have narrow niche preferences. Often these narrow preferences are unsurprising, such as the Huachuca giant skipper's (*Agathymus evansi*) need to be near its host plant, Parry's Huachuca agave (*A. parryi* var. *huachucensis*). Others are less expected. For example, occurrence and density of leaf miners (insect larvae that live in leaves of most plant species) can be strongly correlated with solar radiation, leaf size, and degree of host tree stress, and in most cases these insects are strongly clumped in any given plant host (Bultman and Faeth 1986, 1987; Faeth 1990). Anthropogenic changes can cause shifts in invertebrate distributions in subtle ways. The "ecologically equivalent" Sky Island termite species *Heterotermes aureus* and *Reticulitermes tibialis* are an example. The distribution and foraging activity of both species is controlled by moisture and temperature gradients (Haverty et al. 1974). The former occurs in desertscrub and desert grasslands below 1220 m, whereas the latter generally occurs in grassland, oak-pinon pine-juniper associations, and coniferous forests above 1140 m. However, Reticulitermes may invade areas occupied by *Heterotermes* under suitable moisture and temperature conditions provided by riparian habitats and in areas of human habitation (Haverty and Nutting 1976).

Spring snails have highly restricted, endemic distributions tightly correlated with their very limited habitats. (Note that the vernacular name, "spring snails" is usually used in reference to snails of the family Hydrobiidae, whereas the name "springsnails" is more commonly used for members of the specific hydrobiid genus *Pyrgulopsis*.) Approximately 170 described species of Hydrobiidae live in the U.S. With more than 120 described species, and probably many undescribed species, *Pyrgulopsis* is the largest North American genus in the family. At least 35 described species of *Pyrgulopsis* (and probably another 25 undescribed species) live in the Southwest. The Huachuca springsnail (*Pyrgulopsis thompsoni*) is an ESA candidate species (Arizona Game & Fish 2003). All hydrobiids are gill-breathing, aquatic or semiaquatic snails restricted to permanent waters, particularly those that are spring-fed. These small (usually less than 5 mm in length) snails live in permanent pools or creeks, each species usually associated with a particular spring or spring system. Although hydrobiids are pulmonates (lung breathing), their life history is completely tied to the perennial waters in which they live, and they only disperse if carried by an animal or by floodwaters – they entirely lack the free-swimming dispersal phase typical of most aquatic molluscs. As a result, most species are restricted to a single aquatic system, often a highly restricted spring and pool/creek system. A complete taxonomic analysis and a phylogenetic assessment of America's spring snails are yet to be accomplished. Preliminary molecular phylogenetic studies suggests that species of *Pyrgulopsis* reported as widespread may actually be "species flocks" consisting of cryptic species, each restricted to a single groundwater system (Liu et al. 2003; Hurt 2004; Hershler et al. 2007). Spring snail species are threatened with extinction by anything that threatens the perennial nature of their restricted habitat (e.g., groundwater overdraft, spring or surface water degradation, mining, overgrazing by cattle, altered fire regimes). The Center for Biological Diversity and the Freshwater Mollusk Conservation Society filed a scientific petition in 2009 to protect 42 spring snail species that live in the Great Basin region of Nevada, Utah and California. In 1998, the U.S. Departments of Interior and

Agriculture, the Smithsonian Institution, and The Nature Conservancy signed an M.O.U. pledging to learn more about spring snails, and protect them, on federal and Nature Conservancy land. Arizona Game and Fish Department is on record stating that wide-ranging surveys of spring snails are needed to understand and protect them in the state.

Like spring snails, talus snails (or "ta-lussnails") (family Helminthoglyptidae, genus *Sonorella*) are highly endemic and restricted in their habitat to talus slopes, rocky outcrops, and canyon bottom rock rubble, usually on moister northward-facing slopes, and often on limestone outcrops. Most species are known from only one or a few localities, usually within a single mountain range. *Sonorella* are distributed from Arizona, southern New Mexico, western Texas, and southward into northwestern Chihuahua and northeastern Sonora. They are found from arid, lower elevation foothills to wooded canyons at elevations of 8,000 to 10,000 feet. The taxonomic status of these snails is desperately in need of revision. The shells of *Sonorella* (which average over a half inch in height) are weakly differentiated, and species are usually separated by a combination of geographic location and male genitalia. Walter Miller's revision of the genus (Miller 1967; Bequart and Miller 1973) recognized 68 valid species of *Sonorella* (with 19 subspecies), 57 of them in Arizona (three of these in common with Sonora). Disturbance of their highly restricted habitat could lead to the complete extinction of a talus snail species.

Just as habitat influences invertebrate species presence/absence, many invertebrates modify the habitat in which they live, and in doing so they work to sustain environmental health. Pollinators, termites, and ants are obvious examples, and without them most terrestrial communities would be drastically and fundamentally altered. Most of these relationships are obvious, but not all. For example, the seed predation and plant clearing behaviors of Sky Islands Region harvester ants (*Pogonomyrmex* spp.) have direct effects on plant species distribution and abundance and concentrations of NO_3, P and K in the soil (e.g., Carlson and Whitford 1991).

Experimental studies on the subterranean termite *Heterotermes aureus* suggest that this species removes dead wood at a high rate in desert grasslands — 79 kg/ha/yr, which represents nearly 4 percent of the standing crop biomass and 17.5 percent of the annual production of superficial dead wood (Haverty and Nutting 1975).

Abundance and diversity of invertebrates at six springs in Chiricahua NM (Superintendent Spring, Kraft Spring, Silver Spur Spring, Garfield Spring, Bonita Park Spring, Shake Spring), three springs in Fort Bowie NHS (Lower Mine Spring, Upper Mine Spring, Apache Spring), and five springs in Coronado NMem (Fern Grotto, Joe's Canyon Trail, Yaqui Canyon Complex, Shallow Spring, Unknown Middle Owl) were recently assessed (NPS Sonoran Desert Network), but not in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

Endemism and Evolutionary Radiations

Of all the invertebrates in the Sky Islands Archipelago, molluscs might have the highest known rates of endemism, with each mountain range in the region typically having at least one endemic species (or subspecies) and most having more. Most of these reflect evolutionary radiations that are particular to the Sky Islands Region. Talus snails of the genus *Sonorella* are well-known for their evolutionary radiation in the Sky Islands (over 50 species of *Sonorella* are known from Arizona), and all are narrow-range endemics (McCord 1995; Guralnick 2008; Sea and Land Resources 2009). Only one modern, but unpublished analysis of talus snails has been undertaken (Guralnick 2008), which used mitochondrial genes (12S, COI) to analyze *Sonorella* populations from the Pinaleño, Chiricahua, and Santa Rita Mountains, concluding that the named species were valid and that species clusters on single mountain ranges radiated/evolved in place (rather than being the result of multiple dispersal events during the Pleistocene and Holocene).

Systematic and genetic studies over the past 50 years have shown that numerous species, and species groups, have patterns of endemism in the Sky Islands that appear to have resulted from isolation of woodland habitats at the end of the Pleistocene, subsequent to the last major glacial event, as these habitats became isolated from one another by emerging desertscrub and grassland habitat in the lower valleys that separate these mountain ranges. For example, the oak woodland jumping spider, *Habronattus pugillus*, has genetically distinct, isolated populations on at least 18 Sky Island ranges. Each population is adorned with its own distinct set of courtship ornaments, and males on each range perform their population's own unique dance for females (Maddison and McMahon 2000). *Scaphinotus peters*i, a large, endemic, flightless ground beetle confined to coniferous forests in Southern Arizona at elevations >1800m, also exhibits phenotypic differences among Sky Island populations. Six subspecies of *S. petersi* have been described living on mountains in southern Arizona.

Edge-of-Range Representatives

As noted elsewhere, a great many species (and genera, and families), both temperate and tropical, reach their range end points in the Sky Islands Region. Velvet ants (Mutillidae) provide a good example. The Sky Islands Region includes several temperate species (e.g., *Dasymutilla dugesii*) that reach their farthest south here, and even more that range from the tropics to find their northern limits here. *Dasymutilla magnifica* and several others from the western deserts reach their farthest east in this mountain archipelago, whereas *Dasymutilla nigripes* and others are eastern species that just barely extend across this low point of the Continental Divide. Scorpions show similar patterns, with Sonoran Desert species at the eastern edges of their ranges occurring in many low elevation Sky Island rock outcroppings. Chihuahuan Desert species, typical of areas to the east, tend to occupy the valleys and bajadas of the Sky Islands Region.

Neotropical Representatives

Dragonflies provide a good example of Neotropical representation in the Sky Islands Region. Although several of the species known from this area are common throughout North America, and a handful of others are typical Western species, most are tropical in origin. The Sky Islands Region forms most or all of the U.S. range for at least a dozen tropical dragonfly species, as well as several damselflies. These include the malachite darner (*Coryphaeschna luteipennis*), the spotwinged meadowhawk (*Sympetrum signiferum*), and the plateau dragonlet (*Erythrodyplax connata*). The desert shadow damsel (*Palaemnema domina*) is the only representative of the tropical family Platystictidae found within the United States; outside the Sky Islands Archipelago, the closest reported localities for *P. domina* are Oaxaca and Chiapas, in southern Mexico (Hoekstra and Garrison 1999). While many tropical species in other invertebrate groups range as far north as the Sky Islands Region, it is the tropical butterflies that attract thousands of visitors each year to the region, to see species found virtually nowhere else in the U.S. Because of this attention, butterflies have become one the best-known invertebrate groups in the area.

Vulnerable Species And Habitats

Table C.5 provides a detailed list of the invertebrates of conservation concern known or expected to occur in Chiricahua NM, Fort Bowie NHS and Coronado NMem. Few invertebrates in the Southwest are officially listed as federally threatened or endangered, mainly because we don't have enough information about each to know which are vulnerable. No invertebrates in the Chiricahua or Huachuca Mountains are ESA listed endangered or threatened. The 2009 Arizona Game and Fish Department's review of invertebrates of "concern," as listed in their Heritage Data Management System, included just 175 species in the state, none of which were Crustacea even though many crustaceans are restricted to ephemeral pools and thus are certainly rare and/or endangered (Arizona Game & Fish 2009). Several of the narrowly-endemic talus snails and spring snails of the Chiricahua and Huachuca Mountains are considered species of concern by the forest service, and one (Huachuca springsnail), is an ESA candidate species (see Table C.5). Some entomologists in the region consider the Arizona unicorn mantis (*Pseudovates arizonae*) a species of concern due to its rarity and localized distribution (Lightfoot 2004), but this species has no official status. The IUCN Red List of Pollinator Insects enumerates a number of imperiled species from the Sky Islands. For example, the spectacular Huachuca giant skipper (*Agathymus evansi*), with its 2-inch wingspan, is restricted to just two ranges in the U.S. (Huachucas and Chiricahuas), in mixed pine-oak-juniper woodlands containing the larval host plant, *Agave parryi* var. *huachucensis*. Much of this species' habitat has been lost due to grazing, which, along with fires, threatens the few remaining populations of this butterfly in the U.S.

The various U.S. Forest Service Ranger Districts of the Coronado National Forest (in the Sky Islands Region) have designated "management areas." For most of these areas, selected species have been assigned to "guide management decisions," whereas others have been identified as species that "require special management consideration" (see Table C.5 for a list of these for the Chiricahua and Huachuca Ecosystem Management Areas).

General landscape protections established to protect federally listed species such as jaguars, spotted owls, ferruginous pygmy owls, thick-billed parrots, native fishes, and others help preserve habitats needed by many invertebrates as well. However, species with very small ranges or very specific habitat requirements may need additional targeted management. Endemic talus snails and spring snails, for example, may live on just one hillside or in one isolated spring or ciénega. Negative impacts to such small areas can usually be easily avoided if the need to do so is recognized.

Limestone outcrops are significant contributors to biodiversity in the Sky Islands Region. In fact, so important are these geological formations that the Sonoran Desert Conservation Plan specifically recognizes limestone outcrops as worthy of special conservation status. Limestone outcrops are found around the periphery of the higher mountains—e.g., Catalina, Rincon, Santa Rita, Pinaleño, Huachuca, and Chiricahua Mountains. Some of the smaller ranges, such as the Whetstone, Waterman, Empire, and Mustang Mountains are composed largely of limestone. The Watermans comprise one of the most important Paleolithic limestone uplifts in the Sonoran Desert, and due to the nature of their unique limestone soils they are home to the endangered Nichols Turk's head cactus as well as relict stands of *Bursera* elephant trees. These endangered plants, and many other plants and animals are threatened in the Watermans and elsewhere by buffelgrass invasion, perhaps the single most important ecological threat in southern Arizona at elevations below 4,000 feet. As one moves eastward into southern New Mexico, limestone becomes the dominant rock type in an area of ancient inland seas known as the Permian Basin. Limestone outcrops are also places where aquifers become recharged as water moves relatively quickly through the fractured and porous rock. In southeastern Arizona, most limestone was deposited 200 to 400 million years ago, when a shallow marine environment covered much of central and western North America. In southern Arizona, limestone outcrops are being destroyed by suburban development (e.g., Vail and Empire Mountains), and by mining for marble and for aggregate for cement production, as well as by mining for copper, silver and tungsten. Fonseca (2007) recommended limestone habitats be assessed for biological conservation as part of National Forest and Bureau of Land Management planning processes, and that county governments consider protecting these outcrops in watersheds.

Worldwide, limestone is known to harbor species with restricted distributions, such as cave invertebrates, bats, molluscs, amphibians, and rare plants, and as a result these surface formations are often given special protection. A classic example of a rare species associated with limestone outcrops in the Sky Islands Archipelago is the elusive barking frog (*Craugastor augusti*), a species at the northern edge of its distribution in the Huachuca Mountains that relies primarily on limestone outcrops for shelter and reproductive sites in rain-soaked crevices. Another well-known example is talus snails (*Sonorella*). Limestone talus slopes are critical habitats for most of these molluscs, which obtain calcium carbonate for shell construction from these soils and also use it to buffer metabolic acids generated by respiration during long periods sealed in their shells waiting for rain. Weathered limestone has an abundance of nooks and crannies that provide countless dens for rodents, snakes, Gila monsters, tortoises, lizards, foxes, skunks, coatimundis, coyotes, and other creatures.

Many uncommon species in the Sky Islands are tied to limestone surface deposits by virtue of the cave environments frequently associated with them—a result of limestone's high rate of erosion. These include the Arkenstone cave pseudoscorpion (*Albiorix anophthalmus*), the sphinx cave isopod (*Brakenridgia sphinxensis*) and other isopods (*Brackenridgia* spp., *Amerigoniscus* spp.), various cave crickets (*Ceuthophilus* spp.), a flightless tiger beetle (*Amblycheila baroni*), various rhadine cave beetles (*Rhadine* spp.), several spider wasps (e.g., *Ageniella evansi*, *Auplopus mexicana*), an Arkenstone cave blind agelenid spider (*Neocryphoeca* n. sp.), cave harvestman (two undescribed species of *Sitalcina*), an Arkenstone cave springtail (*Seira* n. sp.), an Arkenstone cave nicoletiid (*Nicoletia* n. sp.), the Spinks cave pseudoscorpion (*Chitrellina chiricahuae*), and the Arizona stygobromus cave amphipod (*Stygobromus arizonensis*) (Muchmore and Pape 1999; Fonseca 2007). The last two species occur in the Chiricahua and Huachuca Mountains, respectively.

High invertebrate diversity is often found in unexpected or surprising places. For example, rare soil types may harbor unique native bee species, stabilized sand dunes may be home to tiger beetles found nowhere else in the region, and soils with impervious layers create perched water tables and ephemeral pools. The diversity of soils present in the region includes microhabitats important to invertebrates such as ground-nesting bees, tiger beetles, centipedes, and others, but overlooked by most biologists. In fact, soil invertebrates have been almost entirely overlooked by biologists working in the Sky Islands Region. (A newly initiated research program of Dr. Wendy Moore, University of Arizona, is examining the systematics and biogeography of Sky Island soil arthropods.) Studies elsewhere have shown that patches of unusual soil contribute disproportionately to invertebrate diversity, but the identity and location of such soil heterogeneity are still subjects of speculation in the Sky Islands Archipelago. Additionally, many flying insect species engage in a behavior called "hilltopping," in which males and females congregate at the tops of low hills to find mates. These topographical "singles bars" may seem to humans as unremarkable bumps on the landscape, but development of hilltops (e.g., homesites) can interrupt the lifecycles of many dragonflies, butterflies, beetles, and other invertebrates.

Both summer and winter rains can create seasonal (ephemeral) pools that quickly teem with fairy shrimps, tadpole shrimp, cladocerans, and ostracods (King et al. 1996). The valleys and mountains of Sky Islands Region have a wide variety of ephemeral waters, including alkaline playas, stock ponds, seasonal washes, rock holes, and other puddle-forming sites. These pools fill with water for anywhere from a few days to several months, once a year or several times per year, and provide habitats for an untold number of invertebrates (Hall et al. 2004). Within weeks of a filling rain, pools such as these, in California, have been documented accumulating over 100 invertebrate species, many of which are found only in these habitats (King et al. 1996). When an ephemeral pool dries, mobile species, including most of the aquatic insects, leave to find other water or to complete a dry-land phase of their lifecycle. Others, such as the freshwater crustaceans, stay put and enter a state of suspended animation until their own pool refills – sometimes many years in the future.

Riparian areas contribute disproportionately to the total invertebrate diversity of the Sky Islands, even though they comprise a small percentage of its overall acreage. Native bee diversity tends to be highest in riparian areas, as does that of butterflies, beetles, ants, spiders, dragonflies, mayflies, stoneflies, caddisflies, and more. Many of these invertebrates depend upon the plant species that grow only in more mesic parts of the Sky Islands Region, while others depend on riparian areas' increased abundance of potential prey species, on soft riparian soils, or on the availability of water itself. Plant assemblages such as willow thickets are probably the primary habitat, in the Sky Islands, that sustains the increasingly rare Arizona viceroy butterfly. Springs offer similar resources, providing isolated habitats that tend to support a unique set of species, including some endemics.

4.1.2.6 Amphibians and Reptiles

The Madrean Archipelago supports a diverse amphibian and reptile fauna (Table C.6). The herpetofaunas of each sky island mountain range in southeastern Arizona, southwestern New Mexico, and in northeastern Sonora are subsets of the herpetofauna of the broad region from the northern Sierra Madre Occidental (SMO) to the Mogollon Rim in central Arizona, which forms the southwestern edge of the Colorado Plateaus. Throughout the area, the lowland vegetation (desertscrub, desert grassland, and foothills thornscrub) is an integral part of the Sky Island Region; the lowland amphibians and reptiles are included in the regional herpetofauna.

Southeastern Arizona is a zone of confluence of several major biotic provinces or ecoregions. Species and vegetation types reach the area from the temperate Rocky Mountains and Colorado Plateaus to the north. Many Mexican herps reach their northern distribution limits in southeastern Arizona and adjacent New Mexico, including both tropical (*Gyalopion quadrangulare* [thornscrub hook-nosed snake], *Oxybelis aeneus* [brown vine snake], and *Senticolis triaspis* [green ratsnake]) as well as montane Madrean species (*Hyla wrightorum* [mountain treefrog], *Sceloporus jarrovi* [Yarrow's spiny lizard], *S. slevini* [Slevin's bunchgrass-lizard], *S. virgatus* [striped plateau lizard], *Lampropeltis pyromelana* [Sonoran mountain kingsnake], *Crotalus lepidus* [rock rattlesnake], *C. pricei* [twin-spotted rattlesnake], and *C. willardi* [ridge-nosed rattlesnake]). In the Sierra Madre, minimum winter temperatures are warmer to the south and species diversity increases dramatically. Another interesting biogeographical connection is between the Colorado Plateaus along the Mogollon Rim from Central Arizona-SMO to western New Mexico and south to the Sierra Madre in western Chihuahua and adjacent Sonora, essentially skipping most of the Madrean Archipelago; e.g., *Hyla wrightorum*, *Coluber taeniatus* (striped whipsnake), *Thamnophis rufipunctatus* (narrow-headed gartersnake), and *T. elegans* (wandering gartersnake). These distributions may reflect past connections to the east between New Mexico and the east side of the Sierra Madre in Sonora.

Other biogeographical elements in the Madrean Archipelago are with Great Plains and desert grassland from the east. There is also a strong Sonoran-Chihuahuan Desert connection, with many widely distributed desertscrub herps. A very important biogeographical connection is with the tropics to the south. The northern limit of tropical deciduous forest as a community is at latitude 28°30'N in the Sierra San Javier, the southernmost sky island. Foothills thornscrub extends farther north, almost to 31° north near Santa Ana, Sonora. (Arizona Upland Sonoran Desert might actually qualify as thornscrub.) However, numerous individual species of tropical animals and plants follow the northern tributaries of the Río Yaqui, especially the headwaters of the Río Bavispe, into desert grassland and Chihuahuan desertscrub in southeastern Arizona and adjacent New Mexico. The herpetofauna of the Madrean Archipelago in Sonora includes more tropical species in the foothills thornscrub skirts of southern sky islands (*Terrapene nelsoni* [spotted box turtle], *Heloderma horridum* [Mexican beaded lizard], *Ctenosaura macrolopha* [mainland spinytail iguana], *Micrurus distans* [west Mexican coral snake], and *Crotalus basiliscus* [Mexican west coast rattlesnake]) as well as montane Madrean species (*Ambystoma rosaceum* [Tarahumara salamander] and *Phrynosoma orbiculare* [Madrean horned lizard]).

Stitt et al. (2005) studied the biogeography of the amphibians and reptiles of Arizona. Although the entire state herpetofauna is only in the 25th percentile for species richness in the United States, it is 2nd in reptiles (Stein 2002). Although anuran diversity is moderately high in Arizona, the abundance of salamanders in other parts of the country eclipses the overall amphibian diversity (Duellmann and Sweet 1999). There are more rattlesnakes in Arizona than anywhere else in the United States. Southeastern Arizona is a hotspot (Lowe 1964, 1992), with about 80% of the herpetofauna of Arizona (120 species — 25 amphibians, 95 reptiles; Stitt et al. 2005) occurs in the Sky Island Region in Arizona (96 species, 20 amphibians, 76 reptiles). Most of the species that occur outside the Sky Island Region are on the Colorado Plateaus in northern Arizona, or the Lower Colorado River Valley subdivision of the Sonoran Desert in southwestern Arizona. The herpetofaunas of Fort Bowie NHS (68 taxa [includes potential species]), Coronado NMem (70 taxa), and Chiricahua NM(44 taxa; Table C.6) represent 70.1%, 72.9%, and 47.9% of the total Arizona-New Mexico herpetofauna. Considering that the herpetofauna of the adjacent Sulphur Springs Valley contains at least 61 species (12 amphibians and 49 reptiles; Rosen et al. 1966), the numbers of species recorded in Chiricahua NM will likely increase.

There are increases in the number of species southward towards the tropics in many taxonomic groups and in species diversity in equivalent biotic communities. But patterns in the amphibians and reptiles in the Madrean Archipelago are complex. There are about 111 total species of amphibians (25 taxa) and reptiles (89 taxa) in the Sky Islands Region in Arizona and Sonora combined. The greatest diversity is in lizards (37 taxa), colubrid snakes (32 taxa), and anurans (23 taxa).

Just south of the Madrean Archipelago in Sonora, Mexican Federal Highway 16 (MEX 16, finished in 1992) crosses the Sierra Madre Occidental, connecting Hermosillo, Sonora and Ciudad Chihuahua, Chihuahua. The environmental gradient along MEX 16 (200 to 2,200 m elevational range) at 28°25'N provides the baseline for comparing sky island faunas and floras with the "mainland" Sierra Madre Occidental (Enderson et al. 2009; Martin et al. 1998; Reina-G. and Van Devender 2005). The vegetation changes from foothills thornscrub and tropical deciduous forest in the tropical lowlands in east-central Sonora to oak woodland and pine-oak forest in the uplands (Van Devender et al. 2005). An additional 30 taxa (9 amphibians, 21 reptiles) occur along MEX 16 in the Yécora area, increasing the combined herpetofauna of the Madrean Archipelago and the Sierra Madre Occidental in eastern Sonora to 148 taxa (35 amphibians, 113 reptiles; Enderson et al. 2009, Lowe 1964).

Some very tropical species reach their northern limits in tropical deciduous forest near Tepoca on MEX 16, including *Anolis nebuloides, Imantodes gemmistratus*, *Lampropeltis triangulum* ssp. *sinaloae*, *Procinura aemula*, *Pseudoficimia frontalis*, and *Trimorphodon tau*. *Sceloporus lemosespinali*, *S. poinsetti*, and *Pituophis deppei* are species that occur in Sonora in the montane highlands in the Sierra Madre. Basswood (*Tilia americana*) and hophornbeam (*Ostrya virginiana*) are temperate deciduous trees that occur from the eastern United States through the Sierra Madre Oriental to central Mexico and back northeast through the Sierra Madre Occidental to Chihuahua (Spellenberg et al. 1996) and eastern Sonora (Martin et al. 1998). The salamander *Pseudoeurycea bellii* and the snake *Storeria storerioides* are similar eastern temperate elements in the Madrean herpetofauna.

The numbers of species in the Sky Island Region in Arizona-New Mexico (97 species, 20 amphibians, 77 reptiles) are slightly lower than in Sonora (99 species, 21 amphibians, and 78 reptiles) in Sonora. The similarity in the numbers of amphibian and reptile species in the Sky Island region in Arizona-New Mexico and Sonora does not mean that the regional herpetofauna is basically uniform. The percentage of the distributions of the Madrean Archipelago herps that reach (or extend from) the Sierra Madre Occidental (ca. 55%) reflects species turnovers in a diverse regional fauna. In contrast to the temperate areas in the eastern and western United States, salamander diversity is very low diversity in southeastern Arizona and northeastern Sonora. The anuran and lizard faunas are very diverse with major species turnovers between Arizona and Sonora. Surprisingly the herpetofauna of tropical foothills thornscrub is not very diverse with fewer taxa than desertscrub, desert grassland, and tropical deciduous forest. The real increase in diversity in the Sierra Madre Occidental herpetofauna is in colubrid snakes, both in the Sierra Madrean and especially in the tropical lowlands.

There are some species that are endemic (or nearly so) to the Madrean Archipelago. *Aspidoscelis* (*Cnemidophorus*) *sonorae* occurs widely in the Sky Island Region in Arizona and Sonora. *Ambystoma tigrinum* ssp. *stebbinsii*, *Lithobates subaquavocalis,* and *Aspidoscelis arizonae* (formerly considered a subspecies of *Aspidoscelis inornata*) occur only in southeastern Arizona. *Aspidoscelis opatae* is found in the Río Bavispe drainage from Huásabas north to Bavispe. *Phrynosoma ditmarsi* is known from a few areas in the sky islands from southeast of Cananea south to Mexico 16 near Tepoca. *Tropidodipsas repleta* is a recently-described snake known only from tropical deciduous forest near Tepoca on MEX 16 (Smith et al. 2005).

There are very few non-native amphibians and reptiles in the Madrean Archipelago. *Lithobates catesbeiana* (bullfrog) has been widely introduced for food in Arizona and Sonora. It is a serious invasive species in ponds and other quiet water habitats, including the San Pedro River. *Ambystoma tigrinum* ssp. *mavortium* has been introduced in stock tanks for fish bait. It is a major threat to the genetic integrity of the native *A. t.* ssp. *stebbinsii*. The Mediterranean gecko (*Hemidactylus turcicus*) is common in urban settings in Tucson and Phoenix. A collection from Douglas, suggests that it will soon be found in towns in Sonora.

4.1.2.7 Mammals

The Madrean Archipelago region is rich in mammal species. The numerous biological communities, diverse topography, and various geological substrates in the mountains provide cover and microenvironments for numerous mammals including rodents, bats, raccoons, ringtails, coati, fox, and cats. Riparian habitats and springs also provide cover, burrows, refuge, food, and drinking water for a variety of mammals. Woodland and forest ecosystems provide habitat and resources for bears, deer, cats, bats, and various other mammals. Acorns from a variety of oaks provide a high caloric energy food for rodents, deer, bears, skunks, fox, and other mammals.

The Desert and Plains Grasslands provide seeds, grasses, and forbs for food and cover for numerous species of rodents. Plains Grassland (Sonoita and San Rafael Valley) hosts newly introduced black-tailed prairie dogs (*Cynomys ludovicianus*), and pronghorn (*Antilocapra americana*) continue to thrive there. Historically, black-tailed prairie dogs were abundant in southeastern Arizona in both Plains and Desert Grasslands but were extirpated from the state. Black-tailed prairie dogs were found on the west side of the Huachuca Mountains, five miles east of the Huachuca Mountains (towards Bisbee), near the town of Dos Cabezas, and in the Sulphur Springs Valley. Plant diversity, grasses, and forbs are enhanced by the presence of prairie dogs and prairie dog burrows also provide refuge for black-footed ferrets (*Mustela nigripes*). Prairie dogs are prey food for the ferrets and there is a direct correlation between the reduction of prairie dogs and reduction of ferret populations. Historically ferrets may have occurred in Graham and Cochise Counties (Hoffmeister 1986) and along with the black-tailed prairie dog colonies in these areas. The introduction of black-footed ferrets has been successful in the Aubrey Valley of Arizona and the recent introductions of black-tailed prairie dogs to the Sonoita area have been promising. Both black-tailed prairie dogs and black-footed ferrets could be possible future reintroduction projects for the grassland habitats of Fort Bowie NHS and Coronado NMem.

Prairie dogs are an important force in maintaining grassland communities by preferentially removing shrubs, which tend to invade the deep soils inhabited by prairie dogs. If the soils are suitable, reintroducing prairie dogs may be a useful management tool in restoring the grassland parcels in the parks. This may be a concern to adjacent ranchers who fear that cattle and horses may break their legs. But on the positive side, prairie dogs enhance the quality of forage for livestock. Both cattle and native grazers preferentially forage in prairie dog habitat.

Chiricahua NM is surrounded by protected and private undeveloped land creating a large area of contiguous, unfragmented habitat for wildlife. Chiricahua NM has the highest mammal species richness (70 species) than for any other park unit in the Sonoran Desert Network (Powell et al. 2008). Coronado NMem has high species diversity for terrestrial mammals considering its small size. Both Coronado NMem and Chiricahua NM are bordered by USDA Forest Service land. Fifty-seven species of mammals have been documented at Fort Bowie NHS. The Bureau of Land Management manages the majority of the land surrounding Fort Bowie NHS.

Woodland and forest ecosystems provide habitat and resources for bears, deer, cats, bats, and various other mammals. Acorns, nuts, and berries from a variety of oaks and pines provide a high caloric energy food for rodents, deer, bears, skunks, fox, and other mammals in this habitat. Mammals in this ecosystem can find year-round food.

The Mexican gray wolf (*Canis lupus baileyi*) historically was found from east-central Arizona south to northern Mexico. Wolves were usually found 4,000 feet or higher in the mountain ranges and only rarely in the lower deserts. There have been no confirmed reports of naturally occurring Mexican wolves in southwestern United States since 1970. In 1998, captive-bred wolves were introduced to the Blue Range of east-central Arizona and along the border of west-central New Mexico (Gila Wilderness). Even though Mexican wolves historically occurred in most of the "Sky Islands' of southeastern Arizona, it is doubtful that new reintroductions will be carried out in the future in additional areas in Arizona. The Mexican Wolf Recovery Program has been controversial and the wild wolf population in the recovery areas has not increased as planned. It is also doubtful that there will be any Mexican wolf movements from northern Sonora into Arizona since there are probably no wild Mexican wolves remaining in northern Mexico.

Grizzly bears (*Ursus arctos*) historically lived in Arizona along major streams in the lowlands and mountains. Several grizzlies were killed in the Chiricahua and Huachuca Mountains in the 19th century. While J.C. Hancock was stationed in the Chiricahua Mountains in the 1880's, he found bears "thick". One effect of the encampments of armed men was an immediate reduction in the local grizzly populations (Brown 1985). Grizzlies were extirpated in Arizona by the early 20th century. It is very doubtful that grizzlies will be returned to Arizona since this species is controversial to land owners and the livestock industry.

Table C.7 lists the mammals documented in the three parks.

4.1.2.8 Birds

The Madrean Archipelago is an exciting region for birds; nearly 500 species have been recorded in southeastern Arizona. This is more species of birds than occur in any other land-bounded area of comparable size in the United States (Taylor 1995) and the largest number of vertebrate species west of the Great Plains (Pearson and Cassola 1992; Povilitis 1995). Many species of birds use the Sky Islands during migration. River systems in the Madrean Archipelago serve as highways for tropical birds coming from the south. Many birders search for specialty birds from this region, with the most sought-after birds being those from the Sierra Madre Occidental of northern Mexico (Kunzmann et al. 1991). Numerous other "Mexican species" are permanent residents, reaching their northernmost limits in the extreme southwestern United States (Kunzmann et al. 1991). A total of fifteen species of hummingbirds have been recorded for the three parks and many of these species also nest in these areas.

The Desert Grasslands support a variety of sparrows with their abundance of seeds and nesting cover. Numerous rodents provide food for various raptors like prairie falcon (*Falco mexicanus*), ferruginous hawk (*Buteo regalis*), and American kestrel (*Falco sparverius*). Scaled quail (*Callipepla squamata*) and eastern meadowlark (*Sturnella magna lilianae*), like many of the bird species found in the grasslands, build their nests on the ground. The Sulphur Springs Valley is home to wintering raptors (up to 14 species), geese, cranes, sparrows, buntings, blackbirds, and other northern bird species.

Table C.8 lists the birds known to occur in the three parks.

4.1.2.9 Biological Corridors

Rivers

The rivers of the Madrean Archipelago are a system of natural biological dispersal corridors. All of the sky island ranges in Arizona are part of the greater Gila River drainage. The Gila flows from the southern edge of the Rocky Mountains in New Mexico and the San Simon Valley northwest along the north side of the Pinaleño Mountains and the turns southwest between the Santa Teresa and Pinal Mountains to join the San Pedro River at Winkelman.

The headwaters of the north-flowing San Pedro River are mostly in the Sierra de los Ajos and Sierra Elenita near Cananea, Sonora. However, one tributary flows southward from the southeastern edge of the Huachuca Mountains in Arizona through Rancho Los Fresnos before joining the San Pedro. The San Pedro River drains the Huachuca, Mule, Whetstone, Dragoon, Rincon, Galiuro, and Santa Catalina Mountains before joining the Gila River.

The headwaters of the Santa Cruz River are in the San Rafael Valley between the Patagonia and Huachuca Mountains. It flows southward into Sonora past the town of Santa Cruz, and then loops back northward through Nogales back in to Arizona, past Tucson into the Gila River drainage north of Marana. This stretch of the Santa Cruz and its major tributaries (Sonoita Creek, Ciénega Creek, Pantano Wash, and Brawley Wash) drain portions of the Patagonia, Atascosa, Santa Rita, Sierrita, Baboquivari, Rincon, Santa Catalina, and Tortolita Mountains.

In Sonora the Madrean Archipelago is drained by three major rivers. In northeastern Sonora, the Río Bavispe and its tributaries drain most of northeastern Sonora, and adjacent Chihuahua and southeastern Arizona. Arroyo Agua Prieta, Arroyo San Bernardino, Arroyo Guadalupe drain portions of the Peloncillo, Chiricahua, Pedregosa, and Mule Mountains in Arizona and many smaller drainages beginning north of the border. Eventually the Río Bavispe joins the Río Áros well south of the Madrean Archipelago. The western portions of the Archipelago in Sonora are in the Rio Sonora and Río Magdalena (=Asunción and Altar) drainages.

There are interior drainage basins near Lordsburg and in the Animas Valley, New Mexico, and the Willcox Playa in the Sulphur Springs Valley, Arizona.

Mountain Ranges

The north-south-trending mountain ranges and lowland habitats are migratory and dispersal corridors of continental importance. For example, there is a south-to-north wave of flowering in the low elevation thornscrub and desert habitats during the spring. The abundant nectar and pollen in these flowers fuel the northward migration of hummingbirds and nectarivorous bats. These same species migrate southward along the mountain spines in late summer and fall, feeding on high elevation flowers and fruits. If the mountain ranges in the region ran east-west, there would be many fewer migratory species here.

Mammal migrations

Migratory bats wintering in Mexico utilize the sky islands during their movements north in the spring (Krebbs unpublished data). In the Chiricahua Mountains during May 2003 and 2004, numerous silver-haired bats (*Lasionycteris noctivagans*) moved through this mountain range during northward migration (Krebbs unpublished data). Silver-haired bats are highly migratory (Barbour and Davis 1969) and previous studies or reports for this species in the Chiricahua Mountains (Allen 1895; Cockrum and Ordway 1959; Cahalane 1939; Hoffmeister 1986; Schmidt and Dalton 1994) indicate that this species is primarily captured in May and June during migration. Other rare or uncommon bat species in northern Sonora could also utilize mountain ranges in Arizona and along the border. Both of the nectar bats (*Leptonycteris yerbabuenae* and *Choeronycteris mexicana*) have been documented in the Chiricahua, Huachuca, and Dos Cabeza Mountains and for most of the "Sky Islands" in southeastern Arizona. The rare ghost-faced bat (*Mormoops megalophylla*) has not been captured in southeastern Arizona since 1954 and this species may be present in the Chiricahua and Huachuca Mountains. It is not uncommon for Mexican bat species to move north from Sonora and since the nearest known colony of ghost-faced bats is less than 200 miles south of the border of Arizona, the appearance of this species in southeastern Arizona is possible. Other rare species like the spotted bat (*Euderma maculatum*) may be documented in the Chiricahua Mountains during summer inventory and monitoring projects, but have not been captured during the past 11 years of Krebbs' study (2000-2010).

In 1912, a jaguar (*Panthera onca*) was collected at the Chiricahua NM in Bonita Canyon (Brown 1991). Brown (1983) suggested that the jaguar in Arizona ranged widely throughout a variety of habitats from Sonoran desert scrub upward through subalpine conifer forest. Most of the records were from Madrean evergreen-woodland, shrub-invaded semi-desert grassland, and along rivers. Up until 2009, several jaguars had been photographed and documented in southern Arizona. Jaguars have large territories and the Madrean Archipelago region may provide the habitat that this large cat requires to survive. At this time there are no known jaguars in Arizona (Tim Snow pers. comm.) but it is possible that this species may once again occur in this region. The Sky Island Alliance has recently photographed jaguars within 30 miles of the border of Arizona. In the foothills of the Sierra Madre, an estimated 100 jaguars remain in the state of Sonora (Northern Jaguar Project). Brown (1991) stated that the local Indians in the Sierra Bacatete (200 miles south of Arizona) have reported both male and female jaguars present in these mountains. Biological corridors exist between the Sierra Madre and the "Sky Islands" of southern Arizona that would allow additional jaguars to move into this area (Northern Jaguar Project). The current construction of the border wall along the border of Arizona and Mexico would be a major obstacle for jaguars to overcome for any movements from Mexico into Arizona. According to Spangle (2007), the overall area of potential habitat for jaguars in Arizona and New Mexico is equal to or greater than the area of suitable habitat for jaguars in Sonora, Mexico. Recent Federal court orders and decisions (2009-2010) are favorable for the reestablishment of jaguars in some of these mountain ranges and the protection of suitable habitat. A Federal Recovery Plan should help protect jaguars and ensure that animals moving north into Arizona will be protected. The Chiricahua and Huachuca Mountains have suitable habitat necessary to accommodate a jaguar(s).

Ocelots (*Leopardus pardalis*) were historically found in Cochise County in brushy and shrubby vegetation, wooded areas, and in riparian habitats. The Sky Island Alliance has documented (by trail camera) ocelots along the border of Arizona and Mexico. There have been two confirmed sightings of ocelots in Arizona in 2010 and 2011, one of which was in the Huachuca Mountains. The Chiricahua and Huachuca Mountains would provide ample habitat for this cat. Since the ocelot is shy and secretive it would be difficult to observe this species but remote cameras could be utilized to document its presence.

Birds

Many species of birds utilize the sky islands as vital corridors during their north and south migratory travels. These biological corridors provide food, water, and cover during the migrations. In the Madrean Archipelago riparian habitat is also utilized by birds during migration. The river and stream systems in southeastern Arizona provide tropical bird species access into Arizona. Hummingbirds, for example, migrate south through southeastern Arizona during late summer or early fall utilizing the rich nectar flowers found in the mountain ranges. Various species of raptors also utilize mountain ranges during their migrations. Many raptors take advantage of thermal updrafts and air currents that exist over large mountain ranges so that the birds expend the least amount of energy (dynamic soaring) during the migration. The Sulphur Springs Valley is the wintering habitat for several raptor species. This valley could serve as a reintroduction or translocation site for species like the aplomado falcon (*Falco femoralis*). Historically, the aplomado falcon was found in open habitat and grasslands. Habitat destruction and changes in grassland structure resulted in their extirpation from southeastern Arizona. In past years, there have been more reports of sightings for aplomado falcons in southeastern Arizona. The Gray Ranch in New Mexico has several breeding pairs, and young falcons may be dispersing into southern Arizona. In the past, prairie falcons (*Falco mexicanus*) have nested in the organ pipe rock formations in the Chiricahua NM.

Thick-billed parrots (*Rhynchopsitta pachyrhyncha*) breed in the mountains of Chihuahua and Durango, Mexico. The Madrean Archipelago could provide a corridor for birds from the Mexican population to move northward into Arizona. Thick-billed parrots formerly nested in southeastern Arizona but by the late 1930's most of the flocks of parrots had been extirpated. Reintroductions in the 1990's in the Chiricahua Mountains were unsuccessful due to poorly prepared birds and heavy predation. Future reintroductions of thick-billed parrots to the Chiricahua Mountains may be more successful with parrots that are more adapted to the wild.

Spotted owls (*Strix occidentalis*) nest in both the Chiricahua and Huachuca Mountains and these areas provide the necessary resources for this species. Although rare in Sonora, they have been found in the Sierra Madre in coniferous and pine-oak woodland and are probably residents of the higher mountain ranges (Russell and Monson 1998). In 2005, Krebbs captured a young spotted owl during her bat fieldwork at Chiricahua NM. The owl had been observed earlier in the evening as it sat in a tree close to the survey area as the researcher captured bats in a net. It appeared (Krebbs' observation) that this owl was watching (and probably hunting) the bats around the nets. The owl was captured in a net at the same time a bat was captured. Marshall (1957) collected 30 owl pellets in the Sierra Madre that contained varied items such as bats (Russell and Monsoon 1998). The Chiricahua NM's location at the northern end of the Sierra Madres would allow spotted owls easy movement from Sonora into this area.

4.1.2.10 Rare and Endemic Biocommunities and Species

The Arizona Gap Analysis Project (Gebow 2001) identified 4 at-risk plant communities in the Sky Islands Archipelago. Each of these covers less than 100 sq. km and less than 20% of their distributions are well protected:

- Madrean Montane Conifer Forest (Douglas Fir-Mixed Conifer)—distribution edge (but rare elsewhere in the U.S. and subject to human disturbance in Mexico)
- Scrub Grassland (Sacaton-Scrub)
- Rocky Mountain Montane Grassland (Rush)
- Rocky Mountain Riparian Deciduous Forest (Cottonwood-Willow)

None of the above vegetation types are identified under these names in the "azveggap" maps of the three parks in the GIS product.

In contrast to the large number of species in the Sky Island Archipelago, there are relatively few rare and endemic ones within the parks. The main reason for this phenomenon is that the montane island communities have been isolated from one another for only several thousand years since the last Ice Age ended. The known and suspected rare plants are listed in Table 4.3. We could not find enough data to compile a list of rare vertebrates other than the charismatic megafauna.

4.1.2.11 Key Ecological Processes

Key ecological processes are those that are essential to ecosystem integrity. They will function normally in any healthy (i.e., self-sustaining) ecosystem, and therefore can be useful in evaluating the health of ecosystems. Most of these processes are not suitable to be specific targets of management actions in themselves, but monitoring them can help assess the effectiveness of management practices, as well as justify the value of conserving of natural lands (see two paragraphs down). They include the cycling of water and nutrients, the flow of energy, natural disturbance, population dynamics, succession in

Table 4.3. Rare and endemic plants documented in and near the three parks. Boldface species are known to occur in a park (CHIR = Chiricahua NM, CORO = Coronado NMem, FOBO = Fort Bowie NHS).

Scientific name	Vernacular	Documentation	Legal Status
Apacheria chiricahuensis	**Chiricahua rock flower**	**CHIR**	**AZ Salvage Restricted**
Arabis tricornuta	Chiricahua rockcress	In US found only in SE AZ	NatureServe Global Conservation Status G1?
Astragalus hypoxylus	**Huachuca Mountain milkvetch**	**CORO**	**NatureServe Global Conservation Status G1**
Browallia eludens	No common name	Canelo Hills & Mexico	G1G3
Choisya mollis	Santa Cruz Star-Leaf	Occurs W of CORO	G2
Coryphantha robustispina var. *robustispina*	Pima pineapple cactus		ESA Endangered
Dalea tentaculoides	Gentry's indigo bush		NatureServe Global Conservation Status G1
Echinocereus coccineus* var. *arizonicus	**Arizona hedgehog cactus**	**CORO**[1]	**ESA Endangered**
Erigeron kuschei	Chiricahua fleabane	Endemic to Chiricahua Mts	NatureServe Global Conservation Status G1
Gentianella wislizenii	Wislizeni Gentian	High Chiricahuas	G2, ESA SC
Graptopetalum bartramii	Bartram stonecrop	Occurs west of CORO	G3, ESA SC
Heterotheca rutteri	Huachuca Golden Aster	Occurs E of CORO	G2, ESA SC
Hexalectris warnockii	**Purple-Spike Coralroot**	**CHIR**	**G2, ESA SC**
Hieracium pringlei	Pringle Hawkweed	Occurs in Chiricahuas	G2Q, ESA SC
Laennecia eriophylla	Woolly Fleabane	Occurs W of Huachucas	G3
Lilaeopsis schaffneriana var. *recurva*	Huachuca water umbel	In US found only in SE AZ	ESA Endangered
Lilium parryi	Lemon lily	Only 2 AZ sites in Huachucas	G3, ESA SC
Lupinus huachucanus	Huachuca Mountain Lupine	Occurs in Huachucas & Chiricahuas	G2, ESA S
Malaxis porphyrea	No common name	Occurs in Huachucas	G3G4
Muhlenbergia dubioides	Box Canyon Muhly	Occurs in Huachucas	G1
Pectis imberbis	**Beardless chinchweed**	**CORO**	**G3, ESA SC**
Perityle cochisensis	**Chiricahua Rock Daisy**	**CHIR**	**G1G2**
Senecio huachucanus	Huachuca groundsel	Occurs in Huachucas? & Chiricahuas	G2
Spiranthes delitescens	Canelo Hills ladies'-tresses	Occurs near Huachucas	ESA Endangered
Stellaria porsildii	Porsild's starwort	Occurs in Chiricahuas	G1
Talinum marginatum	Tepic Flame Flower	Occurs in Huachucas	G2, ESA SC

[1]The *Echinocereus triglochidiatus* complex has been subjected to such extensive taxonomic revision in recent years that it is not clear which taxa occur where. All records and specimens should be carefully reviewed before finalizing the species lists.

response to disturbance or climate change, evolution, and ecological services such as pollination and purification of water and air.

An often overlooked ecological service is the influence of natural environments on human physical and psychological health. A growing body of research shows that people who have regular access to natural areas have lower rates of diabetes, heart disease, and psychological disorders (Hartig 2008).

Ecological services have tangible economic values, which ecologists and economists are collaborating to quantify (Edwards and Abivardi 1998; Naidoo and Tomasek 2009; Zhoua et al. 2009). In some cases the annual value of ecosystem services is more than twice the annual value of resource extraction (Jonsson and Wardle 2009).

Fire

Fire is one key ecological process that is amenable to direct management. All of the vegetation communities in the Sky Islands Region except Chihuahuan Desertscrub and Thornscrub are subject to fire, and are adapted to it. Wildfires are most frequent in grassland and chaparral; they are less frequent in higher, wetter communities. Recovery time after crown fires is shortest in grassland and chaparral, and longest in the highest elevation forests. (All fires in chaparral are crown fires; everything above ground is killed – although usually in a mosaic pattern in which there are unburned patches. Grass fires are crown fires from the perspective of the dominant grasses, but some woody plants in grasslands may not be topkilled.) Fire frequency influences the vegetation type in transitional zones. For example, if fires in the foothills occur every few years, chaparral and oak woodland may be replaced by desert grassland. Increased fire frequency in Desert Grassland favors perennial grasses and herbaceous perennials over woody shrubs. At slightly higher elevations, fires that recur every few decades may favor chaparral over oak woodland. Perennial grasses require 7-10 years to recover from fire (Drewa and Havstad 2001). If grasslands burn more frequently, the community will be degraded. A more detailed discussion is included in section 4.1.3.9.

Interaction Of Climate, Fire, And Grazing

These three variables powerfully influence whether valleys and lower bajadas in the Sky Islands Region are vegetated with desert grassland (grass-dominated community) or Chihuahuan desertscrub (shrub-dominated community). This phenomenon is superbly summarized by Curtin (2008) and is outlined below. The analysis is based largely on long-term studies done near Portal, Arizona and more recent studies on the Diamond A Ranch (formerly Gray Ranch), southwestern New Mexico. The findings have practical application for land managers.

Desert grassland and Chihuahuan desertscrub dominate the lower elevations of the Southwest from southeastern Arizona and northeastern Sonora to western Texas. The two communities are more finely interwoven than is indicated on most vegetation maps. In general, grassland occurs where soil accumulates (typically on valley floors), while desertscrub dominates on rockier substrates (mostly on slopes). Climate, fire, and grazing have strong influences, especially near boundaries between the two communities.

The proportion of summer versus winter rainfall strongly influences vegetation. A multiyear predominance of summer rain favors expansion of grasses at the expense of shrubs, while a predominance of winter rain favors shrub dominance. This rainfall effect seems to be more important than grazing impacts.

Grazing intensity has significant influences on vegetation. High grazing intensity tends to drive grasslands toward conversion to shrubland (desertscrub) at lower elevations (below about 5000 feet), and savanna toward woodland at higher elevations. But at lower grazing intensities, cattle do not significantly impact plant diversity. On the other hand, pronghorn foraging decreases the diversity of forbs.

Increasing fire frequency has the opposite effects of grazing intensity, e.g., tends to convert shrubland to grassland.

Three decades of study by Jim Brown and colleagues reveal that rodent activity has the same effect as predominant summer rain, i.e., they favor growth of grasses over shrubs. Higher rodent populations also alter winter annuals, but not summer annuals. Kangaroo rats are especially influential in reducing shrub cover. The full picture is complex and still not well understood. Overall, rodent activity has a greater influence on grassland/shrubland vegetation than large herbivores.

It should be noted that the common grass in the study area is the exotic Lehmann's lovegrass. It is not certain whether the same results would be obtained in a more natural flora. It should also be noted that Curtin's analysis suggests that results from small-scale plot studies like those of Brown et al. may not predict outcomes from the same factors acting on large-scale landscapes. In other words, Brown's findings are probably applicable to managing small areas within the parks focus areas, but are perhaps not suitable for managing the Sky Islands Region as a whole.

The interactions among these and other factors are extremely complex and barely understood. For example, if high rodent populations cause an increase in grass over shrub cover, this may increase the probability of a fire. The specific effects of fire in a large landscape can be difficult to measure because numerous herbivores, including pronghorn and cattle, preferentially graze in recently burned areas.

4.1.2.12 Assessing Ecosystem Health

Maintaining healthy ecosystems requires meeting four basic objectives (Noss and Cooperrider 1994):

1. Represent, in a system of protected areas, all native ecosystem types and seral stages (of community succession) across their natural range of variation.

2. Maintain viable populations of all native species in natural patterns of abundance and distribution.

3. Maintain ecological and evolutionary processes, such as natural disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions. (see USEPA 1999 for more discussion.)

4. Manage landscapes and communities to be responsive to short-term and long-term environmental change and to maintain the evolutionary potential of the biota.

While these are clearly stated goals, measuring them is difficult because of the complexity of natural systems. It is the professional opinion of the Principal Investigators and authors of this report that a quantitative assessment of ecosystem health is not feasible for several reasons:

1. A widely accepted definition of ecosystem health does not exist. Definitions may contain aesthetic or economic desired conditions, but these are not necessarily relevant to the intrinsic condition of the ecosystem (see discussion below).

2. While mathematical models to describe ecosystem health are being developed (e.g., Jorgensen et al. 2005), the formulas contain many variables that require an enormous quantity of data. It is unlikely that most land management agencies will be able to compile the needed data in the foreseeable future, rendering these models impractical if not impossible to use.

3. The relative importance of the many ecological variables of an ecosystem and the strength of their interactions are still largely unknown. Moreover, the actual values of most of the variables are also not known with confidence. Minor modifications of model formulas can cause great variability in the output results. While models may be useful academic tools, their outputs are not yet likely to be reliable for making management decisions for the foreseeable future.

For these reasons, we feel that the best way to assess ecosystem health is to consult experts who are familiar with the local area and ecosystems. There are several criteria that should be considered in making the assessment. The most important ones are:

1. The presence of most or all of the keystone species that were known to be historically present is a good indicator that most ecosystem processes are intact.

2. Whether a community's component species exhibit a normal size/age-class distribution, which indicates that populations are reproducing.

3. The presence and abundance of exotic species.

4. More important than #3, the presence and abundance of invasive exotic species.

5. The absence of recent, severe, anthropogenic disturbances such as a crown fire, overgrowth from long-term fire suppression, extensive logging, livestock overgrazing, etc.

6. Evidence of transformation of vegetative communities in the historical time frame.

7. The natural changes that occur on a geological time scale.

Some of the above criteria can be very tricky to evaluate. For example, we observed many dead and dying pines and junipers in Chiricahua NM due to bark beetle infestations (Curculionidae: Scolytinae, Figures 4.14 and 4.15). Populations of bark beetles surge when winters are not sufficiently cold to kill them and if trees are stressed by drought. If global warming continues, it would be expected that these conifers would greatly decline or disappear at their present elevations (and perhaps migrate to higher, colder elevations). However, if these conifers are replaced by other local, native species of trees that are not susceptible to bark beetles, the ecosystem may still be considered to be healthy, even though its species composition has substantially changed.

Normal size/age-class distributions may be difficult to ascertain. Some long-lived species have successful recruitment only a few times in a century, so few or no seedlings may be observed in some surveys. Areas must be surveyed over a period of decades to determine whether some species are maintaining their populations.

Assessing the health of an ecosystem that has recently experienced a major disturbance can easily involve human values that do not necessarily relate directly to scientific definitions of ecosystem health. For example, a century of fire suppression has rendered many forests susceptible to catastrophic crown fires. A forest devastated by such a fire can take centuries to fully recover to climax. (This is, in fact, a very short time in the life of a forest.) Humans consider the aftermath of a devastating fire to be highly undesirable, but this is more an aesthetic opinion than a scientific conclusion about the forest's health. If recovery proceeds without significant intervention and without a prevalence of invasive exotics, the system is in fact healthy even though it's initially unsightly. It could be argued that a forest that is susceptible to a crown fire due to fire suppression is unhealthy. Perhaps; but there are historical records for overgrown forests and subsequent crown fires in prehuman times. The desired condition may be a more important management consideration in these cases than ecosystem health per se.

The frequency of fire is of major importance to ecosystem health. Every combustible vegetation type has a natural range of fire frequency, to which it is adapted. Human activities tend to greatly increase the frequency of fires, which can cause type conversion. Forests can be converted to chaparral, and chaparral can be converted to exotic grassland. The first conversion may still leave a healthy community, but most ecologists as well as land managers would describe the latter event both unhealthy and undesirable.

The perspective of deep time must be considered when assessing what is natural and healthy. Human lifespans are very short compared to the development of biological communities. The Pleistocene Age, which began two million years ago and has probably not ended, is characterized by a series of alternating ice ages and interglacial periods. There have been 15 to 20 glacial cycles. The interglacial climate phases (one of which we now live in) have persisted for a total of only five per cent of the past two million years. During each ice age, communities migrated to much lower elevations than where they now occur; the reverse has occurred during the brief interglacials. This kind of change is natural. There is concern, however, that anthropogenic global warming may force such rapid change that many species may not be able to adapt, or migrate fast enough to stay within their required climate zones. It will take careful monitoring in the coming decades to determine whether this threat to ecosystem health becomes reality.

4.1.3 Threats and Stressors

4.1.3.1 Climate Change / Drought

Scientists' understanding of the effects of climate change on ecosystems is so rudimentary that the analysis here should not be considered to be more than informed speculation.

Even though the cause is not certain, the global climate is warming. Precipitation is not increasing, and may be decreasing. If these trends continue, they will have major impacts on vegetation in the Sky Island Region. In the absence of increasing rainfall, rising temperatures increase the aridity of a habitat by increasing evapotranspiration. In response, biological communities will shift upslope where suitable conditions for their existence occur. The highest elevation communities may be pushed off the tops of the mountains. Some species at lower elevations may not be pushed off the mountaintops, but could perish because the elevation that provides the requisite moisture is too cold for their survival. A latitudinal version of this phenomenon can be seen in the current distributions of numerous tropical plants. For example, coralbean (*Erythrina flabelliformis*) is a common tree in the lowland tropical deciduous forest of southern Sonora. It occurs as far north as southern Arizona in oak woodland at about 5000 feet elevation. It has sufficient moisture in this habitat, but grows as a shrub because it freezes to the ground every few years. It flowers on year-old wood, so it can reproduce between hard freezes. It cannot survive at higher latitudes because at the elevation where there is sufficient moisture, annual hard freezes prevent it from reproducing.

Plants that employ C_4 photosynthesis, which includes most warm-season grasses, are much more efficient than C_3 plants at fixing carbon at high environmental temperatures, and low carbon dioxide concentrations. This advantage decreases as CO_2 concentration increases. Preliminary studies indicate that the increasing CO_2 in the atmosphere may drive conversion of grasslands to Chihuahuan desertscrub.

Climate scientists predict conditions in the Southwestern United States and Northwestern Mexico to become hotter and drier over the next 100 years (Karl et al. 2009; Seager et al. 2007). The average temperature in the Southwest has already increased approximately 1.5 degrees Fahrenheit compared to baselines recorded in the 1960s and 1970s. Projections estimate that annual average temperatures will rise by 4 to 10 degrees Fahrenheit above the baseline by the end of the century (Karl et al. 2009).

Climate change will also impact precipitation; scientists are already observing a northward shift in winter and spring storm tracks. There is some uncertainty, however, surrounding how climate change will affect the summer monsoons of the Southwest region (Karl et al. 2009). With higher temperatures, more precipitation will take the form of rain than snow. With a 5.4 degree Fahrenheit increase in average daily temperature, there will be little or no snow in the region (Bales et al. 2006). Observations from 1950-1999 have already documented a decline in snowpack in the Southwest (Pierce et al. 2008).

Hotter temperatures and changes in precipitation will lead to an increasing probability of drought. Demands will intensify on already limited water supplies, impacting biodiversity, protected areas, outdoor recreation, municipal drinking water, industry, agriculture and ranching (Karl et al. 2009). Occurrence of wildfire is expected to increase in some areas, and vegetation composition is likely to change (Westerling and Bryant 2008; Breshears et al. 2005). Hotter and drier conditions may result in ecosystem shifts upslope, with possible regional extinctions of some species and communities that are already at the highest extent of their range (Gottfried et al. 2005).

4.1.3.2 Hydrologic Alteration

Despite drier conditions, possible future changes in timing and amount of precipitation could result in flooding—putting people, ecosystems, and infrastructure at risk. (Karl et al. 2009; Allan and Soden 2008). Floods will be associated with rapid run-off from rain-on-snow events, decreased snow cover, and an increased fraction of winter precipitation falling as rain (Knowles et al. 2006; Bales et al. 2006).

In the region, the San Pedro River flows from Mexico north through eastern Cochise County. It is one of the few perennial streams in the region, a flyway for migratory birds, and a source of recharge for aquifers that supply drinking water to area residents (Webb and Leake 2006). Hotter and drier conditions may intensify already high demands on this resource. According to the U.S. Geological Survey, groundwater withdrawals associated with population growth in Cochise County may decrease stream flow in the upper San Pedro, affecting riparian ecosystems, and possibly resulting in subsidence and earth fissures (USGS 1996).

Likewise, springs in the region will be affected by groundwater withdrawals, as well as by changes in runoff and groundwater recharge. Regional population growth coupled with climatic changes may eliminate smaller water bodies and wetland, riparian, or aquatic communities dependent on them (Grimm et al. 1997).

4.1.3.3 Debris Flows

Wildfires and rapid run-off may result in more erosion and debris flows in the region. Research in the Tucson area has shown that erosion—and and sediment in stream systems—increases after wildfires for as long as two years. Exposed, burned soils are vulnerable to severe rains, leading to increases in surface runoff, higher peak flows and elevated erosion rates (Desilets et al. 2007).

This pattern has been witnessed several times in Coronado NMem, most recently in 2006, when intense rains resulted in massive landslides. There were 113 slope failures and 66 debris flows within the Huachuca Mountains. Sixty percent of the slop failure and thirty-three percent of the debris flows came from burned areas (Webb et al. 2008). At Fort Bowie NHS, significant rainfall in July 2006 caused numerous flash floods and slope failures. Several of the slope failures combined to form one of the largest debris flows in the site's recent history (past 150 years). The debris flow soured a channel 60 feet wide and 2,000 ft long and had a volume of approximately 480 cubic yards (Webb et al. 2008). The potential for landslides also exists on Sugarloaf Mountain in Chiricahua NM, where easily-eroded, ash-rich soils are buried beneath layers of welded tuff. A landslide in 2001 closed trails in this area for a year and a half (Graham 2009).

4.1.3.4 Border Pressures

The U.S./Mexico border poses a potential threat to natural resources, which can be damaged by illegal immigration, narcotics smuggling, enforcement efforts, and related activities. Beginning with "Operation Gatekeeper" in San Diego in 1995, the U.S. has implemented policies that strictly control border crossings in urban areas, shifting illegal activity to rural areas. Unpopulated federal lands have become attractive locations for illegal border crossings (Coronado Planning Partnership 2008, Vacariu and Neely 2005). Along the southwestern border, stretching from California to Texas, Border Patrol apprehensions of illegal immigrants increased during the late 1990s and peaked at 1,650,000 in federal fiscal year 2000 (GAO 2010).

Unlike California, New Mexico, and Texas, Arizona's borderlands are mostly federal—more than 85 percent of lands along the border (Segee 2006). In 2000, the Department of Interior (DOI) estimated that 113,000 undocumented migrants crossed through DOI lands in Arizona (Segee 2006). By 2003, U.S. Border Patrol estimated that there were 115,000 illegal crossings in Coronado NMem alone (Drake et al. 2005). That year, enforcement officials in Coronado NMem detained over 7,000 undocumented migrants and seized almost 25,000 pounds of marijuana (BLM/NPS 2005). In Fort Bowie NHS, approximately 20 undocumented immigrants pass through the park each week (Powell et al. 2006). There were 540,000 apprehensions along the southwestern border in federal fiscal year 2009. Recently, the Border Patrol's Tucson Sector, which covers Coronado NMem, Chiricahua NM, and Fort Bowie NHS, had the highest number of apprehensions. The number of apprehensions in the Tucson Sector decreased from approximately 400,000 in fiscal year 2006 to nearly 250,000 in 2009 (GAO 2010).

Border regions are under the jurisdiction of many local and federal government agencies—including land management agencies, law enforcement, and military. Efforts among these agencies are often not coordinated within or across borders. In the United States, for example, the 1996 Immigration Act waives any legal obligation for Immigration and Naturalization Services to comply with the Endangered Species Act and National Environmental Policy Act (NEPA; Goodwin 2000). The U.S. Secure Fence Act of 2006 allowed the Department of Homeland Security to construct a fence along the U.S.-Mexico border, not subject to any environmental review, despite potential negative effects on migratory animals (Cohn 2007).

Threats to natural resources associated with illegal border crossings include increased fire risk, wildlife disturbance, habitat destruction or modification, spread of invasive species, trash and human waste, and creation of new roads and trails (Colorado Planning Partnership 2008; Billington et al. 2010). A 2002-2004 study of human use and perceptions of Ironwood Forest National Monument, northwest of Tucson, found that non-recreation, nighttime activity was common within the Monument. The non-recreation activity likely was illegal border crossings and drug trafficking (Billington et al. 2010). Border-related activities also pose a risk to park visitors. In October 2006, the US Fish and Wildlife Service closed a 3,500 acre portion of the Buenos Aires National Wildlife Refuge in southern Arizona due to violence and other problems associated with illegal border crossings in the area (USFWS 2006).

According to the Government Accountability Office (GAO), land managers and Border Patrol agents agree that Border Patrol's presence helps to protect natural and cultural resources by reducing the number of illegal crossings, thereby reducing the amount of traffic on environmentally sensitive areas (GAO 2010). However, enforcement efforts in border areas also pose potential threats to natural resources. Law enforcement use of floodlights, off-road vehicles, and low flying aircraft also pose ongoing threats to natural resources (Schmidt et al. 2007). The Border Patrol uses a combination of personnel, technology, and tactical infrastructure, such as vehicle and pedestrian fences, to try to control their jurisdiction. As of April 2010, the Department of Homeland Security had installed 646 of the planned 652 miles of fencing and vehicle barriers along the southwestern border (GAO 2010), including a pedestrian fence at Coronado NMem. Numerous efforts are underway, or were recently completed, to understand the impact of the infrastructure and border activities on ecological processes and communities including:

- Monitoring the impacts of the pedestrian fence on stream channel morphology of ephemeral washes at Coronado NMem and Organ Pipe Cactus NM (Natural Channel Design, Inc. 2008)
- Investigations on the potential effects of hardening the borer on ecological communities (Sayre and Knight 2010)
- Use of remote sensing to quantify border impacts at Organ Pipe Cactus (NM) and Coronado NMem (Drake et al. 2008)
- Evaluation and development of methods to document unlisted roads and trails (T. Esque pers. comm. 2011)

4.1.3.5 Population, Urbanization and Changing Socioeconomic Conditions

The Southwest is one of the fastest growing regions in the United States. Generally, populations in southeastern Arizona and southwestern New Mexico have increased since 1970 (Figure 4.16). Growth in the region centers in Pima County, Arizona, which includes Tucson—one of the 50 fastest-growing metropolitan areas in the country (US Census Bureau 2009). Only one county—

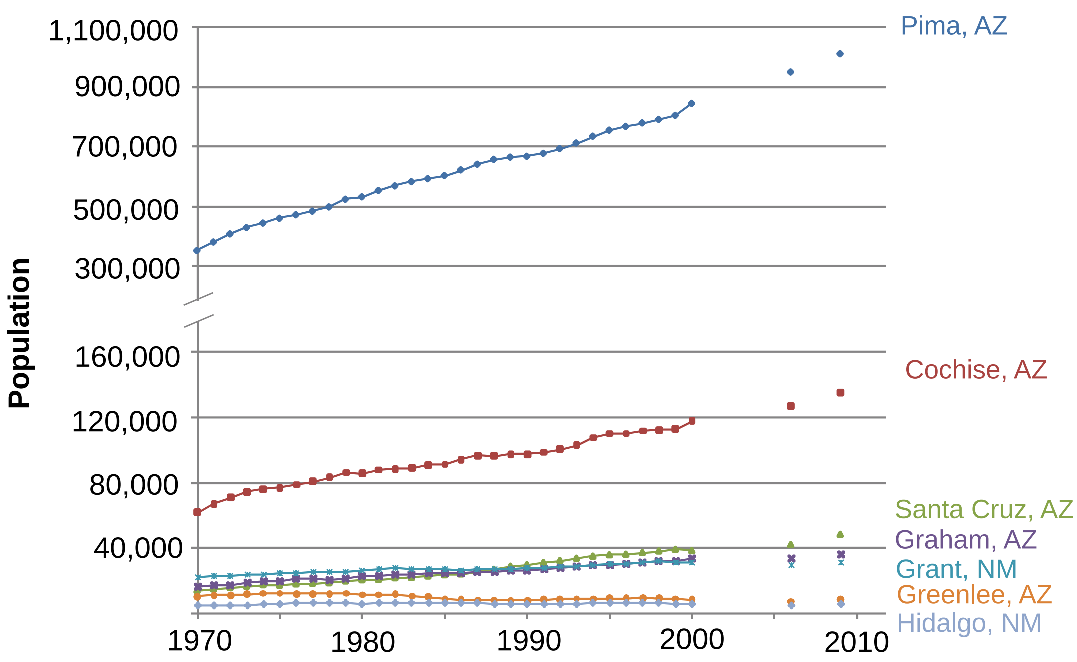


Figure 4.16. Population estimates and projections by county in southeastern Arizona and southwestern New Mexico, 1970-2009. Sources: ESRI 2009; EPS 2009; US Census Bureau 2009.

Greenlee County, New Mexico—decreased in population between the 1970 and 2000 censes.

In northern Mexico, populations are also increasing overall (Table 4.4). From 1995 to 2005, annual population growth averaged 0.5 percent—led by the municipality of Agua Prieta in Sonora, with an annual growth rate of 2.5 percent. Some municipalities shrank during this period, however. For example, Janos, Chihuahua had an annual growth rate of -2.39 percent, mostly losing population to migration to the United States (INEGI 2009).

Projections based on U.S. Census Bureau data predict that population will increase by 1%, 1.27% and 0.79% in the immediate areas (30 km radius—U.S. only) surrounding Chiricahua NM, Coronado NMem, and Fort Bowie NHS, respectively. The projections for areas surrounding the parks predict that population growth will outpace the national rate (0.76%), but fall behind the statewide growth rate for Arizona (2.58%). Most population growth in the Southwest is focused in larger cities.

In the region, most development has occurred in Pima County, which approved 7,485 building permits in 1999 and 11,304 in 2005. The least development was in Greenlee County, which had as few as 1-9 building permits from 1999-2006. Generally, building permits peaked from 2004-2006, and since that period there has been less building in the area (US Census Bureau 1999-2008). Building permit information was not available for nearby parts of New Mexico or Mexico. In the immediate vicinity of the parks, recent growth has mostly been

Table 4.4. Population of municipalities within region located in northern Mexico (INEGI 2009).

	Population	
Municipality	**1995**	**2005**
Agua Prieta	56,289	70,303
Cananea	29,315	32,157
Ascension	19,676	22,392
Imuris	9,028	10,541
Janos	10,794	8,211
Fronteras	6,671	7,470
Naco	4,912	6,010
Arixpe	3,641	2,959
Santa Cruz	1,407	1,786
Bacoachi	1,693	1,456
Cucurpe	913	798

conversion of rural, working landscapes to ranchettes and subdivisions. This type of growth is projected to continue, and could have potential effects on groundwater, wildlife corridors, fire regimes, invasive species, viewsheds, and visitation numbers (Hubbard et al. 2010; Schmidt et al. 2007; Coronado Planning Partnership 2008).

In addition, fifteen acres near the entrance to Chiricahua NM and 100 acres between the Monument and USDA Forest Service land pose concerns to managers. Park managers are concerned that development of the land near the park entrance would affect the rural appearance of the gateway. The 100 acre parcel is the site of previous mining attempts and is at the top of the monument's largest watershed, and managers worry about potential development on the site if it is sold. Near the administrative area of Fort Bowie NHS, the Diamond Ranch Buddhist Colony continues to expanded its development and other nearby parcels could be sold for development. Managers are concerned about visual encroachment in these areas, which could harm visitor experiences at Fort Bowie NHS (NPS 2008).

Figure 4.17 and Figure 4.18 show the distribution of housing in the area in 2000 and projections for the next century. Based on U.S. Census data from 2000, housing is expected to increase 33 percent from 2000 to 2015 in the immediate area surrounding Coronado NMem (U.S. lands only). Near Chiricahua NM, that figure is 28 percent and near Fort Bowie NHS, 23 percent (ESRI 2009). Data incorporating the most recent recession may produce more modest projections for housing growth. All three park units are located in relatively rural areas, and growth in absolute numbers is relatively small. The region around Coronado NMem has more housing units due to its proximity to Sierra Vista, the largest city in Cochise County. In terms of their impacts, cities are not geographically discrete areas in the sense that most of the impacts lie far beyond their borders. The total area of land required to sustain an urban region (its "ecological footprint") is at least ten times that contained within the municipal boundaries (Rees 1992).

In southeastern Arizona and southwestern New Mexico, per-capita income increased from 1990-2000, and is expected to continue to increase, at a slower rate, through 2014. The average per capita income in this region was $14,820 in 2000. The highest per capita income is in Pima County, AZ, at $15,988 in 2000, and the lowest per capita income is in Graham county, AZ and Hidalgo County, NM—around $12,000 in 2000 (ESRI 2009).

Unemployment in southeastern Arizona and southwestern New Mexico is generally low—less than 5 percent 2007 (EPS 2009). Unemployment has decreased in most counties from highs in the 1990s—as high as 25.6 percent in Santa Cruz County, AZ in 1996 (EPS 2009). Projections show unemployment rates increasing slightly by 2014 to 5 percent to 10 percent (ESRI 2009). In the U.S. portion of the region, 493,039 people commute to work—about 96 percent of workers. Commuting times average 21 minutes (ESRI 2009).

According to the 2000 U.S. Census, the strongest industry in southeastern Arizona and southwestern New Mexico is the educational, health and social services industry, employing 100,917 people, or 22 percent of the population in the region (Figure 4.19). Of this, the majority (83,617 people) are in Pima County, Arizona. The next most dominant industries are retail trade, Arts/Entertainment/Recreation/Accommodation/Food Services, and Professional/Scientific/Management/Admin/Waste Mgmt Services.

In northern Mexico, manufacturing and mining are important in some locations, but agriculture is the primary industry, particularly cattle ranching (Instituto Nacional para el Federalizmo y el Desarrollo Municipal 2005). In the United States, the New Mexico Counties (Grant and Hidalgo) and Graham County, Arizona are the most agricultural, each nearly 50 percent farmland. Cochise, Greenlee and Santa Cruz counties in Arizona are less agricultural (each less than 30 percent farmland and as little as 3 percent farmland in Greenlee). Throughout the U.S. portion of the region, proportions of agricultural land have decreased slightly from 35 percent in 2002 to 32 percent 2007 (USDA NASS 2007).

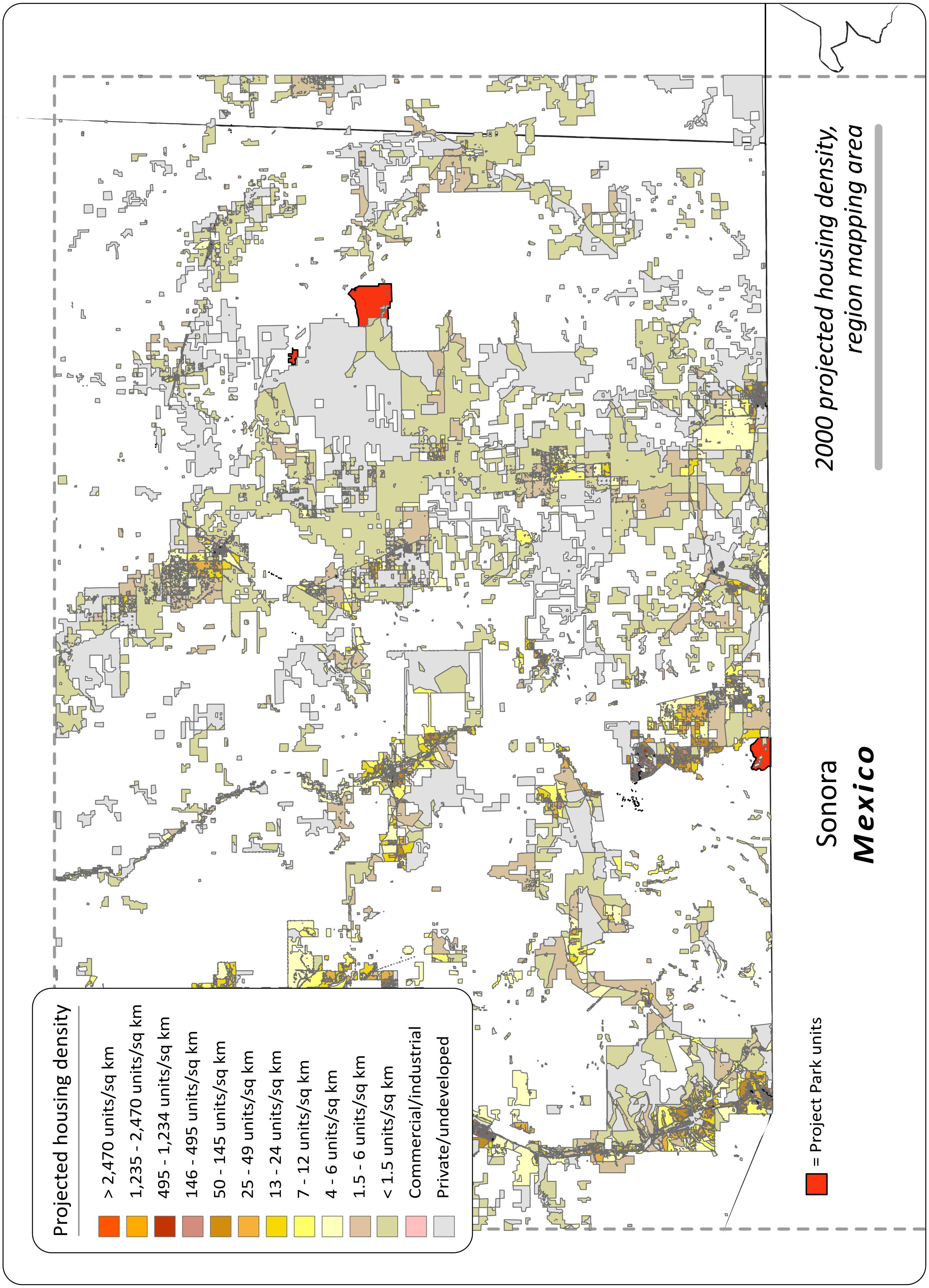


Figure 4.17. Regional housing density estimates, 2000 (NPS 2010b; Theobald 2005).

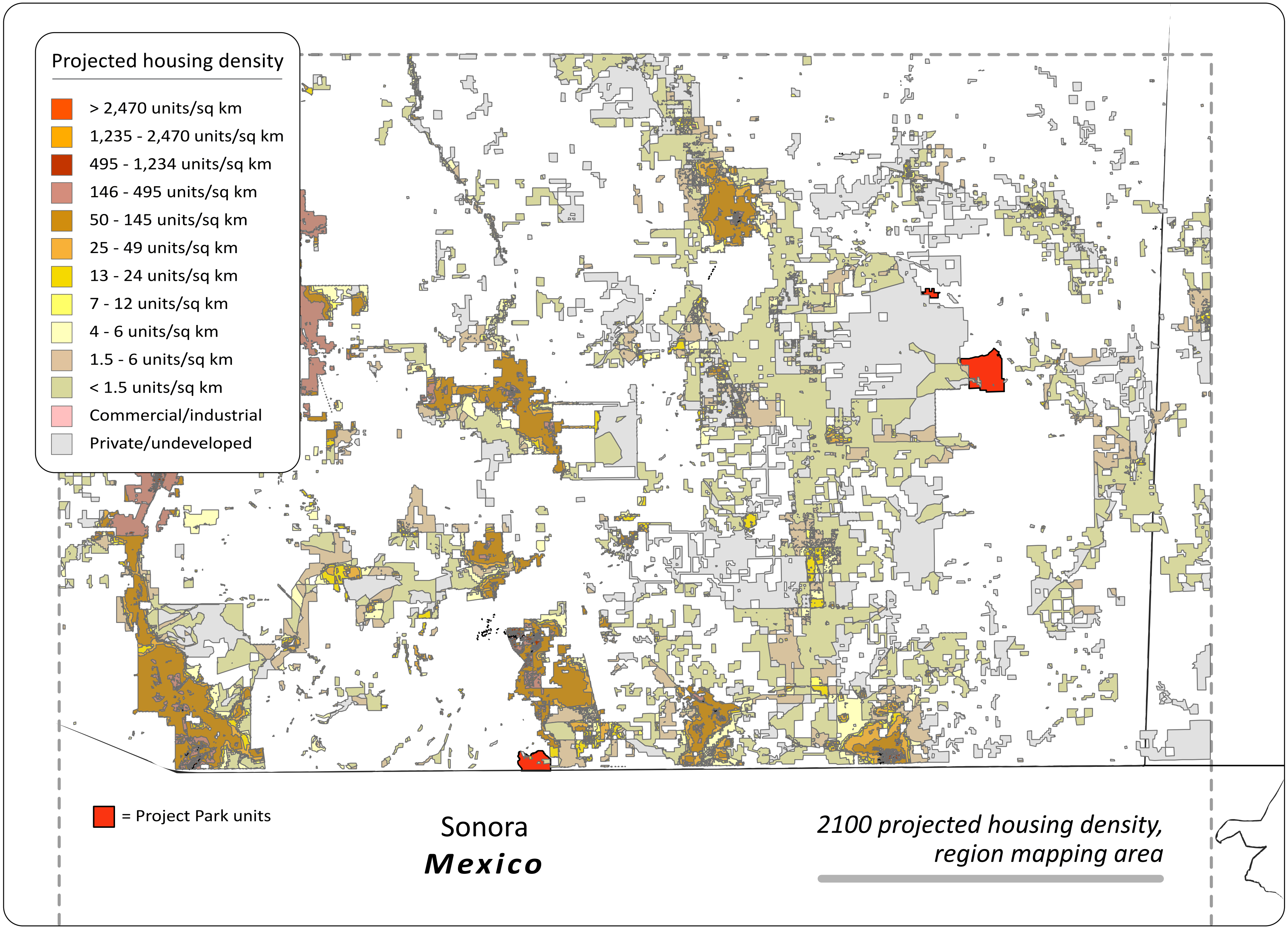


Figure 4.18. Regional housing density projections, 2000 (NPS 2010b; Theobald 2005).

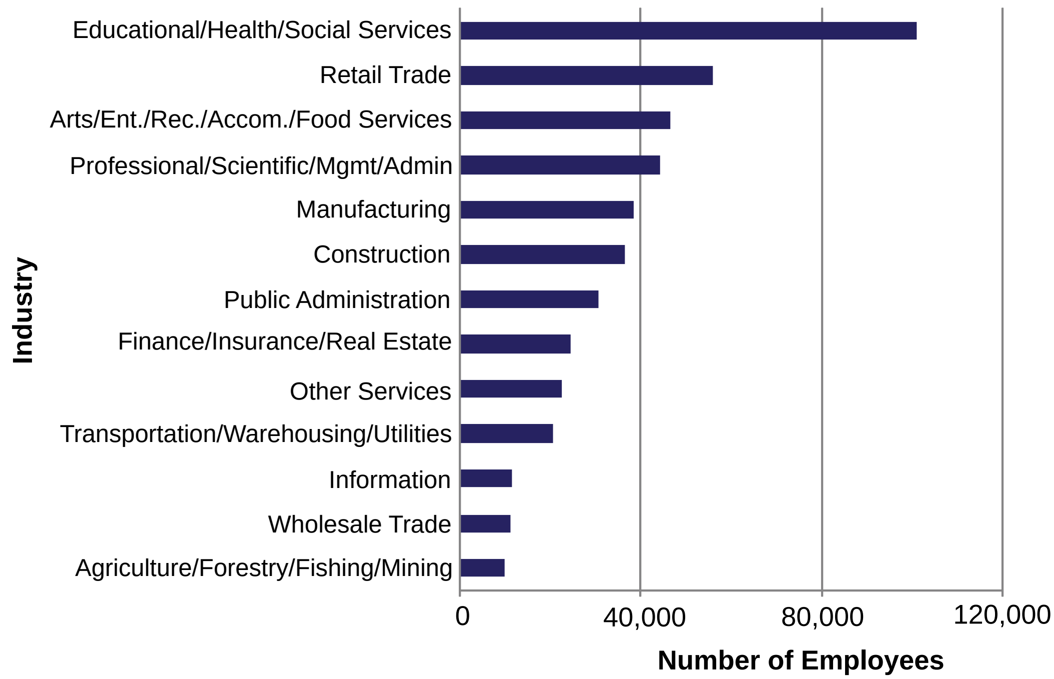


Figure 4.19. Employment by Industry in Southeastern Arizona and Southwestern New Mexico. Source: ESRI 2009.

Historically, copper mining has been an important industry in Cochise County. Bureau of Land Management statistics indicate that within a 30 kilometer radius (U.S. lands only), there are 280 mining claims near Fort Bowie NHS, 195 near Chiricahua NM, and 78 near Coronado NMem. Many of these mines are small, however, and many are currently out of production. There are inactive lead and zinc claims in Coronado NMem and near Chiricahua NM. While in operation, the impacts of mining included acid mine drainage, viewshed impacts, and access issues. If prices climb so that the extraction of lead in this region becomes economically feasible, park personnel may have to address these issues once again (Graham 2009, Schmidt et al. 2007). In recent years, mining is a relatively small part of the local economy, with the greatest number of firms in the services and retail trade industries (Figure 4.17).

4.1.4.6 Power Plants/Energy Development

A new 1,000 megawatt power plant has been approved to be built in Bowie, two miles north of I-10, near Fort Bowie NHS. The natural gas-powered plant is not expected to have negative environmental impacts—emissions and groundwater use (for steam turbines and cooling) will be regulated by the State of Arizona. Construction was originally intended to be completed by 2010 but plans have been delayed due to the recession. Cochise County approved an extension on the building permit until 2015 (Porier 2009). Other potential energy development projects in Cochise County include wind, solar and geothermal development, but there are no plans for large-scale projects in the immediate areas of any of the park units.

There are plans for additional electrical transmission lines in the region—the SunZia project proposes two high-voltage electric transmission lines in New Mexico and southeastern Arizona. The precise route for the transmission lines has not yet been determined. A portion of the project could run through the northern part of Cochise County, but not in the immediate vicinity of the parks (SunZia 2010).

4.1.3.7 Exotic / Invasive Species

Many ecologists have acknowledged the problems caused by invasion of non-native species into communities or ecosystems and the associated negative effects on global patterns of biodiversity (Stohlgren et al. 1999).

Once established, invasive species have the ability to displace native plants and animals (including threatened and endangered species), disrupt nutrient and fire cycles, and alter the character of the community by enhancing additional invasions (Cox 1999; DeLoach et al. 2000; Zavaleta et al. 2001; Osborn et al. 2002).

A number of introduced and potentially invasive species have been documented in the three parks (Table 4.5; Ruffner and Johnson 1991; NPS 1996; SEINet 2009; WeedUS 2009). Several of these exotic species have been introduced to the monuments as a direct result of human activities such as past settlement, grazing, farming, excavation, and construction activities. Many of them will likely not require active management to control their populations; however some species such as cheatgrass and buffelgrass can pose severe threats to wildlife populations, ecosystem dynamics and long-term wilderness sustainability. (The parks are currently too cold for buffelgrass, but climate warming could change that. Additionally, more cold-hardy strains are being actively developed for rangeland use.)

Table 4.5. Introduced non-native and invasive species documented at Chiricahua NM, Coronado NMem, and Fort Bowie NHS, Arizona.

Scientific Name[1]	Common Name[1]	Growth Form[2]	Park		
			Chiricahua	Coronado	Fort Bowie
Ailanthus altissima (Mill.) Swingle	tree of heaven	T		X	
Alternanthera pungens Kunth	khakiweed	F	X		
Anagallis arvensis L.	scarlet pimpernel; poor man's weatherglass; shepard's dock	F	X		
Amaranthus blitoides S. Watson	mat amaranth	F	X		
Asparagus officinalis L.	common asparagus; garden asparagus	F	X	X	
Avena fatua L.	wild oats; oatgrass; flaxgrass	G			X
Brassica rapa L. var. *rapa*	field mustard	F	X		
Brassica tournefortii Gouan	African mustard; Asian mustard; Mediterranean turnip; wild turnip	F	X		
Bromus catharticus Vahl.	rescue grass	G	X		
Bromus hordeaceus L. ssp. *hordeaceus*	soft brome	G	X		
Bromus rubens L.	red brome; foxtail brome; foxtail chess	G	X		X
Bromus tectorum L.	cheatgrass, downy brome	G	X	X	X
Caesalpinia gilliesii (Wall. ex Hook.) Wall. ex D. Dietr.	bird-of-paradise	S/T/V		X	
Centaurea melitensis L.	Maltese star thistle; tocolate	F	X	X	
Cichorium intybus L.	common chicory; blue sailors; succory	F	X		
Cirsium arvense (L.) Scop.	Canada thistle	F		X	
Convolvulus arvensis L.	field bindweed	V/F			X
Cynodon dactylon (L.) Pers.	Bermuda grass	G	X	X	X
Cyperus esculentus L.	yellow nutsedge	G	X		

[1]Plant name information is from the USDA Plants database (USDA, NRCS 2009).
[2]Species' primary growth form: G – grass; F – forb; S – shrub; T – tree; V – vine

Table 4.5. Introduced non-native and invasive species documented at Chiricahua NM, Coronado NMem, and Fort Bowie NHS, Arizona.

Scientific Name[1]	Common Name[1]	Growth Form[2]	Park		
			Chiricahua	Coronado	Fort Bowie
Datura stramonium L.	jimsonweed, toloache	F/S		X	
Descurainia sophia (L.) Webb ex Prantl	Flixweed; herb sophia	F	X		
Digitaria sanguinalis (L.) Scop.	hairy crabgrass	G	X	X	X
Echinochloa colona (L.) Link	corn panicgrass; jungle rice	G	X		X
Echinochloa crusgalli (L.) P. Beauv.	barnyard grass	G	X		X
Elaeagnus angustifolia L.	Russian olive	S/T	X		
Elymus repens (L.) Gould	quackgrass	G		X	
Eragrostis cilianensis (All.) Vign. ex Janchen	stink grass	G	X	X	X
Eragrostis curvula (Schrad.) Nees	weeping lovegrass	G	X		X
Eragrostis lehmanniana Nees	Lehmann lovegrass	G	X	X	X
Erodium cicutarium (L.) L'Hér. Ex Aiton	redstem storksbill; redstem filaree	F	X		X
Euphorbia davidii Subils	David's spurge	F	X		
Hackelochloa granularis (L.) Kuntze	pitscale grass	G	X		
Hordeum murinum L. ssp. leporinum (Link) Arcang.	leporium barley; hare barley	G	X		X
Hordeum vulgare L.	common barley	G	X		
Ipomoea hederacea Jacq.	ivyleaf morning glory	V/F	X		
Ipomoea purpurea (L.) Roth	common morning glory; tall morning-glory	V/F	X		X
Lactuca serriola L.	prickly lettuce	F	X		
Lamium amplexicaule L.	henbit; henbit deadnettle	F			X
Lonicera japonica Thunb.	Japanese honeysuckle	V	X		
Macroptilium gibbosifolium (Ortega) A.Delgado	variableleaf bushbean	F	X		
Marrubium vulgare L.	horehound	F	X		
Medicago sativa L.	alfalfa	F	X		
Melilotus officinalis (L.) Lam.	white sweet clover; yellow sweet clover	F	X		
Nasturtium officinale W.T. Aiton	watercress	F	X		
Nepeta cataria L.	catnip	F	X		
Pennisetum ciliare (L.) Link	buffelgrass	G	X		
Pennisetum setaceum (Forssk.) Chiov.	crimson fountaingrass	G	X		
Plantago major L.	common plantain; broad-leaved plantain	F	X		
Poa annua L.	annual bluegrass	G	X		
Polygonum aviculare L.	prostrate knotweed	F	X		

[1]Plant name information is from the USDA Plants database (USDA, NRCS 2009).
[2]Species' primary growth form: G – grass; F – forb; S – shrub; T – tree; V – vine

Table 4.5. Introduced non-native and invasive species documented at Chiricahua NM, Coronado NMem, and Fort Bowie NHS, Arizona.

Scientific Name[1]	Common Name[1]	Growth Form[2]	Park		
			Chiricahua	Coronado	Fort Bowie
Polygonum convolvulus L.	black bindweed	V/F			X
Polypogon monspeliensis (L.) Desf.	annual rabbitsfoot grass	G	X		
Polypogon viridis (Gouan.) Breistr.	beardless rabbitsfoot grass; water bentgrass	G	X		X
Portulaca oleracea L.	little hogweed, purslane	F	X	X	
Prunus armeniaca L.	apricot	T		X	
Pyracantha koidzumii (Hayata) Rehder	fire thorn	F		X	
Rumex crispus L.	curly dock	F	X		X
Salsola kali L.	Russian thistle; common salt-wort; prickly saltwort	F/S	X	X	X
Salsola tragus L.	prickly Russian thistle; tumble-weed	F	X		
Schedonorus pratensis (Huds.) P.Beauv. (Festuca p.) Huds.	meadow fescue	G	X		
Schismus arabicus Nees	Arabian schismus	G	X		
Schismus barbatus (Loefl. ex L.) Thell.	common Mediterranean grass	G	X		
Setaria viridis (L.) P. Beauv.	green foxtail; green millet; green bristlegrass	G	X		
Sida abutifolia Mill.	spreading fanpetals	F	X		
Sisymbrium irio L.	London rocket	F	X	X	
Sonchus asper (L.) Hill	spiny leaf sow-thistle	F	X		
Sonchus oleraceus L.	common sow-thistle	F	X		
Sorghum halepense (L.) Pers.	Johnson grass	G	X	X	
Tamarix aphylla (L.) Karst.	Athel tamarisk	S/T		X	
Tamarix chinensis Lour.	five-stamen saltcedar	S/T	X		
Taraxacum officinale F.H. Wigg.	common dandelion	F	X		
Tragus berteronianus Schult.	spiked bur grass	G	X		
Tribulus terrestris L.	puncture vine; devil's thorn; cat's head; caltrop	F	X	X	X
Trifolium repens L.	white clover; Dutch clover; ladino clover	F	X		
Verbascum thapsus L.	common wooly mullein	F	X	X	X
Verbascum virgatum Stokes	wand mullein	F	X		
Vinca major L.	bigleaf periwinkle	V/F	X		

[1]Plant name information is from the USDA Plants database (USDA, NRCS 2009).
[2]Species' primary growth form: G – grass; F – forb; S – shrub; T – tree; V – vine

Most of the exotic species documented in the parks do not need urgent action, either because they are not serious threats to the ecosystem (e.g., yellow bird-of-paradise), are fairly easily controlled (e.g., tree of heaven), or because they have apparently already reached their maximum invasive potential and are too extensive to be controlled by feasible measures (e.g., Bermuda grass, London rocket). Those that should be monitored and may need management action are:

> Chiricahua NM Plants: Maltese starthistle, Russian olive, watercress (may compete with water umbel if present), saltcedar, and bigleaf periwinkle (invasive in riparian habitats).
>
> Coronado NMem Plants: tree of heaven, yellow bird-of-paradise, Maltese starthistle, Lehmann lovegrass (management techniques can reduce its dominance), and athel tamarisk. Animals: bullfrog.
>
> Fort Bowie NHS Plants: Lehmann lovegrass (management techniques can reduce its dominance), and curly dock.

However, it is important to realize that many exotic species exist in low numbers for several decades after introduction before they become invasive. Therefore all exotic species need to be monitored for signs of increasing invasiveness.

4.1.3.8 Habitat Fragmentation

The theory of island biogeography, first described by MacArthur and Wilson (1967), has become a fundamental principal of ecology and conservation biology. The number of species supported on an island is directly proportional to the size of the island. (An island is defined as any patch of suitable habitat that is surrounded by a different habitat that is hostile to the subject species or community.) Smaller islands of habitat experience a higher rate of extinction, which is partly responsible for the lower species counts of smaller reserves.

There is ongoing debate as to whether a single large reserve is more or less effective at maintaining stable communities than several smaller reserves totaling the same area. There is, however, consensus on two points. For any given reserve, larger is more stable; and regardless of size, connectivity to other natural areas is important for long-term stability. For example, even the entire Chiricahua Mountain range may not be large enough to support sustainable populations of some highly mobile species such as jaguars, Mexican gray wolves, or thick-billed parrots. While parrots and other birds can fly from range to range, earth-bound species need corridors of natural habitat to migrate between patches of suitable habitat. Areas of heavy human impact such as cities and intensive agriculture need to be the islands that exist within a continuous matrix of natural habitat. If converted land completely surrounds even a large mountain range, the species richness in that range will erode over time.

As indicated in the above paragraph, different species have different susceptibilities to habitat fragmentation. Species of small size may maintain stable populations in a very small area (at least until the climate changes). Highly mobile species are generally more adaptable than less mobile ones. Even roads can fragment habitat for some species. While coyotes will regularly cross highways, bighorn sheep are known to be much shyer. And populations of slow-moving animals such as tortoises and snakes are devastated by well-traveled roads. (Desert tortoise populations are reduced up to a mile from roads, with almost no tortoises living within the first half mile. The same is almost certainly true for other slow-moving animals.)

Management at the ecosystem level over long time scales

Island biogeography theory corroborates the need for cooperative management of contiguous reserves. Until recently most resource management programs were narrowly focused on specific goals such as optimizing timber harvest, suppressing fires, or protecting endangered species. Since the early 1990s there has been increasing focus on ecosystem management (DeBano and Ffolliot 2004). This strategy is both scientifically sound and economically necessary. The goals of different narrow programs often conflict with one another, and working out acceptable resolutions can be difficult in the absence of large-scale temporal as well as areal perspectives. For example, a prescribed burn may be recommended for a specific area, but there is concern that a rare species within the area may be negatively impacted. However, other rare species may benefit from the same action. Looking at the issue on large temporal scale, the impact on the species will be temporary; the habitat will recover in time. Looking at a large areal scale, the existence of other protected refuges for the rare species may render the risk of the burn acceptable. But if every refuge is managed as an isolated project without regard to the others, management may be paralyzed and all of the habitat patches may deteriorate.

4.1.3.9 Fire Suppression / Altered Fire Regime

Fire History

Over the years, records of wild fire activity have been kept by various groups. A summary of the known fires to have occurred in Chiricahua NM, Coronado NMem, and Fort Bowie NHS is provided in Table 4.6.

Table 4.6. Known dates and sizes of fires that occurred in Chiricahua NM, Coronado NMem, and Fort Bowie NHS, Arizona.

Fire	Date	Acres
Chiricahua NM (outside park)		
Rattlesnake	1994	27,500
Coronado NMem		
Peak	June 1988	3700
Fort Bowie NHS		
Hubbard	June 1868	unknown
Beaumont	September 1887	unknown
Dump	April 1890	unknown
Apache Spring	May 1972	67
Bowie Peak	June 1973	9
Helen's Dome	July 1977	5
Bowie Mountain	July 1978	40
Cooper	August 1979	unknown
Bear	June 1984	1560
Bowie Mountain	October 1986	205
Bear I	May 1987	7
Bowie Mountain	May 1987	13
Dome	July 1988	690
Bowie	June 1989	unknown
Bowie Mountain	October 1992	4
Quillian	June 1994	0.1
Bowie	June 1996	unknown
Trailer	August 1996	unknown
Willow	May 1997	7

Grasslands and Desertscrub

Historically, wildland fire was common in the grassland vegetation communities of Arizona. It is difficult to determine exact historic fire frequencies because grasslands lack large trees that could contain fire scars. Historical accounts dating back to 1528, however, suggest that fires were large in size and occurred frequently (Humphrey 1958; Bahre 1991). The historic fire return interval for grasslands is thought to be around every 4 to 10 years (Kaib et al. 1996), which is more frequent than the fire return interval in desert scrub communities. The natural fire return interval for grasslands is long enough for grasses to recover, but not long enough for woody plants to become established before the next fire comes through (Brown and Smith 2000).

The extent to which fire occurred in southwestern grasslands varied geographically and is related to climatic variables such as seasonal and annual rainfall and physiographic variables such as elevation, slope and aspect (Archer 1994). Fire may have been rare in desert grasslands and limited in extent due to low biomass and lack of continuity of fine fuels (Hastings and Turner 1965; York and Dick-Peddie 1969).

Woody plants, such as mesquite and sagebrush were almost nonexistent in the grasslands prior to 1880 (McPherson 1995). Fire most likely prevented shrub establishment because most shrubs found in desert grasslands are not fire resistant, especially as seedlings. Therefore, fire was a significant factor in keeping grasslands from turning into shrublands (Humphrey 1958; Wright and Bailey 1982). Throughout the Southwest, shrubs have invaded former grasslands that historically may have had frequent fires (Wooten 1916; Leopold 1924; Humphrey 1958; Turner et al. 2003). When fires did occur, recovery of the burned areas was generally slow due to low water availability (Brown and Smith 2000).

The grassland and desert scrub vegetation communities in southern Arizona are significantly different from what they were prior to European-American settlement. There are now fewer native plants, more woody plants, and a more fragmented landscape. Perhaps the most significant factor affecting grasslands is the reduction in continuous fuel required to carry a fire (McPherson 1995). The result is that fires do not occur as often as they once did and are generally smaller in size (Bahre 1985). On the other hand, the most significant factor affecting desert scrub communities is the increase in nonnative grasses, which increases fire occurrence in locations where it once was rare (Brooks and Pyke 2001). The result is that common desert scrub plants and animals that are not adapted to fire can be negatively impacted when fires occur more frequently. Desertscrub communities (which do not occur in the parks) may take centuries to fully recover from a severe fire (Esque and Schwalbe 2002).

Once woody plants invade grasslands it is not possible to remove them by simply adding fire back onto the landscape because there is generally not sufficient grassy fuel to carry a fire with enough intensity to kill the woody species (McPherson 1995). Managers must consider herbicides or mechanical controls in conjunction with fire to have an effect. Further, the reintroduction of fire where it has been suppressed often facilitates the invasion of fire-adapted invasive plants that can prevent the reestablishment of historical fire regimes (Brooks and Pyke 2001).

Desert grasslands occur mostly in southeastern Arizona, and species composition varies across the geographic area (Abbott 1997); however, many of these grasslands have undergone extensive vegetation change (Turner et al. 2003). Southeastern Arizona, with hotter temperatures than northern regions, has more pure grasslands with only a minor shrub component. However, these same grasslands also have a higher density of nonnative grass species, which can alter fire regimes (Brooks and Pyke 2001). Although the exact cause of this vegetation change is under debate, it is apparent that fire is a driving force in shaping plant communities' structure and function. Compared to forest communities, grasslands are more flammable, can ignite and spread fire under a wider range of conditions, and are able to recover more rapidly following fire (D'Antonio and Vitousek 1992).

An area of open grassland is found in Chiricahua NM on the north side of Sugarloaf Mountain and may be attributed to a severe fire in the late 19th century (Reeves 1976). The NPS Sonoran Desert Network vegetation mapping crew reported that this area is now a manzanita thicket (Danielle Foster pers. comm. 2009). Prior to fire control, it is believed that some of the present mixed grass-scrub stands were open grassland kept free of shrub invasion by fire (Murray 1982).

Fire is an integral component of the natural resources and ecosystem at Coronado NMem, but little scientific data exists to describe fire effects and history (NPS 1997). Since the memorial was established, wildfires have been suppressed, and prescribed fire has not been used. Wildfires (natural and human caused) occur regularly in the Memorial (NPS 1997).

Although it is recognized that various uses of fire are part of the cultural history of Fort Bowie NHS and the surrounding areas, it is currently managed as a suppression zone for reasons pertaining to historic site protection as well as protection of human life and property within and beyond the park's boundaries (NPS 1999b). However, the management preference for the future is to resume burning to maintain the grassland (Danielle Foster pers. comm. 2009).

Interior Chaparral

Chaparral is highly fire-adapted, and nearly all the dominant species found in chaparral communities are well adapted to fire, whether through rapid resprouting or seedling establishment (Shantz 1947; Wright and Bailey

1982). Chaparral vegetation communities are highly flammable due to a large proportion of dead material and the presence of plants with high volatile oil content. These factors lead researchers to believe that fire is a natural and inevitable part of the chaparral vegetation community (Wright and Bailey 1982).

Historically, wildland fire was a natural but infrequent part of the chaparral vegetation community, probably occurring every 30-100 years (Wright and Bailey 1982; Pase and Brown 1994). Interior chaparral fires were generally high-severity events that covered large areas (Pase and Brown 1994). Although fires were infrequent, species in chaparral were well adapted to survive the passage of a fire, and some could not persist without it. The plants found in chaparral have well-developed root systems that can take in water and nutrients efficiently and allow quick regeneration after a fire, and some species found in this vegetation community require scarification for their seeds to germinate.

The chaparral vegetation community has changed somewhat since the early 1800s, and this vegetation community has been impacted by the suppression of wildland fires by humans. The exclusion of fire in Arizona chaparral has increased the density of plants (Huebner et al. 1999), as well as allowed chaparral to expand into other vegetation communities where it did not historically occur. Interior chaparral composed of evergreen sclerophyll species such as point-leaf manzanita, Tourney oak, Arizona white oak, pinyon pine, and alligator juniper is generally found in a mosaic pattern (Reeves 1976; Murray 1982). Pinyon pine and alligator juniper are considered to be recent invaders of chaparral since the inception of fire control (Murray 1982).The increased density of mature woody plants has in turn crowded out and prevented the growth of understory grasses and forbs (Pase and Brown 1994), a source of fuel for carrying fire. Livestock grazing plays a minor role in further reducing grassy surface fuels that carry fire (Bradley et al. 1992).

Chaparral is most prone to fires during periods of low live fuel moisture content. Low live fuel moisture in chaparral occurs in March to May when the plants are dormant, and from around August to October as the plants mature and harden for the coming winter. Conversely, when lightning is most active (late July through October), the moisture content in chaparral is at its highest because the plants are greening up. Therefore, it is very difficult to get a fire to start or spread during this time. When chaparral is drought-stressed, it burns very easily because the live fuel moisture is at or below dormancy levels.

Once a wildland fire ignites, however, it is carried by dead woody material and dense tree canopies, which burn hotter and faster than grassy fuels (Overby and Perry 1996). Thus, fires in interior chaparral are high-intensity and fast-spreading, especially under windy conditions. After an area of chaparral burns, it is less likely to burn for at least 20 years until enough dead fuel accumulates to support another fire (Tirmenstein 1999). However, other authors disagree. Chaparral is capable of carrying a fire after only five years of regrowth (Halsey 2005), and Moritz et al. (2004) concluded that the probability of a patch of chaparral burning is not correlated with its age.

Pinyon-Juniper and Oak Woodlands

Fire regime information is limited for pinyon-juniper and oak woodlands, particularly in areas dominated by evergreen oak species, because this vegetation community has been infrequently studied (Dolan and Rogstad 2008). The most current information suggests that fires in these woodlands occurred with more variability than the neighboring ponderosa pine forests.

Before major European-American settlement, pinyon-juniper and oak woodlands are thought to have had a mixed-severity fire regime, and it is likely that low, moderate and high-intensity, stand-replacing fires occurred (Swetnam et al. 1992). Fires may have burned for months at a time and burned thousands of acres (Swetnam 1988). On wetter sites, fine herbaceous fuels likely carried low-intensity fires while drier sites saw more stand-replacing fires carried by shrubby understories. The majority of these fires probably occurred in the summer (between May and late

July) when thunderstorms brought lightning ignitions. Historically, wildland fires are thought to have occurred every 5-40 years on most sites dominated by pinyon-juniper and oak woodlands while others went a century or more without a fire (Zouhar 2001).

The current fire regime is quite different from what is thought to have occurred historically. Improper livestock grazing management and fire suppression have altered the naturally complex pinyon-juniper and oak woodland stands. Currently, these stands are mostly uniform with respect to plant species, age and size. Improper livestock grazing management in conjunction with full fire suppression management strategies have decreased the amount of grasses that would naturally be present on a given site. As a consequence, the growth of woody species has been promoted. Now the extremely dense woodlands are difficult to ignite and do not carry fire well without the grassy understory. This leads to infrequent wildland fires occurring within this vegetation community. Periods of dry and hot weather, however, can create conditions in which the abundant woody fuel does ignite. Once it does, the exceptionally crowded woodlands can produce a high-severity, stand-replacing wildland fire. The natural mixed-severity regime that was present on the landscape prior to major European-American settlement has all but disappeared (Allen 1996; Heyerdahl and Alvarado 2003).

The Mexican oak-pine woodland, found throughout the Chiricahua NM, is probably a fire tolerant and fire maintained community although the fire regime is poorly understood (Marshall 1957); Murray (1982) suggests it may be similar to other pine communities. Few studies of fire history or fire effects in these woodlands have been conducted, but the presence and importance of fire within the various woodland community types has been noted (Leopold 1924; LeSueur 1945; Wallmo 1955; Marshall 1957, 1963; Niering and Lowe 1984).

Ponderosa Pine Forests

Historic records and tree-ring studies indicate that ponderosa pine forests did not have the same structure across the landscape. Due to many factors such as slope, aspect, topography, riparian corridors, and elevation, some sites supported dense stands of pine while other sites were more open and savanna-like. This mosaic across the landscape was a primary contributor to the overall biological diversity and ecological value of this forest type. Due to this variability, fire intervals and intensities also varied considerably (Swetnam et al. 1989). Although the stand structure across time and space was complex, it is likely that there were far more open ponderosa pine forests historically than there are now.

The more open stands of ponderosa pine evolved with frequent low- to moderate-severity surface fires and occasional stand-replacement fires (Bahre 1991; Ehle and Baker 2003; Pierce et al. 2004). Due to highly combustible leaf litter, an abundance of cured herbaceous vegetation, and a long season of favorable burning weather, including lightning as a natural ignition source, fire recurred every 2-10 years (Zwolinski 1996; Covington et al. 1997).

Larger, fire-resistant trees and sparse understory trees and shrubs dominated open stands of ponderosa pine. Frequent fires suppressed the growth of less fire-adapted shrubs while favoring grasses and forbs that resprouted from seeds or undamaged root structures after each burn.

The current fire behavior within ponderosa pine and pine-oak forests and associated woodlands of the southwest is quite different than those that existed during pre-settlement times (prior to extensive European-American settlement). Several factors contribute to this change, including local weather conditions and human activities on the landscape. Humans have suppressed wildland fires since the early 1900s, effectively excluding fire from the landscape. Fire exclusion has allowed forests to become excessively dense with extremely high fuel loads. The result is a stand structure that supports much longer flame lengths that either scorch or torch crowns and cause a high percentage of large tree mortality.

Additionally, local weather conditions play a role in fire behavior, and fire hazard across the ponderosa pine and pine-oak landscape in the Southwest is exacerbated by drought. Excessive fuel loads coupled with lower moisture and higher temperatures has resulted in more frequent, higher intensity, large acreage wildland fires throughout the Southwest. Past fire suppression activities allowed forests to become overgrown while lower than average precipitation makes dense forests more flammable. Driven by this fire behavior, stand replacement fires, which were once exceptions have now become the norm.

In Upper Hunt Canyon at Chiricahua NM, a nearly pure pine community exists consisting of ponderosa pine (*Pinus ponderosa*) with an open understory (Reeves 1976). Fire is believed to have frequently occurred in the pine type (Murray 1982).

Mixed Conifer Forests

A mixed-severity fire regime was characteristic of mixed conifer forests before European-American settlement, where low, moderate, and high-intensity, stand-replacing wildland fires occurred (Swetnam and Baisan 1996). This variety of fire intensity and occurrence created patchiness within a single stand of trees and contributed to the variety of species with differing fire tolerances in one forest. The natural fire season was during summer months when lightning ignited most fires, although there is evidence that Native Americans ignited fires in southeastern Arizona before European-American settlement (Seklecki et al. 1996).

There are a variety of opinions about what the historic fire return interval was in mixed conifer forests. It is thought that wildland fires occurred every 5-25 years. Fire regimes in mixed conifer forests are driven more by the amount of fuel moisture than the amount of fuel build-up because they are typically found on relatively moist sites.

Wildland fire occurrence in mixed conifer forests is less frequent than in ponderosa pine forests because of the cool, moist sites that mixed conifer stands occupy. Further, the fire regime in mixed conifer stands has not changed as much as the fire regimes elsewhere. Wildland fires range from moderate- to high-intensity and result in low, moderate and high fire severity on the landscape.

Currently, mixed conifer forests are growing in dense stands with little grassy understory, making fires hard to control (Allen 1996). The fine fuels that carry fires in these forests are made up of woody plants, twigs, branches, young conifer trees, and needles that dry quickly as they fall from trees and are easily ignited during summer thunderstorms.

Montane mixed conifer forest is found on mesic, north-facing slopes and canyon bottoms above 1,600 m (5,249 feet) (Murray 1982). This type is common in Totem and Hunt Canyons of the Chiricahua NM, and they have an overstory of pine and Douglas-fir (*Pseudotsuga menziesii*) and an oak understory (*Quercus* spp). Fire in this community is rare to non-existent, with some exceptions such as in Totem Canyon where low intensity ground fires seem to have occurred (Murray 1982; Swetnam et al. 1989).

Historical Fire Frequencies

Table 4.7 lists the historical fire frequencies for specific vegetation communities found in at the parks.

Livestock Grazing

Cattle and other livestock were introduced into grasslands around 1500 when European explorers brought cows, goats, and sheep to North America (Humphrey 1958). Large-scale cattle ranching in Arizona began in the late 1870s (Bahre 1991).

Livestock grazing has economic and cultural values that are important to individuals and communities. Impacts of livestock grazing on rangeland wildlife and ecosystem are largely dependent on the grazing practices that reduce the ability of the land to sustain long term plant and animal production (Wilson and MacLeod 1991), and may lead to the loss of grassland cover, mortality of plants, and increased erosion. Further, improper grazing practices and increased agricultural production may lead to habitat fragmentation and loss by promoting conditions favorable for shrub encroachment and through increased infrastructure development, such as roads,

Table 4.7. Historical fire frequencies for specific vegetation communities found within Chiricahua NM, Coronado NMem, and Fort Bowie NHS, Arizona (Swetnam et al. 1989; Baisan and Morino 2000; Dolan and Rogstad 2008).

Vegetation Type	Historical Fire Frequency	Location
Thornscrub	(Does not carry fire)	--
Sonoran Desertscrub	8 – 25 year intervals[1]	--
Chihuahuan Desertscrub	8 – 25 year intervals	Fort Bowie
Plains Grassland	2 – 15 year intervals	Chiricahua, Fort Bowie
Desert Grassland	50 – 100 year intervals rare to non-existent	Fort Bowie
Interior Chaparral	probably 30 – 100 year intervals poorly understood	Chiricahua
Great Basin Conifer Woodland	fire tolerant and fire-maintained poorly understood	Chiricahua
Madrean Oak Woodland	2 – 15 year intervals fire tolerant and fire-maintained fire frequency determines woodland structure poorly understood	Chiricahua
Madrean Pine-Oak Forest	4 – 10 year intervals frequent	Chiricahua
Petran Montane Conifer Forest	80 - >400 year intervals rare to non-existent	Chiricahua
Petran Sub-alpine Conifer Forest	50 – 200 year intervalsvaries greatly in severity and frequency	Chiricahua
Riparian Vegetation	--	--

[1]Large desert fires are caused entirely by invasive exotic species

water sources, and fences (Dinerstein et al. 2000). The effects of these land management activities are compounded by extended drought periods and altered hydrological function.

The effects of livestock grazing on biological communities continue to be hotly debated. While overgrazing is generally accepted as a major threat to biodiversity (Cooperrider 1991), less intense grazing can be ecologically sustainable and a useful management tool. High grazing intensity tends to drive grasslands toward conversion to shrubland (desertscrub) at lower elevations (below about 5000 feet), and savanna toward woodland at higher elevations (Curtin 2008). But other authors conclude that moderate grazing prevents succession from grassland to shrubland or woodland in grazing-adapted ecosystems (Watkinson and Ormerod 2001). Some authors document disturbances including plant consumption, nitrogen redistribution (urination and defecation), soil compaction, and increased erosion (Belsky and Blumenthal 1997; Bokdam 2001). Others argue that grazing can increase biodiversity (Milchunas et al. 1998; Perevolotsky and Seligman 1998) and increase habitat heterogeneity (Wisdom and Whitford 1981).

Some of the conflicting conclusions may result from the fact that many studies were conducted on small scales and in degraded habitats (Brussard et al. 1994; Brown and McDonald 1995). The long-term, large-scale studies recently begun in intact grassland on the Diamond A Ranch in New Mexico (Curtin 2008) should produce more reliable and useful information for land managers in the Sky Island Region.

Park Histories

Chiricahua NM – National Park Service. December 1996. Natural and Cultural Resources Management Plan, Chiricahua National Monument. National Park Service, U.S. Department of the Interior.

“There is only one private parcel in the monument, a tract of 2.42 acres, located in the northeast corner which is part of an adjacent 100 acres patented mining claim (King of Lead Mine). The property is currently utilized for grazing, but in the past has been mined.

"The Sulphur Springs valley to the west of the park continues to be used for cattle grazing and agricultural production. Large scale growth in development of real estate and other activities has not occurred in the valley to this date.

"There are indications that native plant communities have been altered by human activities, particularly (a) suppression of lightning-ignited fires, (b) invasion of nonnative plants, (c) air pollution and (d) historic grazing activities. Trespass cattle grazing is an occasional problem. The monument is bordered by private ranches and Forest Service grazing allotments. The rugged terrain makes it difficult to maintain and monitor boundary fences. Some sections of the monument boundary have not been fenced."

Chiricahua NM – 1995; Land-use Impacts in the Sky Islands; p.9; Diana Hadley; Bajada 1995:3(3); National Biological Service; Cooperative Park Studies Unit/The University of Arizona, Tucson, Arizona.

"Grazing, the second most important impact following mining and mineral extraction, reached a peak during the 1890s, when Colin Cameron, an Eastern entrepreneur, ran up to 17,000 head of cattle from his headquarters at the San Rafael de la Zanja, a former Mexican-period land grant on the Santa Cruz River. Under the extremely overstocked range conditions (70 head to the section), Cameron's cattle undoubtedly roamed to the higher elevations (of the Chiricahua Mountains). His overstocking coincided with a series of droughts that began in 1885 and peaked in 1892 and 1902. During the droughts, local ranchers, including the Parkers of Parker Canyon in the Huachucas, sent their cowboys out to cut branches from deciduous trees, particularly ash and cottonwood, in a desperate attempt to keep their cattle from starving. Overstocking, combined with drought remediation practices such as these, had severe negative impacts on forested areas, leading to the downcutting of water courses, increased erosion, disappearance of cienegas and wetlands along the Santa Cruz River, the depletion of extensive stands of carrizo, or reeds – formerly so dense that cattle could hide in them – and marked a decrease in the number of migratory waterfowl."

Coronado NMem – Ruffner, G.A. and R.A. Johnson. 1991. Plant Ecology and Vegetation Mapping at Coronado National Memorial, Cochise County, Arizona. Technical Report No. 41. Cooperative National Park Resources Studies Unit, School of Natural Resources, University of Arizona, Tucson, AZ. 73pp.

"The lands encompassed by CORO have been subject to multiple human land use practices including grazing, mining, woodcutting, fire suppression, exotic plant introduction, settlement and visitation.

"Grazing in the San Pedro River valley and Huachuca Mountains area began in 1540 with the introduction of horses, cattle and other domestic livestock by Coronado. Subsequently, there was about a 100-year lapse until the mid-1600s, after which the San Pedro watershed has probably been grazed regularly. By 1700 cattle and other livestock occurred in southeastern Arizona and adjacent Sonora (Wagoner 1952). Cattle probably ranged into the Huachuca Mountains by the early 1800s when ranches began operating at and near their base (Hoffmeister and Goodpaster 1954).

"The number of cattle in southeastern Arizona increased dramatically following the American Civil War and cessation of Indian raids. Arizona's cattle industry was centered in the extensive grasslands of southeastern Arizona. In 1880, 35,000 domestic cattle roamed throughout Arizona (20,000 south of the Gila River). Over one million cattle were in the area by 1890 (Wagoner 1952). One ranch grazed up to 40,000 cattle in or near the Huachuca Mountains (Hoffmeister and Goodpaster 1954).

"Grazing within Coronado NMem is now limited to that which does not interfere with recreation development, as per legislation establishing the memorial. The NPS now has long-term grazing management through allotment plans, minimizing overgrazing in the memorial. The two existing grazing allotments, Joe's Spring and Montezuma, occur primarily in the grasslands of the eastern portion of the memorial. Both allotments are administered by the USDA Forest Service through NPS.

"Joe's Spring Allotment consists of 1,369 acres and lies entirely within the memorial. This allotment occurs in the northeastern portion of the memorial, and extends from Montezuma Peak eastward along the northern boundary to the eastern boundary of the memorial and south to the township boundary just north of the entrance road. Since 1942, grazing in the Joe's Spring Allotment has been 432 animal unit months (AUMs), whether grazed seasonally or yearlong (Coronado National Forest 1989). Currently, grazing is restricted to mid-November through mid-July. The only water source on this allotment is a tank bounded by a corral. This allotment will be subject to a new grazing plan in 1991.

"The Montezuma Allotment consists of 2,067 acres, which includes a state land lease to the east of the memorial. Within the memorial, this allotment lies directly south of the Joe's Spring Allotment and extends south to the international border and east to the memorial boundary, and continues onto the state land lease. This allotment excludes the Montezuma Ranch inholding along the eastern edge of the memorial.

"Grazing in the Montezuma Allotment is set at 504 AUMs (Coronado National Forest 1986). The only water source on this allotment is a stock tank, which was formerly surrounded by a corral. This allotment is grazed yearlong. A new grazing management plan was initiated in 1988 for this allotment.

Grazing has caused extensive changes in the composition and structure of biotic communities in the memorial and throughout southeastern Arizona. Extensive cattle grazing in the late 1800s, however, was apparently only an interacting component along with long-term shifts in seasonal distribution of precipitation and freezing temperatures, to cause these vegetation changes and the accompanying cycles of erosion and arroyo cutting. Hastings and Turner (1965) concluded, 'About cause then, the best answer seems to be that the new vegetation-if one may call it that – has not arisen from climatic variation alone, but in response to the unique combination of climatic and cultural stresses imposed by the events of the past eighty years; that climate and cattle have united to produce it.' Fire suppression and eruptions of lagomorph and rodent populations have also been suggested as possible processes causing change in southwestern plant communities."

Coronado NMem – 1997. Resource Management Plan. Coronado National Memorial, National Park Service, U.S. Department of the Interior. Unpublished Internal Document.

"Grazing has been monitored with two production-utilization evaluations prepared by the US Forest Service in two allotments. A range site invention was prepared under contracted arrangements with the Range Management School, University of Arizona. The SOAR staff is preparing an allotment plan and environmental assessment."

Fort Bowie NHS – April 2000 Natural and Cultural Resources Management Plan, Fort Bowie National Historic Site, National Park Service, U.S. Department of the Interior; Unpublished Internal Document. 100pp.

"Cattle grazing: There is ongoing cattle grazing on the NPS property itself, as well as surrounding public and private lands. Impacts include vegetation reduction, changes in vegetation composition, soil disturbance, and erosion." (This is no longer true. –Danielle Foster pers. comm. 2009).

Fort Bowie NHS – Carrie Dennett. 1998. Fire History and Effects: A literature review for Fort Bowie National Historic Site. Fort Bowie National Historic Site, National Park Service, Department of the Interior. Unpublished internal document. 42pp.

"Fort Bowie National Historic Sites lies within two grazing allotments: the Silverstrike Allotment and the Apache Springs Allotment. The Silverstrike Allotment has been in operation since the early 1880s, and includes 380 acres which lie within the park boundary. Cattle are currently grazed on this allotment year round. The history of the Apache Springs Allotment is not well documented; the first known grazing privileges were bought around 1970. Cattle are currently grazed on this allotment, which includes 590 acres of park land, from November 1 to March 31.

"It is suspected that the combination of 80 years of fire suppression and grazing of livestock caused the influx of the many species of mesquite into the historic site. Historic photographs of the 1860s show the fort area primarily as a grassland; today, mesquite has outcompeted grama grass in most areas, becoming the dominant species."

4.2 Park-wide Conditions

4.2.1 Chiricahua NM

A rigorous quantitative assessment of ecosystem health is not practical at this time. However, the NRCA team concludes that Chiricahua NM is currently in very good health. Table 4.8 summarizes the current condition of indicators and their respective reference conditions at Chiricahua NM. Indicators are summarized at the park-wide level. Insufficient information was available to assess conditions at the management area level. The sections below are organized by ecosystem characteristic then resource and give information on the indicators for each resource, including the reference conditions, data sources, and confidence levels.

Our professional opinions are tempered by significant data gaps, and several actual and possible future threats are identified in this report.

Of the regional threats identified in section 4.1.3, the most significant ones for Chiricahua NM are climate change, exotic species, and fire. No exotic species invasions are known to be occurring at this time.

4.2.1.1 Supporting Environment

Climate

Climate drives and regulates many ecological, biological, and physical processes and influences the distribution of plant and animal species. Long-term patterns in temperature and precipitation are primary factors in limiting potential ecosystem structure and function (Whitford 2002). Other limiting factors include the length, intensity, seasonality, and variability of weather events. Climate also affects the susceptibility of an ecosystem to disturbance and extreme weather events can be a source of disturbance (i.e. flood). Because of the influence of climate and weather on ecological processes, temperature and precipitation are included as indicators.

The "Chiricahua NM" COOP station (part of the National Weather Service cooperative observer program) dates back to 1909 and is the primary source of long-term climate data within Chiricahua NM. In general, Chiricahua NM experiences a climate typical of the region. While there is a large gap in data from 1919 to 1948, the record was nearly complete between 1948 and 2005 (Davey et al. 2007). However, the record is incomplete from 2005—2008. For the 1971 to 2000 historic average period, the Chiricahua NM COOP station met the Western Meteorological Organization's standard for the number of missing values. Therefore, we utilize the historic average (1971-2000) as the reference condition and report recent climate in comparison to the historic averages (1971-2000) from the station (Table 4.9).

While the recent precipitation record is incomplete, reliable data are available from 2000-2004 and for 2009 (Table B.2; WRCC 2010b). Precipitation in the past ten years was variable but typically lower than the 30-year historic average (1971-2000; Figure 4.20). Between 2000 and 2010 (excluding years with one or more months with five or more days of missing data), the average annual precipitation at Chiricahua NM was 16.6 inches, lower than the 1971-2000 average of 20.95 inches and the overall station average(1909-2010) of 19.1 inches (Figure 4.20). In 2003, Chiricahua NM received less than eight inches of precipitation while 2000 was the only year to exceed the historic average with an annual precipitation total of 21.91 inches. Precipitation totals for the remaining recent years with reliable climate infor-

Table 4.8. Condition indicators in Chiricahua NM.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Supporting Environment						
Climate	Temperature	Average June maximum temperature	above to near average	30-yr avg. (1971-2000)	low	Gray 2008
		Average January minimum temperature	above to near average	30-yr avg. (1971-2000)	low	
	Precipitation	Average annual precipitation	below average	30-yr avg. (1971-2000)	low	
Air Quality	Air Quality	Wet Deposition	significant concern for nitrogen, moderate for sulfur	< 3 kg/ha/yr nitrogen or sulfur	high	NPS ARD 2009
		Ozone	moderate	< 75 parts per billion (ppb)	high	
		Visibility	moderate	Current Group 50 – Estimated Group 50 Natural < 2 dv	high	
Surrounding Land Use	Land Use	Percent Natural vs. Converted	5% converted (w/in 30km of park)	unknown	n/a	n/a
Surface Water Quantity	Water Quantity	Spring flow	7 of 8 springs flowing in June 2010	Flow present in June	moderate	Authors' professional opinion
Groundwater Quantity	Water Quantity	Depth to Groundwater	Undetermined	No significant declines from historic levels	n/a	Authors' professional opinion
Water Quality	Water Quality	Various	Good	viaries by measure	high	Arizona Department of Environmental Quality
Soils	Soil Quality	Surface soil aggregate stability	40% rated as "very stable"	> 20% rated as "very stable"	moderate	Hubbard et al. 2010
		Bare ground cover	Average 5% bare ground cover	bare ground cover < 30%	moderate	Gori and Schussman 2005
		Biological soil crust cover	Average < 1% cover	unknown	moderate	n/a
		Soil biological health	Unknown	unknown	n/a	n/a

Table 4.8. Condition indicators in Chiricahua NM.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Biological Integrity						
Rare, Endangered, Threatened, or Candidate Species	Lesser long-nosed bat (LLB)	Monitoring of roosts and of agave (food plants)	Present in park	No decline in numbers over time; no decline in agave plants over time.	Moderate	LLB are migratory and only present in SE Arizona in the late summer as they begin their southbound migration. They rely solely on agaves for food at this point in their life cycle, and on caves and mines for roosts.
	Mexican gray wolf	n/a	Extirpated	Stable population in Madrean Archipelago	High	n/a
	Mexican spotted owl	Monitoring population numbers	Unknown	No decline in numbers over time	High	
	Jaguar	n/a	Extirpated	Habitat suitable for natural recolonization		
	Chiricahua leopard frog	n/a	Extirpated	Stable population reestablished	High	
Keystone Species	Pines (*Pinus* spp.)	Areal cover, size/age-class distribution	Moderate mortality from bark beetle infestations	Stable populations of several species	High (with good monitoring)	Observation by authors
	Oaks (*Quercus* spp.)	Areal cover, size/age-class distribution	Apparently stable populations	Stable populations of several species	High (with good monitoring)	Authors' professional opinion
	Large predator ecological niche	Number of species and population levels	Three of the four species have been extirpated; only mountain lions remain	At least two species established with stable populations. Monitor large herbivores for possible overpopulation; manage if necessary.	High	NPS I&M database
Species of management concern			Largely unknown	Be aware of which non-T&E species may need attention.		Data gap; existing lists are probably incomplete.

Table 4.8. Condition indicators in Chiricahua NM.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Extirpated Species	Unknown	Unknown	Unknown	unknown	n/a	n/a
Invasive Species	Exotic plants	Number of species; areal coverage trends	Numerous established species, none exhibiting invasive behavior	Established exotics not increasing; no new species	Moderate	NPS I&M database
	Exotic animals	Number of species; population trends	Few established species; populations low and stable	Established exotics not increasing; no new species	Moderate	NPS I&M database
Vegetation Communities	Madrean oak woodland	Species composition, areal coverage	Well represented, healthy	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Madrean pine-oak Forest	Species composition, areal coverage	Well represented, significant pine mortality from bark beetles	Self-sustaining with minimal intervention	High	Authors' professional opinion
	"Krummholz Chaparral"	Species composition, areal coverage	Small area? healthy	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Desert Grassland	Species composition, areal coverage	Small area in park, significant number of exotic grasses present	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Riparian communities	Species composition, areal coverage	Small area in park, healthy but stretches overgrown with trees	Self-sustaining with minimal intervention	Moderate	Authors' professional opinion
Ecological Processes	Fire	Unknown	Unknown	unknown	n/a	n/a
	Grazing	Unknown	Unknown	unknown	n/a	n/a

Table 4.9. Historic climate averages (1971-2000) for Chiricahua NM weather station, which meets the World Meteorological Organization's standard for historic climate calculations. Data from NOAA (2002).

Climate Characteristic	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Max. Temp. (°F)	57.5	60.5	66.1	73.3	81.4	90.2	89.1	86.2	83.5	75.3	64.8	57.8	73.8
Mean Temp. (°F)	44	46.3	50.7	56.7	64.3	73.3	74.8	72.9	69.7	61	50.5	44.3	59
Min. Temp. (°F)	30.4	32.1	35.2	40	47.2	56.4	60.5	59.6	55.8	46.7	36.2	30.8	44.2
Precipitation (in)	1.56	1.34	1.34	0.47	0.44	0.94	4.12	3.83	1.91	1.73	1.31	1.96	20.95

mation (2001-2002, 2004, and 2009) were between 16 and 20 inches (WRCC 2010b). Approximately 46 percent of the annual precipitation fell during the summer monsoons during July, August, and September 2000-2010, similar to the historic average for the station (WRCC 2010b; NOAA 2002).

While the recent temperature record is incomplete for Chiricahua NM, reliable data are available from 2000-2004 (Table B.3; WRCC 2010b). Between 2000 and 2004, maximum temperatures typically exceed 80°F from May through September and maximum temperatures generally approached or exceeded 90°F in June and July. Such values are typical of the maximum temperatures recorded at the Chiricahua NM station since 1909. The average maximum temperature for June from 2000-2004 was 91.4°F, which is over 1°F warmer than the 1971-2000 historic average (90.2°F) and nearly 1°F warmer than the overall historic average (1909-2010) maximum temperature for June (90.5°F; Figure 4.20). However, there is not a significant trend in the June maximum temperature for the Chiricahua NM station.

From 2000 and 2004, snow was occasional and minimum temperatures were typically at or near freezing from December through February, similar to the historic average period (1971-2000). The average minimum temperature for January from 2000-2004 was 31.5°F, which is over 1°F warmer than the 1971-2000 average (30.4°F) and the overall station average minimum temperature (29.9°F) for January (Figure 4.20). However, there is not a significant trend in the January minimum temperature for the Chiricahua NM station.

Overall, Chiricahua NM temperature indicators (June maximum temperature and January minimum temperature) were slightly above average compared to their respective reference conditions. January minimum temperatures and June maximum temperatures from 2000-2004 were 1°F warmer than their respective 30-year averages. The precipitation indicator was below average compared to the 30-year average (1971-2000). However, the author's confidence in this assessment is low due to a lack of reliable data for 2005-2008 for precipitation and for 2005-2009 for temperatures.

Air Quality

Air quality affects vegetation, wildlife, and water as well as scenery, vistas, and viewsheds. Because understanding changes in air quality can help interpret changes in park resources and other indicators as well as evaluate compliance with legislative requirements, air quality is included as an indicator. There are three main components used to measure air quality: visibility, ozone, and atmospheric deposition. Chiricahua NM is designated as a Class I airshed under the Clean Air Act and contains air monitoring stations to measure atmospheric deposition, visibility, and ozone. The NPS Air Resources Division administers an extensive monitoring program to measure air quality in NPS units. In addition, they developed an approach for assessing the condition of air quality within NPS units (NPS ARD 2009). The NPS Sonoran Desert Network and NPS Air Resources Division summarize air quality data collected

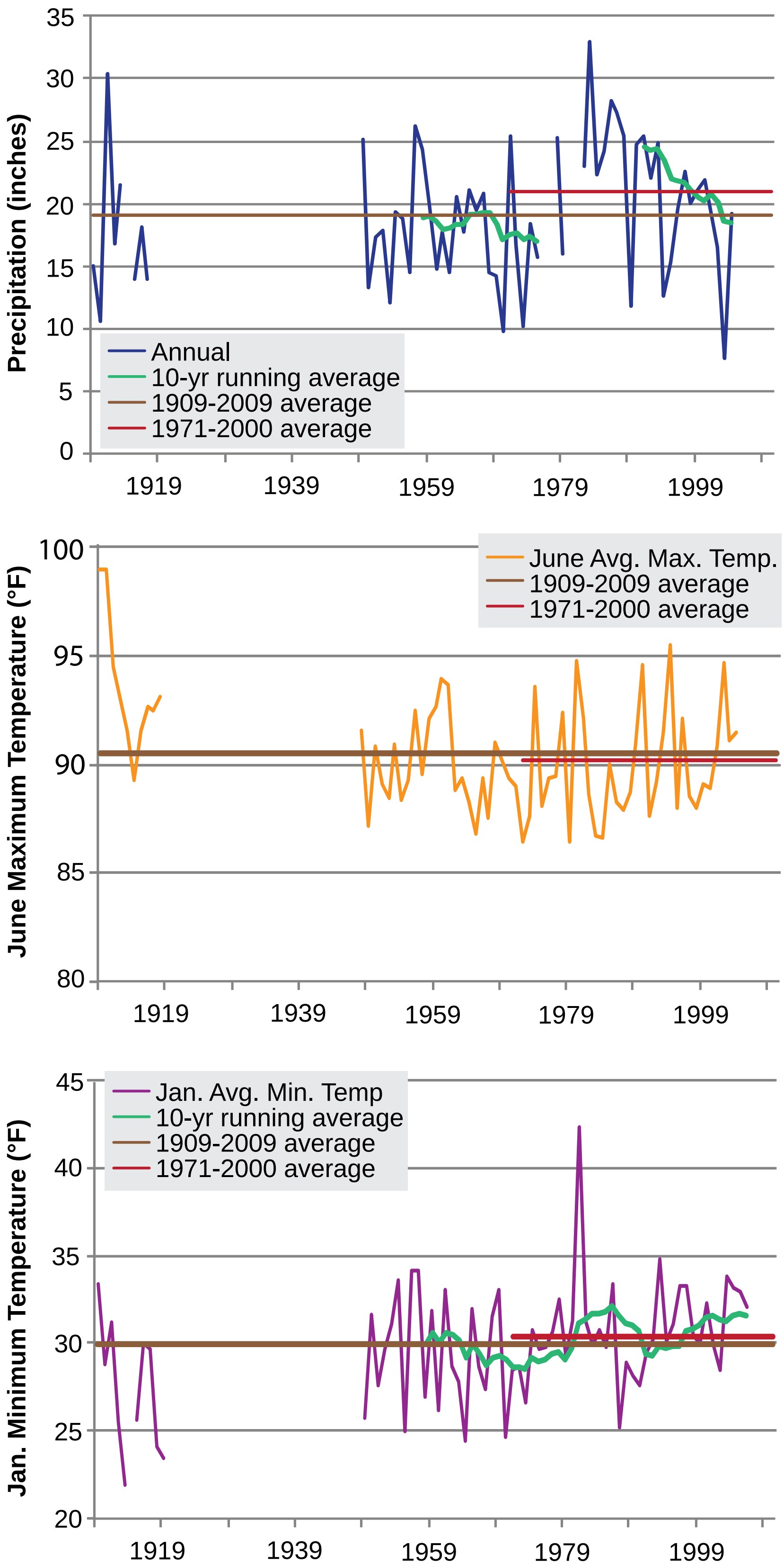


Figure 4.20. Annual precipitation (top), average June maximum temperatures (middle), and average January minimum temperatures (bottom) at Chiricahua NM, 1909-2009 (WRCC 2010b; NOAA 2002)

at Chiricahua NM (Table B.8), described in subsequent paragraphs. Because air quality is measured at Chiricahua NM, the author's confidence in this assessment of air quality is high.

The Clean Air Act confers special protection of visibility in Class I areas. Light extinction, the total of light scattering and light absorption components, on the 20% haziest and clearest days is reported as deciviews, a visual index analogous to the sound decibel index. Pristine conditions score zero on the deciview scale and as visibility decreases, the deciview number increases. At Chiricahua NM, natural visibility conditions are 2 deciviews (dv) on the 20% clearest days and 7 dv on the 20% haziest days. Results from 2008 show that the 20% clearest days scored as 3.94 dv while the 20% haziest days were 12.23 dv. Long-term trends at Chiricahua NM show significant improvements in visibility on the 20% clearest days and non-statistically significant increases on the 20% haziest days (NPS SODN 2010a).

Visibility is also assessed using the "Group 50" visibility conditions of current conditions compared to "natural" conditions. Group 50 is defined as the mean of visibility observations falling within the 40th to 60th percentiles, as expressed in deciviews (dv). The visibility condition is expressed as

Visibility Condition = Current Group 50 – Estimated Group 50 Natural

The NPS Air Resources division defines descriptive ratings based on the Visibility Condition calculation. Visibility is rated as "good" if the Visibility Condition is less than two, "moderate" if the Visibility Condition is between two and eight, and "significant concern" if the Visibility Condition is greater than eight (NPS ARD 2009). The 5-year average for Visibility Condition at Chiricahua NM from 2004-2008 was 6.1 dv (NPS ARD 2010bb). Therefore, the visibility condition at Chiricahua NM is rated as "moderate" (NPS SODN 2010a).

A national standard for ozone of 75 parts per billion (ppb) averaged over an 8-hour period was set by the Environmental Protection Agency (EPA) to protect the environment and human health (Mau-Crimmins and Porter 2007). Areas are in compliance with the standard if the three-year average of the fourth-highest daily maximum 8-hour concentrations measured over the course of a year do not exceed 75 ppb. The NPS Air Resources Division rates ozone as "good" if ozone concentrations are equal to or less than 60 ppb, "moderate" if for ozone concentrations between 61 and 75 ppb, and "significant concern" if ozone concentrations are greater than 76 ppb (NPS ARD 2009).

The 5-year average (2004-2008) fourth-highest eight-hour ozone concentration is 69.2 ppb (NPS ARD 2010bb). Since 1990, the ozone level at Chiricahua NM has not exceeded the EPA standard. However, the ozone level has been close consistently to the standard (NPS ARD 2009). Several plant species at Chiricahua NM are known to be sensitive to ozone, such as ponderosa pine (*Pinus ponderosa*) and skunkbrush (*Rhus trilobata*) (NPS SODN 2010b). Based on the NPS Air Resources Division's reference condition and the 2004-2008 average fourth-highest eight-hour ozone concentration (69.2 ppb), ozone at Chiricahua NM is rated as "moderate."

According to the NPS Air Resources Division, parks with wet deposition less than 1 kg/ha/yr are in "good" condition, 1-3 kg/ha/yr are in "moderate" condition, and greater than 3 kg/ha/yr have a "significant concern" for deposition. Additionally, parks with ecosystems potentially sensitive to nitrogen or sulfur are adjusted up one category (NPS ARD 2009). Between 2004 and 2008, the average total wet deposition of nitrogen was 2.7 kg/ha/yr and the average total wet deposition of sulfur was 1.3 kg/ha/yr (NPS ARD 2010b). Since vegetation at Chiricahua NM may be sensitive to nitrogen deposition, nitrogen deposition condition is a "significant concern" (NPS SODN 2010c) while sulfur deposition is rated as "moderate."

Land Use

Chiricahua NM is nested within the Chiricahua Mountains and the larger Madrean Archipelago, which contains a variety of land uses. Land use is the human use of landscapes, such as residential, agricultural, and developed areas. A change in housing density, and associated roads, can fragment the landscape, decrease the size of the functional ecosystems, reduce connectivity among native habitat patches, isolate species in small patches, and increase the contrast in vegetation structure and function along park boundaries. Such changes can have major implications ecosystem properties including fire frequency, species distributions, water quality, air quality, habitat fragmentation, and soil erosion (Gross et al. 2009). Because understanding the extent and configuration of land use can provide insight into the status and trend of park resources, land use is an indicator. However, there are no reference conditions for land cover in the Madrean Archipelago.

The NPScape landscape dynamics monitoring project provides landscape-level data to evaluate land use surrounding NPS units. Data provided by the NPScape project includes a suite of standardized, national-scale products (e.g., land cover, housing density, population density, and other socioeconomic data) for a 30 kilometer (km) area around each park unit, called the "local area" (Gross et al. 2009). The local area for Chiricahua NM includes Fort Bowie NHS. Within a 30km radius of Chiricahua NM, approximately 40% of the land is managed by the federal government (24% U.S. Forest Service, 14% Bureau of Land Management, 1.7% National Park Service), 40% is private land, and 20% is state trust lands (Arizona State Land Department; NPS 2010c; USGS 2009).

Current estimate of housing density reflect generally low housing density around Chiricahua NM and suggest that less than 20% of the local area has dwellings. Most of the developed area has very low housing density of less than 1.5 units per square kilometer (NPS 2010b; Theobald 2005). The federal and state lands limit development in the area. Housing density projections for 2100 are modest but do not include the potential for the sale of and subsequent development on state trust lands. Projections suggest that the total area developed will remain similar to the 2010 estimate. However, the density of some of the developed areas will increase modestly (NPS 2010b; Theobald 2005).

Nearly 95% of the area surrounding Chiricahua NM is considered "natural" (based on 2001 the National Land Cover Database; Figure 4.21). Only 5% of the land was converted and developed or used as pasture or for crop cultivation (Figure 4.21, NPS 2010d; Homer et al. 2004; Fry et al. 2009). Table B.9 describes the National Land Cover Database land cover classes and reclassification for calculating percent of natural and converted land cover.

Groundwater

The NPS Sonoran Desert Network initiated groundwater monitoring at Chiricahua NM in 2007. Figure 4.22 shows depth to water measurements in at three wells within Bonita Canyon. Recent depth to water measurements appear fairly stable. While periodic water level measurements have been ongoing only for a short time, current water levels are very similar to those measured when the wells were drilled. In the Headquarters area, depth to water was 12.5 ft in 1956, while the average depth to water over the 2008 to 2010 monitoring period is 11.2 ft. In the campground area, depth to water in 1962 was 28.5 ft, compared to an average of 27 feet between 2008 and 2010. At Faraway Ranch, depth to water in 1979 was 18.5 ft, compared to an average of 17.1 feet between 2008 and 2010. In every case, water levels are higher than they were when these three wells were constructed decades ago. Figure B.1 shows the groundwater monitoring locations.

Seeps and Springs

Seeps and springs are critical surface water sources in the semi-arid Madrean Archipelago. They are important sources of water for plants and animals and represent the primary interface between groundwater and surface water. Therefore, the presence of flow at seeps and springs in June is included as an indicator.

In June 2010, the NPS Sonoran Desert and Chihuahuan Desert Networks collaborated on a seeps, springs, and tinajas inventory across their network parks. Field crews surveyed eight seeps and springs at Chiricahua NM: Bear Scat Spring, Bonita Park Spring, Garfield Spring, Kraft Spring, Roadside Seep,

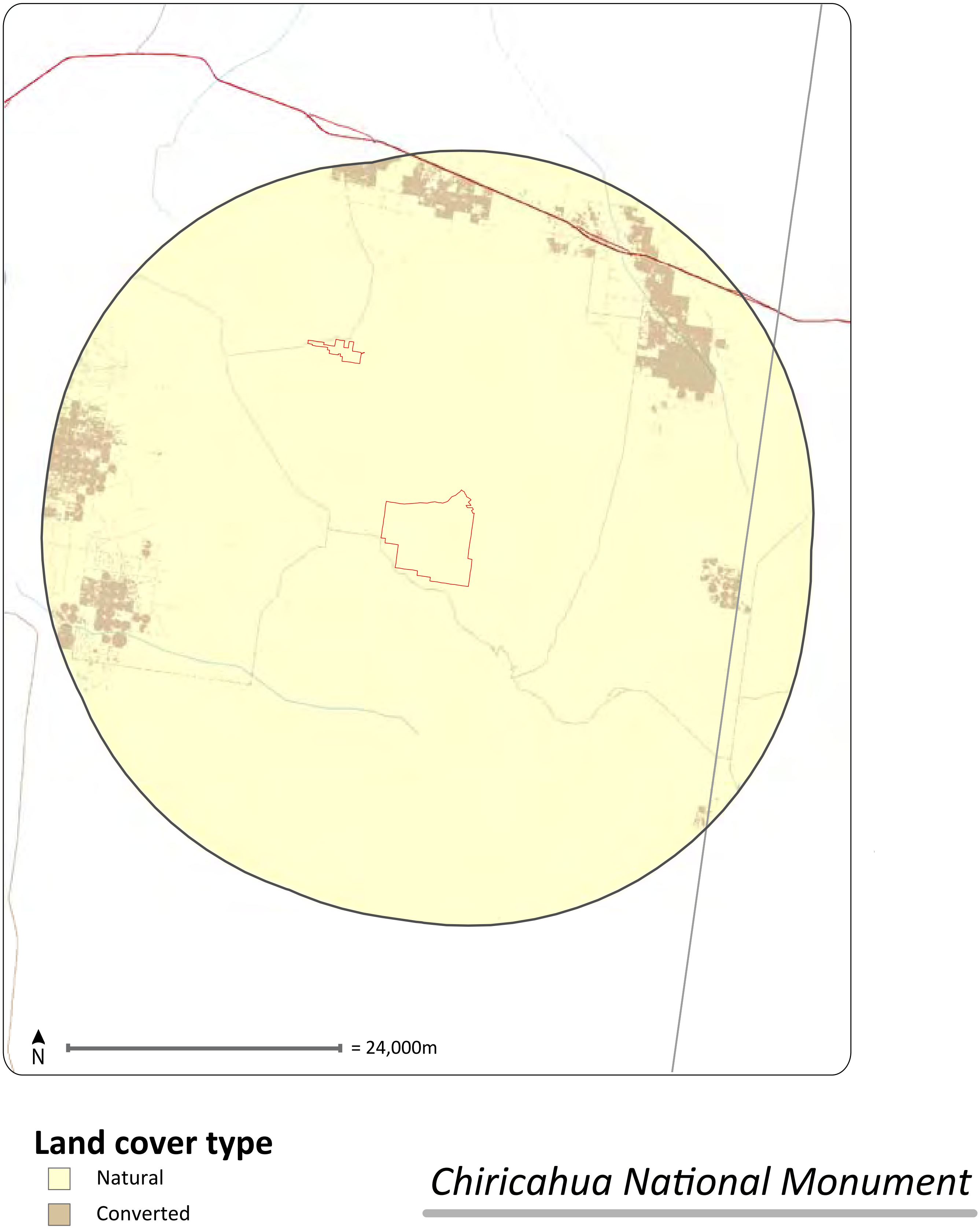


Figure 4.21. Natural versus converted land cover within 30 kilometers of Chiricahua NM (NPS 2010d; Homer et al. 2004; Fry et al. 2009).

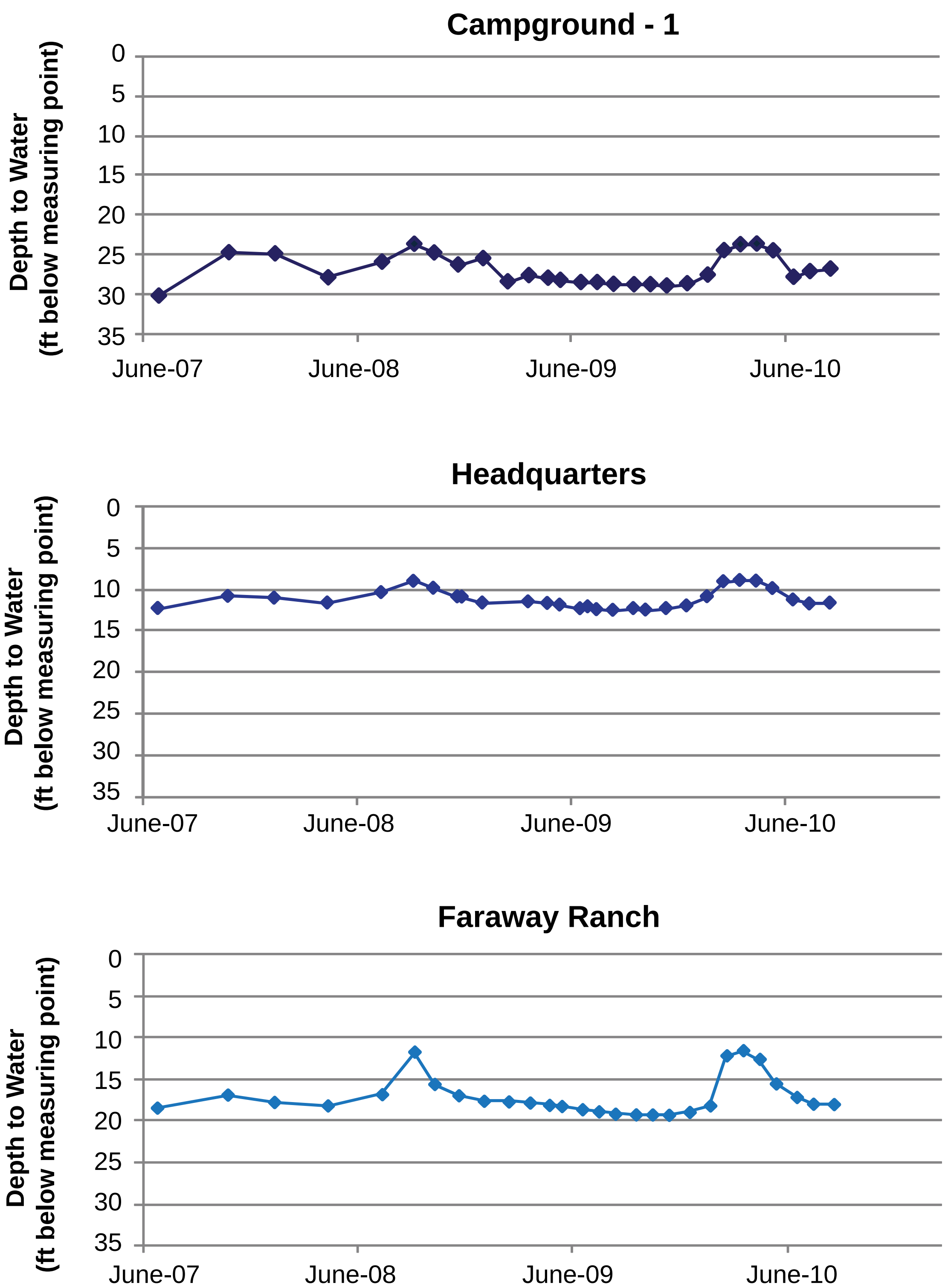


Figure 4.22. Depth to water measurements in Bonita Canyon, Chiricahua NM (NPS SODN 2011).

Shake Spring, Silver Spur Spring, and Superintendent Spring. The crews collected data on hydrology, isotopes, geology, and invertebrates at most of the seeps and springs (NPS SWNC 2010). Abundance and diversity of invertebrates were not assessed in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

NPS field crews measured discharge at the springs using the volumetric method (Table B.10). Crews captured the flow by constructing a small earthen dam using local materials, inserting a tube into the dam, and collecting the water flowing from the tube in a container with known volume. The total amount of time required to completely fill the container was recorded and then flow rate was calculated (NPS SWNC 2010).

Water was observed flowing at seven of the eight seeps and springs. Flow was not observed at Kraft Spring. Discharge was measured at seven seeps and springs (Table B.10) and ranged from 0.0075 liters/second (Garfield Spring) to 0.07 liters/second (Bear Scat Spring; NPS SWNC 2010). Data from 2010 has not undergone quality assurance/quality control, so the author's confidence in the exact discharge results is low. However, the author's confidence that the data represent presence of flow in June, prior to the monsoon, is moderate.

During the NPS Sonoran Desert Network inventory, abundance and diversity of invertebrates at six springs in Chiricahua NM but not in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

Water Quality

Water quality sampling was conducted at Chiricahua NM as part of the Baseline Water Quality Inventory (Brown 2005). Analysis results from the water quality inventory are shown in Table B.11. For the purpose of establishing applicable water quality criteria, designated use classification guidelines are prescribed in Arizona Administrative Code Title 18, Ch. 11 Department of Environmental Quality – Water Quality Standards. All of the surface waters sampled in the SODN Level I Baseline program are designated as Aquatic and Wildlife (A&W) waters, with those located at elevations over 5,000 ft designated as cold waters (A&Wc) and those located below 5,000 ft designated as warm waters (A&Ww). Elevations and designated uses for each site are provided in Table B.12.

As shown in Table B.11, analyses of three samples from each of two perennial springs at Chiricahua National Monument (Brown 2005) were reviewed. Samples were obtained at Shake Spring and an unnamed spring above Shake Spring, both located in the upper reaches of the Bonita Creek drainage. Since the elevation of Shake Spring is about 5,690 ft and the unnamed spring above Shake Spring is about 5,710 ft (Brown 2005), the designated use of these waters is classified as A&Wc.

Piper plots show the relative proportions of major anions and cations for spring and seep samples. Figure B.4 contains piper plots showing major ion proportions for Chiricahua NM, Coronado NMem and Fort Bowie NHS, individually and in combination with samples from all three parks.

Stiff diagrams are graphical shapes representing milliequivalents per liter (meq/L) of major anions and cations for individual water samples. These diagrams allow for rapid comparison of water types and concentrations among many samples. Stiff plots for the Chiricahua NM samples are shown in Figure B.5, stiff plots for Fort Bowie NHS are shown in Figure B.6, and stiff plots for Coronado NMem are shown in Figure B.7. The plots shown in Figure B.5 clearly illustrate the similarity of the calcium-sodium-bicarbonate (Ca-Na-HCO_3) water types for the two Chiricahua NM sample sites throughout the year.

The pH, shown in Figure B.8, ranges from 6.7 to 7.5 for the samples from these springs. Dissolved oxygen was below the 6 mg/L standard for all of the sampling events (Figure B.9). Relatively low concentrations of the major ions are present, average total dissolved solids (TDS) for the six Chiricahua NM samples are 256 mg/L and average specific conductance is 357 uS/cm °C (Figure B.10). Alkalinity and hardness are also low (Figure B.11). Low concentrations are attributed to the situation of the springs in the upper reaches of the watershed and relatively low solubility of the silicate-rich rhyolitic tuff substrate at the park. The primary contributing aquifer for these springs is the densely welded pumiceous ash-flow tuff that blankets the park in this watershed. To the extent that some of these waters originate in the southwest strand of the Apache Pass Fault (Drewes 1982), water quality may also be influenced by the composition of rocks encountered in the nearby reaches of that fault.

Compared to samples from springs at Fort Bowie NHS and Coronado NMem, both springs at Chiricahua NM showed elevated levels of dissolved fluoride (Figure B.12), beryllium (Figure B.13), and manganese (Figure B.14) but the reported concentrations for these would not be considered to be especially high in a broader context. None of those parameters are addressed in the standards for A&Wc designated use. The presence of workings from the King of Lead in an upstream tributary drainage may or may not be related to the presence of these parameters at these springs. Analysis of water samples collected in 1996 showed particularly elevated levels of cadmium and zinc at King of Lead workings (Higgins 1996).

The NPS water quality baseline report (NPS WRD 1997a) reviewed water quality data from 13 stations in and near Chiricahua NM. None of the samples reported from water bodies inside the park exceeded applicable water quality criteria.

In summary, natural water sources sampled at Chiricahua NM were reviewed and compared to State of Arizona standards for Aquatic and Wildlife designated use. All locations failed to meet the standard for dissolved oxygen at least once (Figure B.9). Sources of dissolved oxygen to waters include gaseous exchange at the water surface and the liberation of oxygen by photosynthesis. Possible explanations of the presence of low dissolved oxygen in these waters include the following processes:

1. The spring waters sampled originate as groundwater, which is typically depleted in dissolved oxygen relative to flowing surface waters. Groundwaters are often depleted in dissolved oxygen due to reduced exposure to air and sunlight relative to surface waters. Infiltrating groundwaters are depleted in dissolved oxygen by organic decay metabolism in soils and by the oxidation of inorganic minerals present in a reduced state, such as pyrite and siderite. Hem (1985) cites values of dissolved oxygen in groundwaters sampled in southern Arizona between 2-5 mg/L. Many of the samples were reported to have dissolved oxygen values in this range (Figure B.9).

2. Many of the springs sampled have limited surface areas for gaseous exchange, and are sometimes stagnant, reducing opportunity for oxygen enrichment by gaseous exchange.

3. Aerobic biotic metabolic processes including decay and activity of bacteria that oxidize dissolved metals such as iron and manganese, and abiotic oxidation of dissolved minerals in the springs themselves may consume dissolved oxygen at a more rapid rate than oxygen can be replenished by gaseous exchange at the surface or through photosynthesis.

4. Maximum daytime temperatures in the warm months can be high, limiting the solubility of oxygen in small water bodies that can heat up rapidly.

Insofar as the processes listed above are believed to be reasonable explanations for the presence of low dissolved oxygen levels in the springs sampled, and that the processes are naturally occurring, the presence of dissolved oxygen in these waters below state criteria is not considered to be problematic or requiring attention. Waters impacted by mining activities do not appear to be negatively impacted in the case of dissolved oxygen at any higher rate than do waters distant from mining impact areas.

All of the remaining sampled parameters were in compliance with A&W criteria for surface waters. For these reasons, water quality at Chiricahua NM is considered to be in good condition.

Soils

As described in Section 4.1.1, dynamic soil characteristics and soil biota can change over relatively short periods of time and are directly influenced by management actions. Soil surface cover, biological soil crust composition and cover, and surface soil aggregate stability are important dynamic soil properties and relate to soil and site stability and hydrologic function. While biological soil crusts are an important component of the vegetation and soil community at Chiricahua NM, reference conditions for biological soil crust composition and cover are undetermined for the Madrean Archipelago. Hubbard et al. (2010) proposed reference conditions for soil cover and surface soil aggregate stability for Fort Bowie NHS. Because no other relevant reference conditions have been proposed for the Madrean Archipelago, we adopt those from Hubbard et al. (2010) and include soil aggregate stability and soil cover as indicators. The soil cover reference condition focuses on the percent cover of bare ground and adopts work done by the Bureau of Land Management and The Nature Conservancy at Las Cienegas National Conservation Area. Gori and Schussman (2005) set the desired amount of exposed (no vegetative cover) bare ground cover at 30% to minimize erosion potential. Since Chiricahua NM is not grazed, we use a stricter reference condition of 30% bare ground cover regardless of vegetative cover.

Hubbard et al. (2010) proposed a reference condition for surface soil aggregate stability, as measured using a modified wet aggregate stability field method, based on professional judgment and Herrick et al. (2005). In the soil aggregate stability field method, samples are scored from 1 to 6, with 6 being the most stable. Hubbard et al. (2010) suggested a reference condition where the percentage of soil aggregates in the "6" class should be greater than 20%.

The NPS Sonoran Desert Network initiated vegetation and soils monitoring at Chiricahua NM in 2007. Fourteen permanent field-monitoring sites were established and sampled in 2007, 13 in 2008, nine in 2009, and nine in 2010 (Figure B.20; NPS SODN 2010d). The Sonoran Desert Network uses a multi-year sampling strategy where one-fifth of the sites are sampled within a given year with the entire complement completed after five field seasons. Thus, data collected in 2007-2010 represent only 75% of the sampling for the 5-year period. Therefore, it is critical that the reader understands that this data is presented with a moderate confidence rating for its ability to assess current conditions.

At each site, the Sonoran Desert Network established permanent, 20 × 50-m sampling plots. Vegetation sampling was done in conjunction with soil cover and stability measures along six 20-m transects within a plot utilizing the line-point intercept method with points spaced every 0.5m. Soil cover was recorded by substrate class (e.g., rock, gravel, litter, bare ground, etc.), with biological soil crust cover recorded to morphological group (e.g., light cyanobacteria, dark cyanobacteria, lichen, moss). Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2005) at up to 48 locations per plot. Samples were scored from 1 to 6, with 6 being the most stable. Hubbard et al. (in review) details the monitoring techniques.

Based on the 45 collected by the NPS Sonoran Desert Network from 2007-2010, soil substrate cover was dominated by plant litter and duff. Gravel, rock, and bedrock also significantly contributed to soil cover. Less than 10% of the soil surface was bare soil (Table 4.10; NPS SODN 2010d). Biological soil crusts account for less than 1% of the substrate cover. See Table B.13 for plot-specific results.

NPS Sonoran Desert Network crews sampled soil aggregate stability at 42 of the 45 monitoring sites. Overall, surface aggregate stability averaged 3.97. Samples collected under vegetation tended to be more stable than those collected from areas without canopy cover (Table 4.11). Thirty-four of the 42 sites had an average surface soil stability rating of at least 3 (somewhat stable; Table B.14). Two sites had an average surface soil stability rating of less than 2 (somewhat unstable).

Overall, over 40% of the samples were in the 6 (very stable) category (Table 4.11).

Overall, Chiricahua NM soil indicators meet their respective reference conditions. The areas of the park included in the NPS Sonoran Desert Network 2007-2009 monitoring effort appear to be well-protected from soil erosion. The overall soil aggregate stability of the sites was moderate, suggesting that the sites can resist erosion and that the soil-biotic system is functioning. However, several of the sites had low stability ratings, suggesting potential local erosion risks. Total cover of the sites was very high, with little exposed bare soil. Biological soil crust cover was low (<1%). A large amount of cover comes from litter, and duff, which could leave the sites susceptible to erosion if fire or drought removed those materials. This assessment represents three-quarters (75%) of the intended sample size for monitoring sites. Therefore, confidence in the data and its ability to assess current conditions is moderate.

Table 4.10. Park-wide soil surface cover (mean % cover by class and standard error), Chiricahua NM. Summary of 45 plots of data from 2007-2010 Sonoran Desert Network monitoring (NPS SODN 2010d).

Soil Substrate	% Cover Mean ± SE
Bare ground	7.6% ± 1.0
Gravel	15.4% ± 1.6
Litter and Duff	47.5% ± 2.8
Rock and Bedrock	25.0% ± 2.2
Plant base	4.3% ± 0.4
Biological Soil Crust	0.18% ± 0.08

4.2.2.2 -Biological Integrity

Major Biomes

Chiricahua NM is covered mostly with Madrean oak woodland and Madrean pine-oak forest, with a little desert grassland in the western margin. There is a very small area of riparian vegetation. Chiricahua NM is one of only three NPS areas that contain Madrean biota (the others are Coronado NMem and Guadalupe Mountains National Park).

Biological Diversity

Chiricahua NM supports the high biodiversity that is expected for the region (Table ES.2). Although the monument is a small percentage of the area of the Chiricahua Mountains, its 803 documented and strongly suspected plant taxa comprise about two-thirds of the estimated 1200 taxa in the Chiricahua flora. It has nearly 40% of the estimated flora of the Arizona portion of the Sky Island Archipelago (AZ SIA). It has nearly 42% of the AZ SIA region's reptiles and amphibians (50 of 120). However, it has substantially fewer herps than the other two smaller parks, probably because its higher elevation is too cold for many reptiles. That it has nearly 70% of the known AZ SIA mammals (69 of approx. 100) is quite remarkable. The 192 documented bird species seems low, especially considering that smaller Coronado NMem and tiny Fort Bowie NHS have almost as many. Either Chiricahua NM has less habitat diversity than the other two parks, or substantially more birds may yet be found here.

Table 4.11. Park-wide soil surface aggregate stability class (mean and standard error) and proportion of samples in "very stable" (=6) category, Chiricahua NM. Summary of 42 plots of data from 2007-2010 Sonoran Desert Network monitoring (NPS SODN 2010d).

	Average Soil Stability[1] Mean ± SE	% samples in category 6[1] Mean ± SE
All samples (n=1392)	3.97 ± 0.11	43.6% ± 3.8
Under vegetation (n=1033)	4.23 ± 0.06	46.9% ± 3.8
No vegetation (n=359)	3.22 ± 0.11	32.3% ± 4.7

[1]Samples rated on stability scale from 1-6. Category 1 = very unstable; category 6 = very stable

Biological Corridors

See section 4.1.2.9 for the general treatment of biological corridors. Chiricahua NM is mostly montane, so it is probably more important as part of the southward summer/fall migration corridor of birds and bats than it is as a spring corridor.

Exotic Species

Although there are numerous exotic species established in the parks, the great majority do not appear to be invasive (e.g., they are not causing significant ecological harm or posing a health hazard). Some are invasive, but are already so widespread and well established that control is probably not feasible, e.g., Bermuda grass, filaree, and London rocket. Most of these species also seem to have attained their maximum invasive potential; they probably are not increasing further, at least not into undisturbed habitats. Those that should be monitored and may need management action are: Maltese starthistle, Russian olive, watercress (may compete with water umbel if present), saltcedar, and bigleaf periwinkle (invasive in riparian habitats).

Rare and Endemic Biocommunities and Species

Chiricahua NM has populations of the rare plants *Hexalectris warnockii* and *Perityle cochisensis*; more possibilities are listed in Table 4.3. Rare vertebrates that are currently or were historically present are jaguar, lesser long-nosed bat, Mexican spotted owl, and Chiricahua leopard frog (Table 4.8). The lists are probably incomplete; see discussion of data gaps in Section 5.1.

Ecosystem Health

The grassland in and adjacent to Chiricahua NM is mapped as native and considered healthy (although we observed some Lehmann's lovegrass along the road).

The woodlands and forests away from heavily trafficked areas are presumed to be mostly healthy, because they have not been subjected to major disturbances such as heavy grazing, logging, or extensive crown fires for several decades. However, many pines in Chiricahua NM are dying from infestations of at least two bark beetle species. Outbreaks are correlated with weakening of trees by drought and lack of hard frosts that control beetle populations. This does not necessarily indicate an unhealthy community; but if this phenomenon is a result of long-term climate change, significant alteration of the species composition of the forest can be expected. The forest along the creek and road is very dense. While high density of trees can develop naturally, it is likely a result of long-term fire suppression. Extensive areas of dense trees and buildup of dead biomass increases the probability of crown fire. Catastrophic fire is a significant threat to park facilities located in these dense vegetation patches. The deep shade probably also greatly reduces the diversity of water-dependent species that could be supported by Silver Spur Spring. (The proximity of the road also has a negative impact, e.g., from people and vehicles disturbing and running over wildlife.)

A small area adjacent to the parking lot at Massai Point is heavily trampled by visitors. There is a dense network of footpaths that are devoid of understory vegetation. Some of it is on rather steep slopes. Erosion may not be a problem because the area is mostly rock, but it should be monitored. The damaged area is quite limited and seemingly not a problem at this time.

4.2.2 Coronado NMem

A rigorous quantitative assessment of ecosystem health is not practical at this time. However, the NRCA team concludes that Coronado NMem is currently in very good health. Table 4.12 summarizes the current condition of indicators and their respective reference conditions at Coronado NMem. Indicators are summarized at the park-wide level. The sections below are organized by ecosystem characteristic then resource and give information on the indicators for each resource, including the reference conditions, data sources, and confidence levels.

Our professional opinions are tempered by significant data gaps, and several actual and possible future threats are identified in this report.

Table 4.12. Condition Indicators in Coronado NMem.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Supporting Environment						
Climate	Temperature	Average June maximum temperature	average	30-yr avg. (1971-2000)	low	Gray 2008
		Average January minimum temperature	above to near average	30-yr avg. (1971-2000)	low	
	Precipitation	Average annual precipitation	average	30-yr avg. (1971-2000)	low	
Air Quality	Air Quality	Wet Deposition	moderate	< 3 kg/ha/yr nitrogen or sulfur	moderate	NPS ARD 2009
		Ozone	moderate	< 75 parts per billion (ppb)	moderate	
		Visibility	moderate	Current Group 50 – Estimated Group 50 Natural < 2 dv	moderate	
Surrounding Land Use	Land Use	Percent Natural vs. Converted	7% converted (w/in 30km of park w/in U.S.)	none	n/a	n/a
Surface Water Quantity	Water Quantity	Spring flow	unknown	Flow present in June	n/a	Authors' professional opinion
Groundwater Quantity	Water Quantity	Depth to Groundwater	stable	No significant declines from historic levels	high	Authors' professional opinion
Water Quality	Water Quality	Various	Good	viaries by measure	high	Arizona Department of Environmental Quality
Soils	Soil Quality	Surface soil aggregate stability	45% rated as "very stable"	> 20% rated as "very stable"	low	Hubbard et al. 2010
		Bare ground cover	Average 5% bare ground cover	bare ground cover < 30%	low	Gori and Schussman 2005
		Biological soil crust cover	Average 0% cover	unknown	n/a	n/a
		Soil biological health	Unknown – data gap	Undefined	n/a	n/a

TTable 4.12. Condition Indicators in Coronado NMem.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Biological Integrity						
Rare, Endangered, Threatened, or Candidate Species	Lesser long-nosed bat (LLB)	Monitoring of roosts and of agave (food plants)	Present in park	No decline in numbers over time; no decline in agave plants over time.	Moderate	LLB are migratory and only present in SE Arizona in the late summer as they begin their southbound migration. They rely solely on agaves for food at this point in their life cycle, and on caves and mines for roosts.
	Mexican gray wolf	n/a	Extirpated	Habitat suitable to sustain species	High	n/a
	Mexican spotted owl	Monitoring population numbers	Unknown	No decline in numbers over time	High	
	Jaguar	n/a	Extirpated	Habitat suitable for natural recolonization		
	Jaguarundi	n/a	Reported as historically present, but unlikely to be true	n/a	High	Absence of specimens or other reliable records (photos, prints) from AZ or Sonora.
	American peregrine falcon	Presence of stable population	Currently present			
	Ocelot	Monitor for immigration from Mexico	Historically present			
Keystone Species	Oaks	Species composition and areal coverage	Healthy	Oak woodland on southern slope is a reference site	High	Authors' professional opinion
	Pines	Species composition and areal coverage	Insufficient data	Self-sustaining populations		
	Large predator ecological niche	Number of species and population levels	Three of the four species have been extirpated; only mountain lions remain	At least two species established with stable populations. Monitor large herbivores for possible overpopulation; manage if necessary.	High	NPS I&M database

TTable 4.12. Condition Indicators in Coronado NMem.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Species of management concern	Huachuca springsnail	Monitoring populations	Unknown if present in CORO	Stable populations (if present)	High	
			Largely unknown	Be aware of which non-T&E species may need attention.		Data gap; existing lists are probably incomplete.
Extirpated Species						
Invasive Species	Exotic plants	Number of species; areal coverage trends	Numerous established species, none exhibiting invasive behavior	Established exotics not increasing; no new species	Moderate	NPS I&M database
	Exotic animals	Number of species; population trends	Few established species; populations low and stable	Established exotics not increasing; no new species	Moderate	NPS I&M database
	Bullfrog	Presence of established population	Reported as present	Eradication desirable	Moderate	Todd Esque pers. comm.
Vegetation Communities	Plains Grassland	Species composition, areal coverage	Well represented, healthy	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Desert Grassland	Species composition, areal coverage	Areal coverage and condition uncertain; ecotonal with oak woodland	Self-sustaining with minimal intervention	Low	Authors' professional opinion
	Madrean Oak Woodland	Species composition, areal coverage	Well represented, healthy	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Madrean Pine-oak Forest	Species composition, areal coverage	Well represented, healthy	Self-sustaining with minimal intervention	High	Authors' professional opinion
	Riparian communities	Species composition, areal coverage	Small area in park, needs careful management	Self-sustaining with minimal intervention	Low	Authors' professional opinion
Ecological Processes	Fire	Unknown	unknown	n/a	n/a	n/a
	Grazing	Unknown	unknown	n/a	n/a	n/a
Special Themes						
Border Impacts	Channel Morphology	Bankfull width	Unknown	Less than 10% change in bankfull width	Unknown	Natural Channel Design, Inc. 2008.
	Unlisted roads/ trails	Extent of unlisted roads and trails	unknown	n/a	n/a	n/a

Border pressures are probably the greatest threat to Coronado NMem. The impacts of border activity have not been fully quantified but monitoring and research are underway. Border activity is, or could become, one of the main stressors in the park. The most likely early indicator of habitat degradation from the disturbance is invasion of exotic species. If any become established, they could spread rapidly along the fence, roads, and trails. Most other stressors such as climate change and regional population growth are beyond the control of park managers.

4.2.2.1 Supporting Environment

Climate

Climate drives and regulates many ecological, biological, and physical processes and influences the distribution of plant and animal species. Long-term patterns in temperature and precipitation are primary factors in limiting potential ecosystem structure and function (Whitford 2002). Other limiting factors include the length, intensity, seasonality, and variability of weather events. Climate also affects the susceptibility of an ecosystem to disturbance and extreme weather events can be a source of disturbance. Because of the influence of climate and weather on ecological processes, temperature and precipitation are included as an indicator.

The "Coronado NM Headquarters" COOP station dates back to 1960 and is has a nearly complete record from 1960 through 2004. However, the record is incomplete from 2005—2008. For the 1971 to 2000 historic average period, the Coronado NM Headquarters COOP station met the Western Meteorological Organization's standard for the number of missing values. Therefore, we report recent weather in comparison to historic averages from the station (Table 4.13; NOAA 2002).

Coronado NMem experiences a climate typical of the region. Between 1971 and 2000, the average annual precipitation at Coronado NMem was 21.18 inches. Approximately one-half of the annual precipitation fell during the summer monsoons during July, August, and September (NOAA 2002). While the recent precipitation record is incomplete, reliable data are available from 2000-2004 and for 2009 (Figure 4.23 ;Table B.4; WRCC 2010c). Precipitation in the past ten years was variable but typically near the 30-year historic average (1971-2000). In 2002, Coronado NMem received less than 17 inches of precipitation and 2000 (30.61 inches) and 2004 (22.45) were the only years to exceed the historic average. Precipitation totals for the other recent years with reliable climate information (2001, 2003, and 2009) were between 17.5 and 19.5 inches (WRCC 2010c).

Between 2000 and 2010, there is reliable temperature data for all of 2000-2004 and for some months during 2005-2010. Maximum temperatures typically exceed 80°F from May through September and maximum temperatures generally approached or exceeded 90°F from June through September (Table B.5). Such values are typical of the maximum temperatures recorded at the memorial station since 1960. The average maximum temperature for June for years with reliable data (2000-2004, 2007-2009) was 91.2°F, which is similar to overall station average maximum temperature for June (91.4°F; Figure 4.23) and the 1971-2000 historic average (91.6°F). There is not a significant trend in the June

Table 4.13. Historic climate averages (1971-2000) for Coronado NM Headquarters weather station, which meets the World Meteorological Organization's standard for historic climate calculations. Data from NOAA (2010)

Climate Characteristic	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Max. Temp. (°F)	58.3	62.3	67.5	74.7	82.1	91.6	89.8	86.9	84.7	76	65.8	58.7	74.9
Mean Temp. (°F)	45.3	48.3	52.3	58.6	66.1	74.9	75.4	73.1	70.4	61.9	52	45.8	60.3
Min. Temp. (°F)	32.3	34.2	37	42.5	50	58.1	60.9	59.2	56.1	47.8	38.2	32.9	45.8
Precipitation (in)	1.87	1.63	1.21	0.45	0.32	0.64	4.49	3.74	1.79	1.95	1.11	1.98	21.18

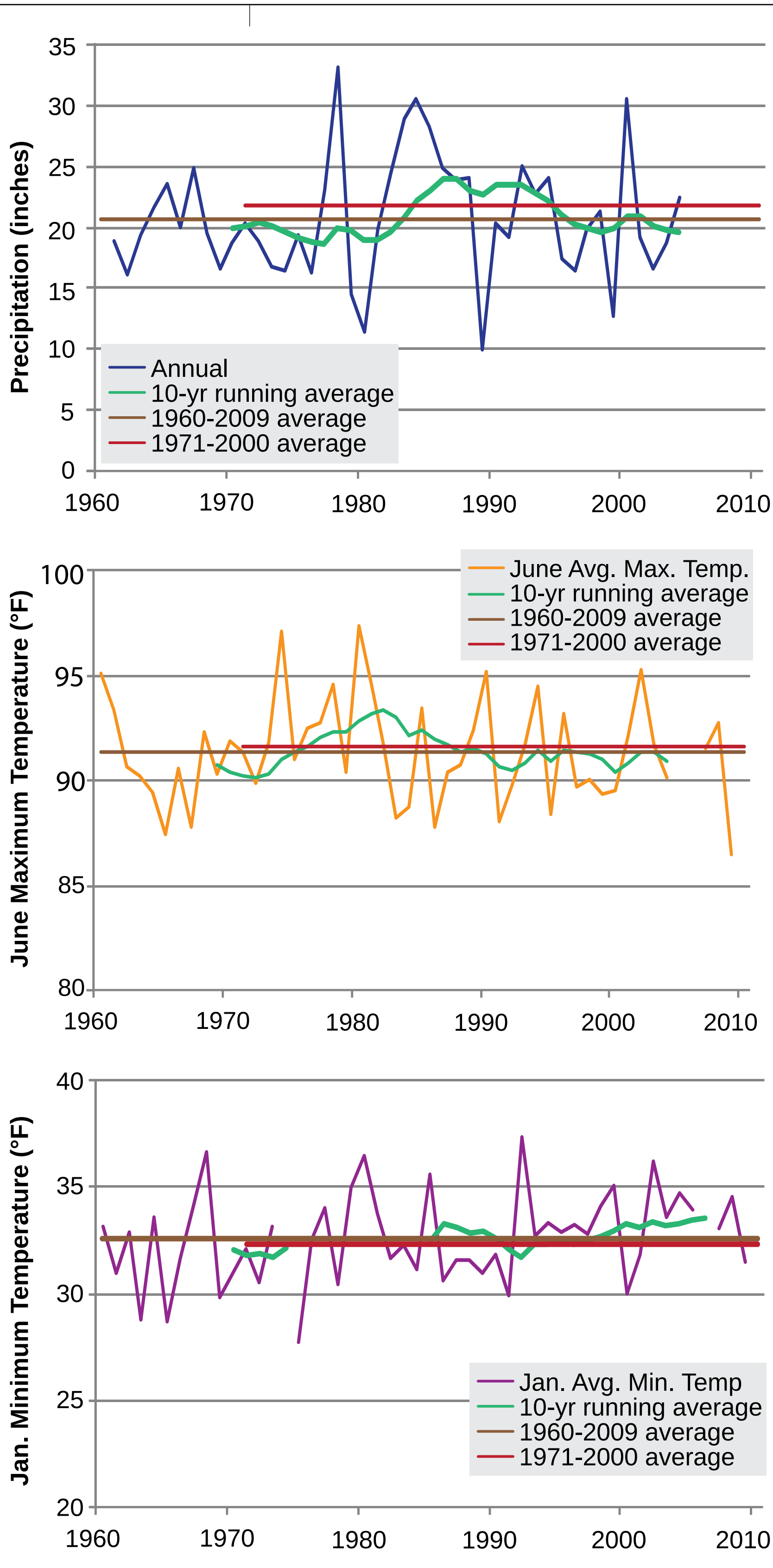


Figure 4.23. Annual precipitation (top), average June maximum temperatures (middle), and average January minimum temperatures (bottom) at Coronado NMem headquarters, 1960-2009 (WRCC 2010c; NOAA 2002).

maximum temperature for the Coronado NMem headquarters station.

From 2000 and 2010, snow was occasional and minimum temperatures were typically at or near freezing from December through February, similar to the historic average period (1971-2000). The average minimum temperature for January for years with reliable data (2000-2006, 2008-2010) was 33.5°F, which is over 1°F warmer than the 1971-2000 average (32.3°F) and nearly 1°F warmer than overall station average minimum temperature (32.6°F) for January (Figure 4.23). There is not a significant trend in the January minimum temperature for the Coronado NMem headquarters station.

Overall, Coronado NMem temperature indicators (June maximum temperature, and January minimum temperature) were at or slightly above average compared to their respective reference conditions (30-year averages from 1971-2000). January minimum temperatures were greater than 1°F warmer than the 30-year average while the June maximum temperatures were near the 30-year average. The precipitation indicator was near average compared to the 30-year average (1971-2000). However, the author's confidence in this assessment is low due to a lack of reliable data for precipitation and temperature from 2005-2010.

Air Quality

Air quality affects vegetation, wildlife, and water as well as scenery, vistas, and viewsheds. Because understanding changes in air quality can help interpret changes in park resources and other indicators as well as evaluate compliance with legislative requirements, air quality is included as an indicator. There are three main components used to measure air quality: visibility, ozone, and atmospheric deposition. The NPS Air Resources Division administers an extensive monitoring program to measure air quality in NPS units. In addition, the NPS Air Resources Division models 5-year air quality estimates for all NPS units (Table B.8; NPS ARD 2010b). The NPS Sonoran Desert Network and NPS Air Resources Division summarize air quality data collected at Coronado NMem, described in subsequent paragraphs. Because

NPS Air Resources Division models air quality data for Coronado NMem, the author's confidence in this assessment is moderate.

The Environmental Protection Agency set a national standard for ozone of 75 parts per billion (ppb) averaged over an 8-hour period to protect the environment and human health (Mau-Crimmins and Porter 2007). Areas are in compliance with the standard if the three-year average of the fourth-highest daily maximum 8-hour concentrations measured over the course of a year do not exceed 75 ppb. The 5-year average (2004-2008) fourth-highest eight-hour ozone concentration modeled for Coronado NMem is 69.4 ppb (NPS ARD 2010b). The NPS Air Resources division rates ozone as "good" if ozone concentrations are equal to or less than 60 ppb, "moderate" if for ozone concentrations between 61 and 75 ppb, and "significant concern" if ozone concentrations are greater than 76 ppb (NPS ARD 2009). Based on the 2004-2008 fourth-highest eight-hour ozone concentration modeled for Coronado NMem of 69.4 ppb and the reference condition set by the NPS Air Resources Division, ozone at Coronado NMem is rated as "moderate." However, the ozone condition is close to being a "significant concern."

According to the NPS Air Resources Division, parks with wet deposition less than 1 kg/ha/yr are in "good" condition, 1-3 kg/ha/yr are in "moderate" condition, and greater than 3 kg/ha/yr have a "significant concern" for deposition. Between 2004 and 2008, the modeled average total wet deposition of nitrogen was 1.9 kg/ha/yr and the average total wet deposition of sulfur was 0.9 kg/ha/yr (NPS ARD 2010b). Therefore, nitrogen and sulfur deposition conditions are rated as "moderate."

One of the methods that the NPS Air Resources Division uses to assess visibility is the deviation of current "Group 50" visibility from "natural" conditions. Group 50 is defined as the mean of visibility observations falling within the 40th to 60th percentiles, as expressed in deciviews (dv). The visibility condition is expressed as

> Visibility Condition = Current Group 50 − Estimated Group 50 Natural

The NPS Air Resources division defines descriptive ratings based on the Visibility Condition calculation. Visibility is rated as "good" if the Visibility Condition is less than two, "moderate" if the Visibility Condition is between two and eight, and "significant concern" if the Visibility Condition is greater than eight (NPS ARD 2009). The modeled 5-year average for Visibility Condition at Coronado NMem from 2004-2008 was 7.8 dv (NPS ARD 2010b). Therefore, the visibility condition at Coronado NMem is rated as "moderate."

Land Use

Coronado NMem is nested within the Huachuca Mountains and the larger Madrean Archipelago, which contains a variety of land uses including a military installation and the nearby city of Sierra Vista. Land use is the human use of landscapes, such as residential, agricultural, and developed areas. A change in housing density, and associated roads, can fragment the landscape, decrease the size of the functional ecosystems, reduce connectivity among native habitat patches, isolate species in small patches, and increase the contrast in vegetation structure and function along park boundaries. Such changes can have major implications to structural and functional ecosystem properties including fire frequency, species distributions, water quality, air quality, habitat fragmentation, and soil erosion (Gross et al. 2009). Because understanding the extent and configuration of land use can provide insight into the status and trend of park resources, land use is an indicator. However, there are no reference conditions for land cover in the Madrean Archipelago.

As described in Section 4.2.1.1, the NPScape landscape dynamics monitoring project provides landscape-level data to evaluate land use surrounding NPS units. Data provided by the NPScape project includes a suite of standardized, national-scale products (e.g., land cover, housing density, population density, and other socioeconomic data) for a 30 kilometer (km) area around each park unit, called the "local area" (Gross et al. 2009). Within the U.S., the local area includes most of Sierra Vista and the U.S. Army's Fort Huachuca as well as portions of Bisbee and

Naco. Within the U.S. portion of Coronado NMem's "local area," over 50% of the land is managed by the federal government (28% U.S. Forest Service, 10% Bureau of Land Management, 1% National Park Service, 16% Department of Defense), 30% is private land, and 11% is state trust lands (NPS 2010c; USGS 2009).

Current estimate of housing density reflect moderate housing densities in the U.S. portion of the local area around Coronado NMem and suggest that approximately 27% of the local area has dwellings. About half of the developed area has relatively low densities of less than 3 units per square kilometer. However, some areas exhibit moderate densities of 7-145 units per square mile and a few areas are developed densely at more than 500 units per square kilometer (NPS 2010b; Theobald 2005). Housing density projections for 2100 are modest but do not include the potential for development on current state trust lands. Projections suggest that the total area developed will remain similar to the 2010 estimate. However, the density of some of the developed areas will increase modestly (NPS 2010b; Theobald 2005).

Approximately 93% of the U.S. area surrounding Coronado NMem is considered "natural" (based on 2001 the National Land Cover Database). Approximately 7% of the land was converted and developed or used as pasture or for crop cultivation (Figure 4.24; NPS 2010d; Homer et al. 2004; Fry et al. 2009). Table B.9 describes the National Land Cover Database land cover classes and reclassification for calculating percent of natural and converted land cover.

Groundwater

Groundwater at Coronado NMem is a vital resource, providing potable water for park operations and sustaining numerous springs situated throughout the park. Storage of groundwater reserves is likely minimal on mountain slopes, where soils are coarse and thin and fractured granitic rocks have limited porosity. Alluvium in Montezuma Canyon transmits surface and subsurface drainage toward the valley below. The southeastern quadrant of the park consists of a gently sloping fan terrace covered by alluvium carried from the slopes of the nearby mountains. Recharge from the Huachuca Mountains percolates toward the center of the basin within the permeable deposits and rocks of the fan terrace.

The groundwater monitoring program at Coronado NMem includes four wells on the fan terrace and one higher up on the mountain slope (Figure B.2). Groundwater levels in Montezuma Canyon were measured regularly prior to the 2006 debris flow event. Depth to water in Montezuma Canyon at the park's original water supply well were around 40 ft prior to the 2006 event. Following that time, depth to water in that well rose to around 20 ft below measuring point, and a level of only 5 ft below measuring point was measured in winter of 2008. Depth to water at a new water supply well that was constructed on the mountain slope near the park's water tank is about 210 feet.

NPS monitoring of water levels at a high density of wells in the Montezuma Ranch area of the Memorial was conducted between about 1998 and 2004 (Figure B.2). Repeated measurement of these wells revealed the presence of water levels that differ greatly within a relatively small area at the Ranch (Figure 4.25). Analysis of these water level data, which show similar water levels within groups of nearby wells, strongly suggests the presence of a series of step-like blocks upon which groundwater ponds and flows downward towards the center of the basin. One of the ranch wells shows significant response to drought and wet periods. The other three are much less impacted by changes in water availability to the basin. The deepest well in the ranch area is Border Well, measured in 1975 with a water level 625 ft below the surface. This well is very near the U.S. border with Mexico and is not monitored due to difficult access conditions (NPS SODN 2011).

Seeps and Springs

Seeps and springs are critical surface water sources in the semi-arid Madrean Archipelago. They are important sources of water for plants and animals and represent the primary interface between groundwater and surface water. Therefore, the presence of

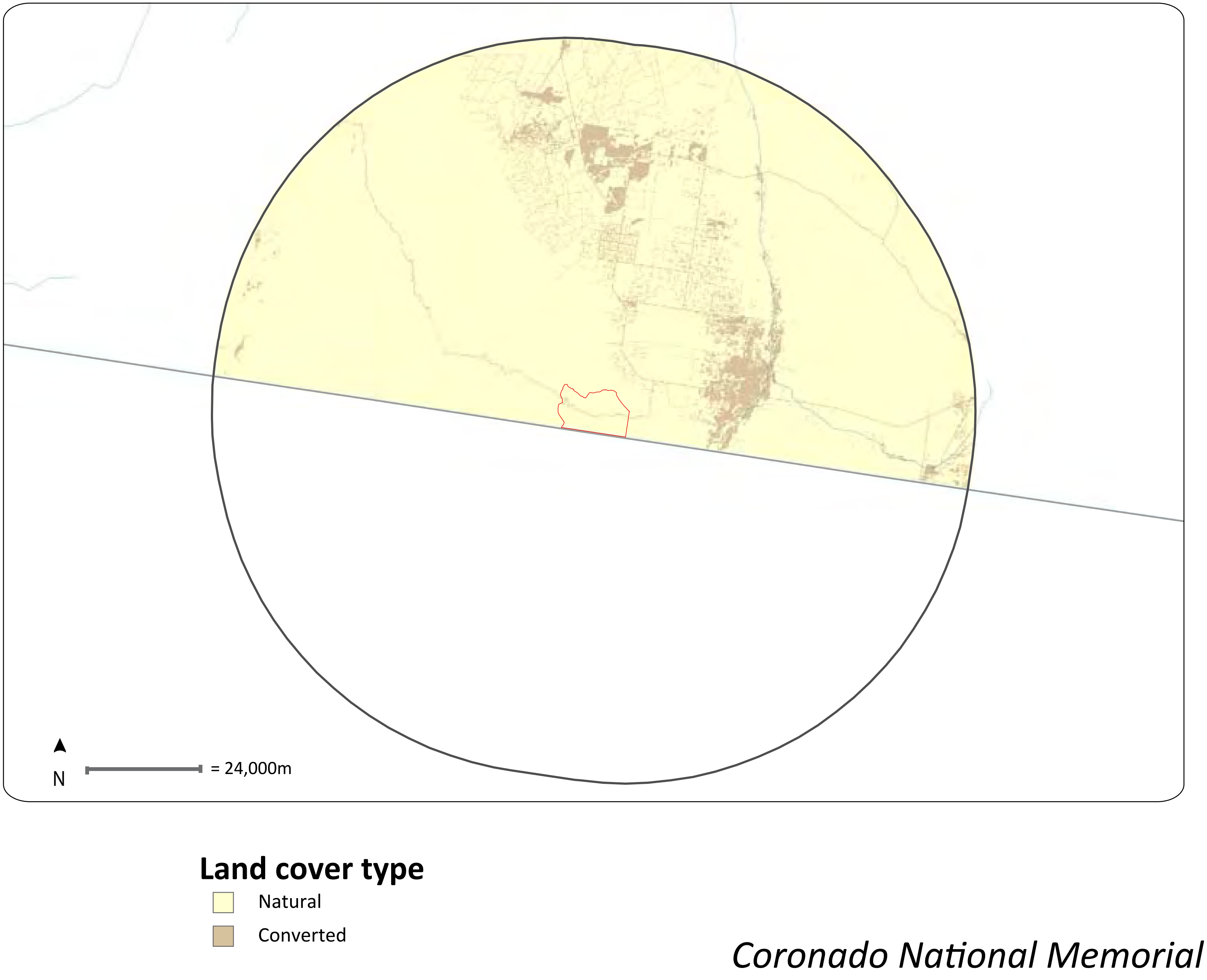


Figure 4.24. Natural versus converted land cover within 30 kilometers of Coronado NMem (NPS 2010d; Homer et al. 2004; Fry et al. 2009)**.**

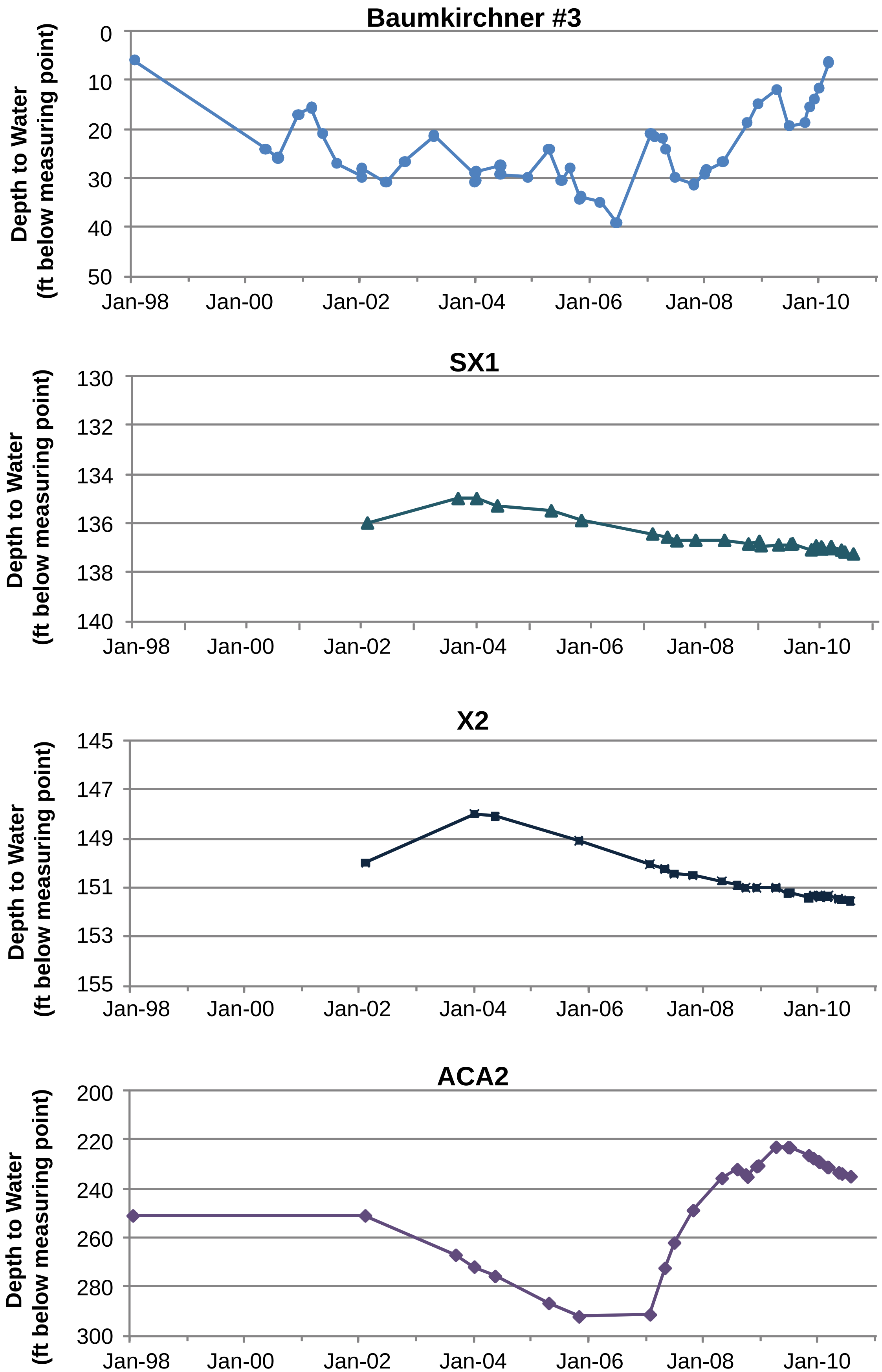


Figure 4.25. Depth to water measurements at Coronado Nmem (NPS SODN 2011).

flow at seeps and springs in June is included as an indicator.

In July 2010, the NPS Sonoran Desert and Chihuahuan Desert Networks collaborated on a seeps, springs, and tinajas inventory across their network parks. Field crews surveyed twelve seeps and springs at Coronado NMem: Blue Waterfall Site 1, Blue Waterfall Site 2, East Forest Lane Seep, Fern Grotto Site 1, Joe's Canyon Trail Site 2, Joe's Canyon Trail Site 3, Joe's Spring, Sparkes, Swallow Spring Site 3, Unknown Middle Owl, Yaqui Canyon Complex Site 1, and Yaqui Canyon Complex Site 3. The crews collected data on hydrology, geology, and invertebrates at most of the seeps and springs (NPS SWNC 2010). Abundance and diversity of invertebrates were not assessed in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

NPS field crews measured discharge at the springs using the volumetric method (Table B.10). Crews captured the flow by constructing a small earthen dam using local materials, inserting a tube into the dam, and collecting the water flowing from the tube in a container with known volume. The total amount of time required to completely fill the container was recorded and then flow rate was calculated (NPS SWNC 2010).

Water was observed flowing at nine of the twelve seeps and springs. Flow was not observed at East Forest Land Seep, Blue Waterfall Site 2, and Sparkes. Discharge was measured at eight seeps and springs and ranged from 0.0023 liters/second (Unknown Middle Owl) to 0.11 liters/second (Joe's Canyon Trail Site 2; NPS SWNC 2010). Discharge at Joe's Canyon Trail Site 3 was too small for measurement. Data from 2010 has not undergone quality assurance/quality control, so the author's confidence in the exact discharge results is low. Because the data were collected in July, after the monsoon rain started, the data are not included in Table 4.12.

Water Quality

Water quality sampling was conducted at Coronado NMem as part of the Baseline Water Quality Inventory (Table B.11; Brown 2005). For the purpose of establishing applicable water quality criteria, designated use classifications are prescribed in Arizona Administrative Code Title 18, Ch. 11 Department of Environmental Quality – Water Quality Standards. All of the surface waters sampled in the SODN Level I Baseline program are designated as Aquatic and Wildlife cold waters (A&Wc).

Water quality samples from sites at Coronado NMem show significantly more variability than was observed for samples from Chiricahua NM or Fort Bowie NHS. The piper plot of Coronado NMem samples shown in Figure B.4 illustrates this, as does the mix of different water types listed in Table B.12 for these samples, which range from Ca-Na-Mg-SO_4-HCO_3 to Ca-HCO_3. Calcium is the dominant cation for all of the samples, with sodium and/or magnesium also present in significant quantities for more than half of the samples (Figure B.15). Whereas bicarbonate was the dominant anion in samples from both Chiricahua NM and Fort Bowie NHS, dominant anions present at Coronado NMem include both bicarbonate and sulfate (Figures B.4 and B.7). Water quality variability at Coronado NMem is attributed to a much more diverse geologic environment, to the presence of abandoned mine features and possibly to the localized impact of unauthorized human use. The following paragraphs address water quality results for the sites sampled at Coronado NMem.

<u>Fern Grotto and Joe's Spring</u> - Fern Grotto and Joe's Spring are located on the southern slopes of the Huachuca Mountains, at elevations of 6,000 ft and 6,300 ft respectively. Waters from both of these sources are classified as Ca-HCO_3-SO_4, except for a sample from Joe's Spring collected in November 2003, which was determined to be a Ca-HCO_3 type. The designated use of both of these springs is A&Wc. Major ion composition for these samples is summarized in B.4 and B.7.

Fern Grotto is located adjacent and upslope of a northwest striking fault, below a slope of caldera-collapse breccia that includes dacite tuff, megablocks of sandstone and shale, blocks of limestone, and calc-silicate hornfels (NPS Geologic Resource Division 2008) that likely originated as a result of thermal alteration of limestone. Higher dissolved solids and sulfate in the water at Fern Grotto relative to the nearby Joe's Spring may be attributed to the more soluble rock types and geologic disturbance history in the surrounding environs. Nitrate levels at Fern Grotto are the highest of all of the samples reviewed (Figure B.16), a result that may be related to use of this location by wildlife or by unauthorized visitors.

Joe's Spring is situated high on the mountain slope within the Huachuca granite, below outcrops of rhyolite and dacite porphyry rocks. In addition to the higher position of this spring in the watershed relative to Fern Grotto, lower solubility of the surrounding rock types and predominance of silicate minerals in these volcanic rocks may explain the generally lower concentrations of ions at Joe's Spring relative to Fern Grotto.

Relatively high levels of barium (Table B.17) were measured at both Fern Grotto and Joe's Spring.

<u>Blue Waterfall seeps above and below an unnamed mine</u> - Also on the south slopes of the Huachuca Mountains at lower elevations of 5,700 ft and 5,625 ft are the locations from which samples named Blue Waterfall seeps above and below an unnamed mine were obtained. These seeps are named after the copper blue color of seepage coming from the area below the mine. This mining feature is known as Headquarters 93 - 025 in NPS abandoned mineral lands records, and is described as a sulfide replacement body at the edge of a crystalline marble bed (Karst Solutions, 2009). Arsenopyrite, limonite and crusts of native sulfur were identified as present on the surface at the inclined shaft that is the abandoned mine. The pH for samples from these two sites ranged from 6.7 to 8.1 (Figure B.8 and Table B.11).

Figures B.4 and B.7 show that these two samples differ from most of the other samples reviewed in that they have higher proportions of sulfate than all of the others with one exception. The water types for the samples above the mine shaft are consistently Ca-Na-Mg-SO_4-HCO_3, and those samples were shown to have the lowest calcium concentrations of all of the samples reviewed. Rock types in the surrounding area include the Huachuca granite and dikes of rhyolite porphyry (NPS Geologic Resource Division 2008). Above the mine, water quality is generally good and, except for dissolved oxygen, meets Arizona Department of Environmental Quality (ADEQ) standards for its designated use.

In contrast, water quality at the Blue Waterfall seep that daylights below the mine shaft is substantially different, including significantly increased hardness and total dissolved solids, higher concentrations of calcium, magnesium, sulfate, chloride, fluoride, aluminum, beryllium, cadmium, nickel, and manganese (Table B.11). ADEQ A&Wc standards for cadmium, copper and zinc were greatly exceeded at the seep below the mine. The sample collected at this location in September 2003 was determined to be a Ca-Mg-SO_4 type. Several water samples were collected and analyzed at and in the vicinity of Headquarters 93-025 between 1977 and 1993, those results are reported in the park's Baseline Water Quality Report (NPS WRD 2000). Exceedances of zinc, copper and selenium standards for A&Wc are reported in the Baseline report at this location.

<u>State of Texas Mine #11 and State of Texas Seep</u> - These two samples were taken from surface waters in the area of a group of 24 mining features collectively known as State of Texas Mine. These State of Texas Mine workings are located adjacent to a northwest striking fault zone and were the source of lead, silver and zinc ores (Sanchez et al. 2001). Both of these locations have a designated use of A&Wc. State of Texas Mine #11 is designated State of Texas 93-011 in NPS abandoned mineral lands records. Located at an elevation of about 5,825 ft, this feature is a horizontal adit about 50 ft long that has been secured with cable netting to limit access. As Figures B.4 and B.7 show, samples from State of Texas Mine #11 were found to be a Ca-Na-SO_4-HCO_3 type. The water is high in sulfate relative to other anions but cations present were relatively similar to the other waters sampled. The pH at this loca-

tion was 7.8 and 8.1 during the two events when this was measured (Figure B.8). Total dissolved solids and specific conductance at State of Texas Mine #11 are moderate with averages of 469 mg/L and 652 uS/cm @ 25°C, respectively (Figure B.10). Alkalinity and hardness are also moderate (Figure B.11). Nitrate is slightly higher at this location than at nearby sites, possibly due to use by wildlife. Bats are known to inhabit some of the State of Texas Mine workings. Sulfate levels at State of Texas Mine #11 are elevated relative to most of the other samples reviewed (Figure B.18), but not as high as the Blue Waterfall seep below an unnamed mine discussed above. Figure B.19 shows that uranium levels at State of Texas Mine #11, with an average of 119 ug/L, are the highest for any of the samples reviewed. There is no uranium standard for A&Wc.

Based on coordinates provided by U.S. Geologic Survey (Brown 2005), the State of Texas Seep is located downstream of Sparkes spring in Montezuma Canyon. There is a feature in this area that is designated as State of Texas Mine #93-038 in NPS abandoned mineral lands records, and we believe that this is the feature from which this sample was obtained. Water quality at this location is classified as Ca-Mg-HCO_3-SO_4 (two samples) and Ca-Mg-HCO_3 (one sample). Figure B.4 shows that water quality at this location is more similar to sites unimpacted by mining than those with higher sulfate concentrations. Stiff diagrams for the State of Texas seep samples are shown in Figure B.7. Mining impacts are clear when comparing State of Texas seep with stiff diagrams of State of Texas Mine #11 and Blue Waterfall seep below unnamed mine (Figure B.7), which contain significantly higher sulfate concentrations. The pH for this site averages 7.0 (Figure B.8). Total dissolved solids are slightly elevated compared to the nearby State of Texas Mine #11, and specific conductance, alkalinity, and hardness are all among the highest for all samples collected at Coronado NMem (Figures B.10 and B.11). Nitrate is not elevated at this site. Among metals, there was one very high concentration of manganese recorded for the sample of September 2003 (1,500 ug/L, Figure B.14), and the greatest concentration of dissolved iron (371 ug/L) of all the samples discussed here was reported for this location at the same time. There is no A&W standard for managanese, and the A&W standard for dissolved iron is 1,000 ug/L, so neither of these measurements caused an exceedance of applicable standards.

The NPS baseline water quality report did not report exceedances of A&Wc parameters for either of the State of Texas Mine locations discussed here (NPS WRD 2000).

Clark-Smith Mine - Clark-Smith Mine feature is located along a northwest striking fault zone at an elevation of 6,025 ft, adjacent to the same fault as that along which the State of Texas Mine features are located. Designated use of waters from this location are A&Wc. Figure B.4 shows the proportions of major ions in waters at Clark-Smith Mine. The three samples are classified as Ca-Mg-HCO_3-SO_4 and plot with the group of minimally impacted or unimpacted by mining waters at Coronado NMem on the piper plot (Figure B.4). As shown in Figure B.7, concentrations of major ions at Clark-Smith Mine are similar to those at Joe's Spring, also a relatively high elevation water source. The pH at Clark-Smith Mine are near neutral with an average of 7.3 (Figure B.8), and like most of the other water samples reviewed here, dissolved oxygen levels at this site were below the standard for A&Wc (Figure B.9). Total dissolved solids and specific conductivity are moderate and average 390 mg/L and 578 uS/cm @ 25°C respectively. Concentrations of most of the metals shown in Table B.11 were within the range of the other samples from Coronado NMem, except for zinc (Table B.11) and uranium (Figure B.19), which were somewhat elevated compared to results for these parameters from many of the samples. Nitrate was also higher than all of the other Coronado NMem samples except for Fern Grotto (Figure B.16).

Yaqui Spring - Yaqui spring is located in the Yaqui Canyon drainage south of Coronado Peak at an elevation of 6,175 ft. Designated water use for Yaqui Spring is A&Wc. Proportions of major ions for the Yaqui Spring sample are shown on Figure B.4. The two samples from this site were classified as Ca-HCO_3-SO_4 (May 2003) and Ca-HCO3

(November 2003). Figure B.7 shows the magnitude of major ion concentrations for this sample. As Figure B.7 shows, a higher level of sulfate was present in the sample from May 2003 relative to that of November 2003, but major cations present were consistent between these two samples. The pH was higher during the May sampling event at 8.4, relative to the November sample which was 7.4. Yaqui Spring was the only location sampled that exceeded the ADEQ standard for A&Wc dissolved oxygen at both sampling events. Total dissolved solids and specific conductance were moderate for this sample averaging 355 mg/L and 531 uS/cm @ 25°C respectively. Alkalinity and hardness were also moderate, at 215 mg/L and 273 mg/L respectively.

Levels of metals at Yaqui Spring were moderate and within the range of concentrations measured at the other sites reviewed (Table B.11). Figures B.4 and B.7 indicate that calcium is the dominant cation for all of the samples, a result associated with the geologic settings within which these parks occur. Sodium, potassium and magnesium are minor cations for all but one of the samples. The piper plot also shows that bicarbonate is the dominant anion present for all of the samples except for three mining-impacted samples from Coronado NMem.

In summary, natural water sources sampled at Coronado NMem were reviewed and compared to State of Arizona standards for Aquatic and Wildlife designated use. Samples show high levels of variability, which is attributed to a diverse geologic environment, to the presence of abandoned mine features and possibly to the localized impact of unauthorized human use.

All locations failed to meet the standard for dissolved oxygen at least once, except for Yaqui Spring. However, natural processes are reasonable explanations for the presence of low dissolved oxygen levels in the springs sampled; therefore the presence of dissolved oxygen in these waters below state criteria is not considered to be problematic or requiring attention.

With the exception of dissolved oxygen, only one of the locations, Blue Waterfall seep below an unnamed mine (Headquarters 93-025), was determined to be exceeding applicable water quality standards. That location has been identified as a target for closure and backfilling. All of the remaining samples were in compliance with A&W criteria for surface waters. For these reasons, water quality at Coronado NMem is considered to be in good condition.

Soils

As described in Section 4.1.1, dynamic soil characteristics and soil biota can change over relatively short periods of time and are directly influenced by management actions. Soil surface cover, biological soil crust composition and cover, and surface soil aggregate stability are important dynamic soil properties and relate to soil and site stability and hydrologic function. While biological soil crusts are an important component of the vegetation and soil community at Coronado NMem, reference conditions for biological soil crust composition and cover are undetermined for the Madrean Archipelago.

Hubbard et al. (2010) proposed reference conditions for soil cover and surface soil aggregate stability for Fort Bowie NHS. Because no other relevant reference conditions have been proposed for the Madrean Archipelago, we adopt, with slight modification, those from Hubbard et al. (2010) and include soil aggregate stability and soil cover as indicators. The soil cover reference condition focuses on the percent cover of bare ground and adopts work done by the Bureau of Land Management and The Nature Conservancy at Las Cienegas National Conservation Area. Gori and Schussman (2005) set the desired amount of exposed (no vegetative cover) bare ground cover at 30% to minimize erosion potential. In this assessment, we use a stricter reference condition of 30% bare ground cover regardless of vegetative cover.

Hubbard et al. (2010) proposed a reference condition for surface soil aggregate stability, as measured using a modified wet aggregate stability field method, based on professional judgment and Herrick et al. (2005). In the soil aggregate stability field method, samples are scored from 1 to 6, with 6 being the most stable. Hubbard et al. (2010) suggested a reference condition where the percentage of soil aggregates in the "6" class should be greater than 20%.

The NPS Sonoran Desert Network initiated vegetation and soils monitoring at Coronado NMem in 2009. Six permanent field-monitoring sites were established and sampled in 2009 and in 2010 (Figure B.21; NPS SODN 2010e). Since Coronado NMem is a large park for the Sonoran Desert Network, they use a multi-year sampling strategy where one-fifth of the sites are sampled within a given year with the entire complement completed after five field seasons. Thus, data collected in 2009-2010 represent only 40% of the sampling for the 5-year period. As such, this assessment utilizes only 40% of the intended sample size. Therefore, it is critical that the reader understands that these data are presented with a low confidence rating for its ability to assess current conditions.

NPS Sonoran Desert Network terrestrial vegetation and soils plots were allocated through a Reversed Randomized Quadrant-Recursive Raster (RRQRR) spatially balanced design using strata based on a combination of elevation intervals and soil rock fragment classes. The sampling frame for Coronado NMem includes all terrestrial areas within park boundaries, except for areas with slopes ≥45° (for crew safety), within 100-m of roads and buildings, within 50-m of washes trails, and selected cultural features. The total area excluded from the sampling frame was 1,971 acres, or approximately 41% of the park area (Hubbard et al. in review). Therefore, inference from the plots at Coronado NMem is to all terrestrial areas of the park, except for the areas described above.

At each site, the Sonoran Desert Network established permanent, 20 × 50-m sampling plots. Vegetation sampling was done in conjunction with soil cover and stability measures along six 20-m transects within a plot utilizing the line-point intercept method with points spaced every 0.5m. Soil cover was recorded by substrate class (e.g., rock, gravel, litter, bare ground, etc.), with biological soil crust cover recorded to morphological group (e.g., light cyanobacteria, dark cyanobacteria, lichen, moss). Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2005) at up to 48 locations per plot. Samples were scored from 1 to 6, with 6 being the most stable. We include this data in the assessment of park-wide conditions but again caution the reader that we have low confidence that this data can reliably assess current conditions.

Based on the 12 plots collected by the NPS Sonoran Desert Network from 2009-2010, soil substrate cover was dominated by plant litter and duff. Gravel, rock, bedrock, and plant bases also significantly contributed to soil cover. Less than 5% of the soil surface was bare soil (Table 4.14; 2010d). Average biological soil crust cover was one percent. See Table B.15 for plot-specific results.

All 12 of the NPS Sonoran Desert Network sites had an average surface soil stability rating of at least 3.5, the midpoint between "very stable" and "very unstable." Overall, nearly half of the samples were in the 6 (very stable) category (Table 4.15). Samples collected under vegetation tended to have higher stability values than those collected in open spaces. However, the sample size is too small to draw any conclusions (NPS SODN 2010e). See Table B.14 for plot-specific results.

Table 4.14. Park-wide soil surface cover (mean % cover by class and standard error), Coronado NMem. Summary of 12 plots of data from 2009-2010 Sonoran Desert Network monitoring (NPS SODN 2010e).

Soil Substrate	% Cover Mean ± SE
Bare ground	11.5% ± 4.4
Gravel	5.6% ± 2.9
Litter and Duff	67.2% ± 4.2
Rock and Bedrock	3.8% ± 2.3
Plant base	10.9% ± 1.9
Biological Soil Crust	1.0% ± 0.7

Table 4.15. Park-wide soil surface aggregate stability class (mean and standard error) and proportion of samples in "very stable" (=6) category, Coronado NMem. Summary of 12 plots of data from 2008 Sonoran Desert Network monitoring (NPS SODN 2010e).

	Average Soil Stability[1]	% samples in category 6[1]
	Mean ± SE	Mean ± SE
All samples (n=465)	4.48 ± 0.08	43.5% ± 4.1
Under vegetation (n=415)	4.64± 0.09	46.6% ± 4.2
No vegetation (n=50)	3.12 ± 0.28	9.4% ± 4.4

[1]Samples rated on stability scale from 1-6. Category 1 = very unstable; category 6 = very stable

Overall, Coronado NMem soil indicators meet their respective reference conditions. The areas of the park included in the NPS Sonoran Desert Network 2009-2010 monitoring effort appear to be well-protected from soil erosion but represent only 40% of the intended sample size for the park. The overall soil aggregate stability of the sites was moderate to high, indicating that the sites can resist erosion and that the soil-biotic system is functioning. Total cover of the sites was very high, with little exposed bare soil. Biological soil crust cover was low (1%) on the monitoring plots. A large amount of cover comes from litter and duff that could leave the sites susceptible to erosion if fire or drought removed those materials.

While the data collection was recent and utilized peer-reviewed methods, the six monitoring plots represent a fraction (40%) of the intended sample size for monitoring sites. Therefore, confidence in the data and its ability to assess current conditions is low.

4.2.2.2 Biological Integrity

Major Biomes

Coronado NMem is one of only three NPS areas that contain Madrean biota (the others are Chiricahua NM and Guadalupe Mountain National Park). There is also a substantial area of desert grassland.

Biological Diversity

Coronado NMem is remarkably diverse for its modest size (Table ES.2). Its total of 651 plants is not far behind Chiricahua NM's 803. It has more than half of the amphibians and reptiles (74) and two-thirds (67) of the mammals in the Arizona Sky Island Archipelago. It has the most birds (200) of the three parks, which is 40% of the total for the Arizona part of the region.

Biological Corridors

Because of its range of elevations, Coronado NMem is part of both the northward and southward migratory corridors described in section 4.1.2.10.

Exotic Species

Although there are numerous exotic species established in the parks, the great majority do not appear to be invasive (e.g., they are not causing significant ecological harm or posing a health hazard). Some are invasive, but are already so widespread and well established that control is probably not feasible, e.g., Bermuda grass and filaree. Most of these species also seem to have attained their maximum invasive potential; they probably are not increasing further, at least not into undisturbed habitats. In addition to bullfrog, there are several plants that should be monitored and may need management action including: tree of heaven, yellow bird-of-paradise, Maltese starthistle, Lehmann lovegrass (management techniques can reduce its dominance), and athel tamarisk.

Rare and Endemic Biocommunities and Species

Coronado NMem has the rare plants *Astragalus hypoxylus*, *Pectis imberbis*, and possibly *Echinocereus coccineus* var. *arizonicus* (the taxonomic status of this population is not settled). Other possibilities are listed in Table 4.4. Rare vertebrates that are currently or were historically present are grizzly bear, Mexican gray wolf, jaguar, jaguarundi (improbable), ocelot, lesser long-nosed bat, American peregrine falcon, and Mexican spotted owl (Table 4.12). The lists are probably incomplete; see data gaps identified in section 5.1.

Ecosystem Health

Most of the grassland within Coronado NMem is native and healthy. The far western end of the park is classified as shrub-invaded nonnative grassland and is therefore degraded.

The woodlands and forests away from heavily trafficked areas are presumed to be mostly healthy, because they have not been subjected to major disturbances such as heavy grazing or logging for several decades. Extensive areas were severely burned recently. Natural succession appears to be proceeding with little or no human input, so these areas are also healthy even if they are unsightly.

4.2.2.3 Special Themes

Border Impacts

Numerous efforts are underway, or were recently completed, at Coronado NMem to understand the impact of the infrastructure and border activities on ecological processes and communities including:

- Monitoring impacts of the pedestrian fence on stream channel morphology at Coronado NMem and Organ Pipe Cactus NM (Natural Channel Design, Inc. 2008)
- Investigations on the potential effects of hardening the borer on ecological communities (Sayre and Knight 2010)
- Use of remote sensing to quantify border impacts at Organ Pipe Cactus NM and Coronado NMem (Drake et al. 2005)
- Evaluation and development of methods to document unlisted roads and trails (T. Esque pers. comm. 2011)

Data collection on the impacts of the pedestrian fence on stream channel morphology is ongoing. Natural Channel Design, Inc. conducted a baseline channel morphology survey, upstream of the pedestrian fence, in three ephemeral washes (Steep Wash, Montezuma Canyon, and West of Forest Wash) at Coronado NMem in 2005. Within each wash, they established at least four cross-sections near and upstream of the pedestrian fence (Natural Channel Design, Inc. 2008). The NPS Sonoran Desert Network resurveyed the washes in 2010. In general, large floods are expected to cause significant morphological change (Natural Channel Design, Inc. 2008). However, there had not been flow events significant enough to alter the channel morphology (E. Gwilliam, pers. comm. 2011). The Natural Channel Design, Inc. (2008) suggests that changes in bankfull width of 10% or greater near the pedestrian fence that are dissimilar from changes in the upstream cross-sections are indicative of impacts from the pedestrian fence.

Drake et al. (2005) evaluated the use of remote sensing to monitor unlisted/social trails and roads. The study resulted in a large number of errors of commission where trails were digitized based on satellite imagery that were not seen on the ground. As expected, faint trails were not seen in the satellite imagery. A new study is underway to evaluate and develop methods to document unlisted trains on NPS lands, including Coronado NMem (T. Esque pers. comm. 2011). Based on existing data, we cannot report on the spatial extent of unlisted roads at trails at Coronado NMem.

4.2.3 Fort Bowie NHS

A rigorous quantitative assessment of ecosystem health is not practical at this time. However, the NRCA team concludes that Fort Bowie NHS is currently in very good health. Table 4.16 summarizes the current condition of indicators and their respective reference conditions at Fort Bowie NHS. Indicators are summarized at the park-wide level. Insufficient information was available

Table 4.16. Condition Indicators in Fort Bowie NHS.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Supporting Environment						
Climate	Temperature	Average June maximum temperature	unknown – unable to compare to 30-year average	Unavailable	n/a	Gray 2008
		Average January minimum temperature	unknown – unable to compare to 30-year average	Unavailable	n/a	
	Precipitation	Average annual precipitation	unknown – unable to compare to 30-year average	nUnavailable	n/a	
Air Quality	Air Quality	Wet Deposition	moderate	< 3 kg/ha/yr nitrogen or sulfur	moderate	NPS ARD 2009
		Ozone	moderate	< 75 parts per billion (ppb)	moderate	
		Visibility	moderate	Current Group 50 – Estimated Group 50 Natural < 2 dv	moderate	
Surrounding Land Use	Land Use	Percent Natural vs. Converted	10% converted	none	n/a	n/a
Surface Water Quantity	Water Quantity	Spring flow	3 of 3 springs flowing in June 2010	Flow present in June	moderate	Authors' professional opinion
Groundwater Quantity	Water Quantity	Depth to Groundwater	stable	No significant declines from historic levels	low	Authors' professional opinion
Water Quality	Water Quality	Various	Good	viaries by measure	high	Arizona Department of Environmental Quality
Soils	Soil Quality	Surface soil aggregate stability	36% rated as "very stable"	> 20% rated as "very stable"	moderate	Hubbard et al. 2010
		Bare ground cover	Average < 5% bare ground cover	bare ground cover <30%	moderate	Gori and Schussman 2005
		Biological soil crust cover	Average <1% cover	unknown	n/a	n/a
		Soil biological health	Unknown – data gap	Undefined	n/a	n/a

Table 4.16. Condition Indicators in Fort Bowie NHS.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Biological Integrity						
Rare, Endangered, Threatened, or Candidate Species	Lesser long-nosed bat (LLB)	Monitoring of roosts and of agave (food plants)	Present in park	No decline in numbers over time; no decline in agave plants over time.	Moderate	LLB are migratory and only present in SE Arizona in the late summer as they begin their southbound migration. They rely solely on agaves for food at this point in their life cycle, and on caves and mines for roosts.
	Mexican spotted owl	Monitoring population numbers	Unknown; possibly present	No decline in numbers over time	High	n/a
	Mexican gray wolf	n/a	Probably historically present	Habitat suitable to sustain species		
	Grizzly bear		Historically present			Reintroduction probably not possible
	Chiricahua leopard frog	n/a	Historically present	Reestablish stable population	High	
	Jaguar	n/a	Historically present	Habitat suitable for natural recolonization	Moderate	
Keystone Species	Large predator ecological niche	Number of species and population levels	Three of the four species have been extirpated; only mountain lions remain	Monitor large herbivores for possible over-population; manage if necessary	High	NPS I&M database
Species of management concern			Largely unknown	Be aware of which non-T&E species may need attention.		Data gap; existing lists are probably incomplete.
Invasive Species	Exotic plants	Number of species; areal coverage trends	Numerous established species, none exhibiting invasive behavior	Established exotics not increasing; no new species		
	Exotic animals	Number of species; population trends	Few established species; populations low and stable	Established exotics not increasing; no new species	Moderate	NPS I&M database

Table 4.16. Condition Indicators in Fort Bowie NHS.

Ecosystem Characteristic	Indicator	Measure	Current Condition	Reference Condition	Confidence	Reference Condition Source
Vegetation Communities	Desert Grassland		Small area in park, much of it ecotonal with oak woodland		Moderate	NPS I&M database
	Madrean Oak Woodland		Well represented, healthy			
	Riparian communities		Small area in park, threatened by erosion, needs management to protect/ restore			
Ecological Processes	Fire	Unknown	unknown	n/a	n/a	n/a
	Grazing	Unknown	unknown	n/a	n/a	n/a
Special Themes						
Erosion	Erosion	Soil loss	59,000 m^3 in Apache Spring watershed	none	high	n/a

to assess conditions at the management area level. The sections below are organized by ecosystem characteristic then resource and give information on the indicators for each resource, including the reference conditions, data sources, and confidence levels.

Our professional opinions are tempered by significant data gaps, and several actual and possible future threats. The most significant threats to Fort Bowie NHS appear to be climate change, fire, and possibly exotic species invasion.

4.2.3.1 Supporting Environment

Climate

Climate drives and regulates many ecological, biological, and physical processes and influences the distribution of plant and animal species. Long-term patterns in temperature and precipitation are primary factors in limiting potential ecosystem structure and function (Whitford 2002). Other limiting factors include the length, intensity, seasonality, and variability of weather events. Climate also affects the susceptibility of an ecosystem to disturbance and extreme weather events can be a source of disturbance (i.e. flood). Because of the influence of climate and weather on ecological processes, temperature and precipitation are included as an indicator.

While the climate at Fort Bowie NHS is similar to that of Chiricahua NM, relying on the Chiricahua NM weather station may not provide accurate enough information for Fort Bowie NHS (see Section 4.1.1.3). Fort Bowie NHS maintains a National Weather Service Cooperative Observer Program-style weather station, located between the maintenance and administration area and the Visitor Center. The staff at Fort Bowie NHS has collected daily weather data for nearly four decades (since 1970) with remarkable consistency. These data are not reported to the data to the Weather Service Office in Tucson. Since 1988, staff recorded weather data on National Weather Service/Weather Bureau datasheets. Prior to 1988, several forms were used to record data. Staff from the NPS Sonoran Desert Network and Chiricahua NM digitized all existing handwritten weather observations through 2009 (Figure 4.26). While the data underwent one round of quality control and quality assurance, the quality assurance process was not completed. Therefore, the results presented here are with a moderate level of confidence. These data cannot be compared to a 30-year average they were not calculated for the station.

Precipitation at Fort Bowie NHS is highly variable with annual totals ranging from six to over 22 inches between 1988 and 2009 (Table B.6). Between 2000 and 2009, the average annual precipitation at Bowie was 15.03 inches, which is less than the 1988-2009 station precipitation average of 16.46 inches (Figure 4.26; NPS 2010a). From 2000 to 2009, Fort Bowie NHS received nearly half (47%) of its annual precipitation during the summer monsoon season.

Between 1988 and 2009, there is reliable temperature data for all of 1988-1995, 1997-2001, and 2003-2009 and for most months during 1996 and 2002. During 2000-2010, maximum temperatures typically exceed 80°F from May through September and maximum temperatures generally exceeded 90°F in June and July (Table B.7). The average maximum temperature for June for years with reliable data (2000-2001, 2003-2009) was 94.8°F, which is slightly warmer than the 1988-2009 station average maximum temperature for June (94°F; Figure 4.26). The average minimum temperature for January for 2000-2009 was 34.1°F, which is warmer than the 1988-2009 station historic average (33.4°F; Figure 4.26).

Air Quality

Air quality affects vegetation, wildlife, and water as well as scenery, vistas, and viewsheds. Because understanding changes in air quality can help interpret changes in park resources and other indicators as well as evaluate compliance with legislative requirements, air quality is included as an indicator. There are three main components used to measure air quality: visibility, ozone, and atmospheric deposition. The NPS Air Resources Division administers an extensive monitoring program to measure air quality in NPS units. In addition, the NPS Air Resources Division models 5-year air quality estimates for

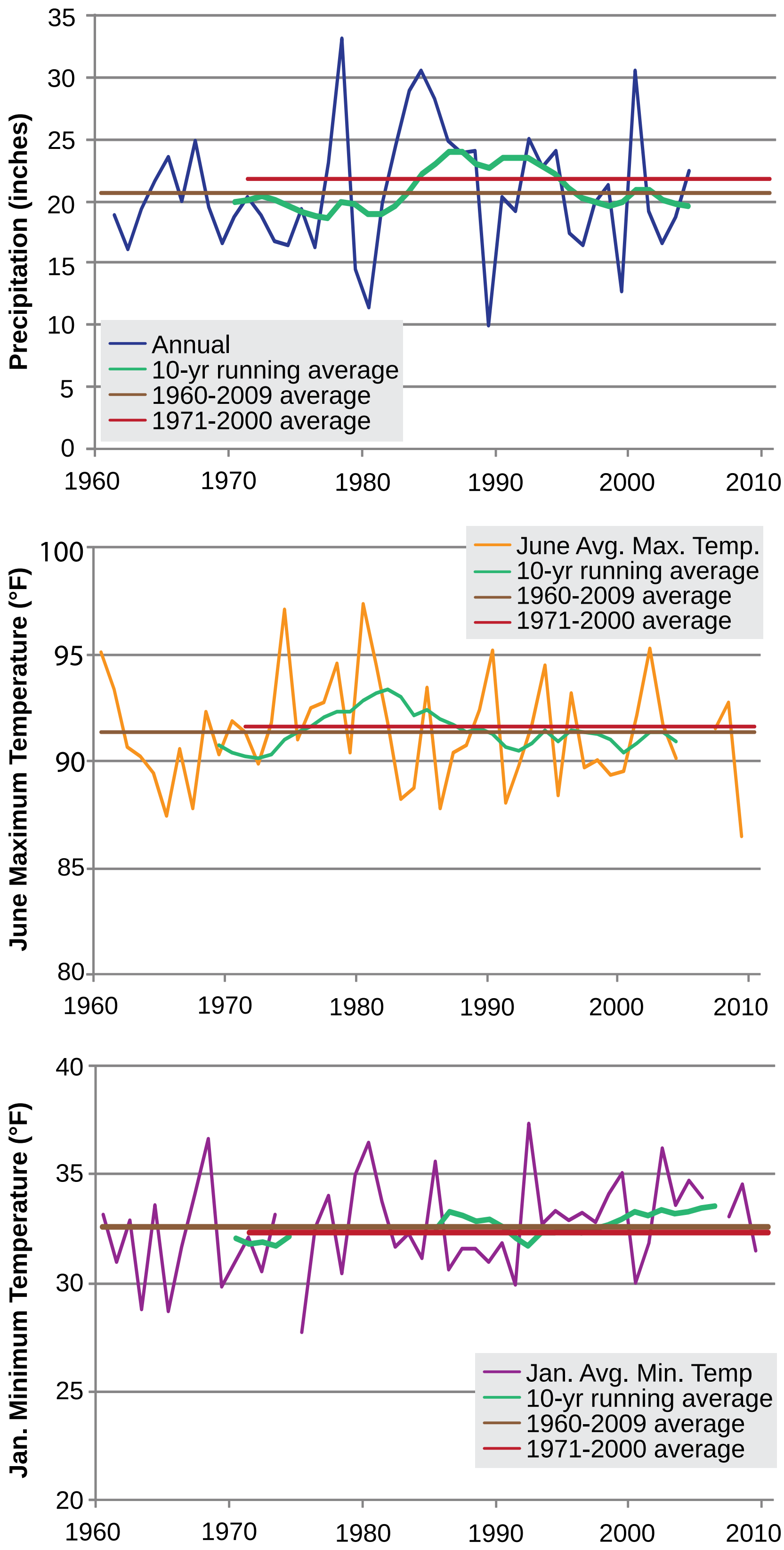


Figure 4.26. Annual precipitation (top), average June maximum temperatures (middle), and average January minimum temperatures (bottom) at Fort Bowie NHS, 1988-2009 (NPS SODN 2010e).

all NPS units (Table B.8; NPS ARD 2010b). The NPS Air Resources Division determined that deposition and ozone monitors within 10 miles of a park boundary may be considered reasonably representative of a park's air quality (NPS ARD 2009), thereby making the deposition and ozone monitoring at Chiricahua NM suitable for reporting on air quality at Fort Bowie NHS. However, this assessment utilizes the modeled data from the NPS Air Resources Division for ozone, visibility and wet deposition to allow for the inclusion of visibility in the condition reporting. Because the air quality data is modeled and not collected at Fort Bowie NHS, the authors' confidence in this assessment is moderate.

Standards for wet deposition relate to the amount, in kilograms (kg), of nitrogen (N) or sulfur (S) deposited over a given area, one hectare (ha), per year. According to the NPS Air Resources Division, parks with wet deposition less than 1 kg/ha/yr are in "good" condition, 1-3 kg/ha/yr are in "moderate" condition, and greater than 3 kg/ha/yr have a "significant concern" for deposition. Between 2004 and 2008, the modeled average total wet deposition of nitrogen was 2.4 kg/ha/yr and the average total wet deposition of sulfur was 1.1 kg/ha/yr (NPS ARD 2010b). Therefore, nitrogen and sulfur deposition conditions are rated as "moderate."

The Environmental Protection Agency set a national standard for ozone of 75 parts per billion (ppb) averaged over an 8-hour period to protect the environment and human health (Mau-Crimmins and Porter 2007). Areas are in compliance with the standard if the three-year average of the fourth-highest daily maximum 8-hour concentrations measured over the course of a year do not exceed 75 ppb. The 5-year average (2004-2008) fourth-highest eight-hour ozone concentration modeled for Fort Bowie NHS is 69.4 (NPS ARD 2010b). The NPS Air Resources division rates ozone as "good" if ozone concentrations are equal to or less than 60 ppb, "moderate" if for ozone concentrations between 61 and 75 ppb, and "significant concern" if ozone concentrations are greater than 76 ppb (NPS ARD 2009). Based on the 2004-2008 fourth-highest eight-hour ozone concentration modeled for Fort Bowie NHS of 69.4 ppb and the reference condition set by the NPS Air Resources Division, ozone at Fort Bowie NHS is rated as "moderate."

The NPS Air Resources Division assessed visibility by looking at the deviation of current "Group 50" visibility from "natural" conditions. Group 50 is defined as the mean of visibility observations falling within the 40th to 60th percentiles, as expressed in deciviews (dv). The visibility condition is expressed as

Visibility Condition = Current Group 50 − Estimated Group 50 Natural

The NPS Air Resources division defines descriptive ratings based on the Visibility Condition calculation. Visibility is rated as "good" if the Visibility Condition is less than two, "moderate" if the Visibility Condition is between two and eight, and "significant concern" if the Visibility Condition is greater than eight (NPS ARD 2009). The modeled 5-year average for Visibility Condition at Fort Bowie NHS from 2004-2008 was 5.9 dv (NPS ARD 2010b). Therefore, the visibility condition at Fort Bowie NHS is rated as "moderate."

Land Use

Fort Bowie NHS is located between the Chiricahua and Dos Cabezas Mountains and is a small component the larger Madrean Archipelago, which contains a variety of land uses. Land use is the human use of landscapes, such as residential, agricultural, and developed areas. A change in housing density, and associated roads, can fragment the landscape, decrease the size of the functional ecosystems, reduce connectivity among native habitat patches, isolate species in small patches, and increase the contrast in vegetation structure and function along park boundaries. Such changes can have major implications ecosystem properties including fire frequency, species distributions, water quality, air quality, habitat fragmentation, and soil erosion (Gross et al. 2009). Because understanding the extent and configuration of land use can provide insight into the status and trend of park resources, land use is an indicator. However, there are no reference conditions for land cover.

As described above in Section 4.2.1.1, the NPScape landscape dynamics monitoring project provides landscape-level data to evaluate land use surrounding NPS units. Data provided by the NPScape project includes a suite of standardized, national-scale products (e.g., land cover, housing density, population density, and other socioeconomic data). The 30 km local area for Fort Bowie NHS includes Chiricahua NM and the town of Bowie but excludes the majority of Willcox.

In and near Fort Bowie NHS (within a 30km radius), approximately 30% of the land is managed by the federal government (10% U.S. Forest Service, 17% Bureau of Land Management, 1.7% National Park Service), 45% is private land, and 25% is state trust lands. Approximately 6% of the land within 30 km of Chiricahua NM is considered protected (NPS 2010c; USGS 2009).

Current estimate of housing density reflect relatively low housing density around Fort Bowie NHS and suggest that less than 20% of the local area has dwellings. Most of the developed area (15% of the total local area) is developed at a very low density of less than 1.5 units per square kilometer with a small percent of land (<3% of the total local area) developed at 1.5 to 3 units per square kilometer (NPS 2010b; Theobald 2005). The large amounts of federal and state land limit development in the area. Housing density projections for 2100 are modest but do not include the potential for development on current state trust lands. Projections suggest that the density of some of the developed areas will increase modestly (NPS 2010b; Theobald 2005).

Approximately 90% of the area surrounding Fort Bowie NHS is considered "natural" (based on 2001 the National Land Cover Database). Ten percent of the land was converted and developed or used as pasture or for crop cultivation (Figure 4.27; NPS 2010d; Homer et al. 2004; Fry et al. 2009). Table B.9 describes the National Land Cover Database land cover classes and reclassification for calculating percent of natural and converted land cover.

Groundwater

In addition to supplying springs, groundwater at Fort Bowie NHS provides the water supply for park operations. Water supplies to the park were pumped from a well in Siphon Canyon from the 1960's to about 2002, after which water was supplied from a well adjacent to the park's administrative area. Static water levels in the limestone aquifer have not changed substantially since that time (Figure 4.28). The presence of iron-related bacteria in the limestone aquifer has resulted in the need for careful management of the water supply system at the fort.

Threats to groundwater resources in the Apache spring watershed are associated with vegetation change from grassland to shrubland and accelerated erosion in the area of the second fort, long-term drought, changes in weather patterns that result in more intense storm events, and increased consumption of limited resources by adjacent landowners. This watershed is the source of the area springs and water supply for the park and should be proactively managed to restore vegetative cover and to enhance infiltration and soil retention.

Seeps and Springs

Seeps and springs are critical surface water sources in the semi-arid Madrean Archipelago. They are important sources of water for plants and animals and represent the primary interface between groundwater and surface water. Therefore, the presence of flow at seeps and springs in June and spring flow are included as indicators.

Average flow rates at Apache Spring have declined from rates of 7.5 to 10 gpm reported in the 1970's by Werrell (NPS Water Resource Division) to rates between 3 and 6 gpm observed since 1999. The cumulative effect of several processes resulted in the decreased flow. The most likely processes include: increased transpiration by plants, soil losses causing increased runoff and reduced infiltration, drought (Filippone 2009). Recently, Filippone (2009) conducted a study on the flow and hydrology of Apache Spring and Lower Mine Tunnel Spring. Data were collected from April 2005 to July 2006,

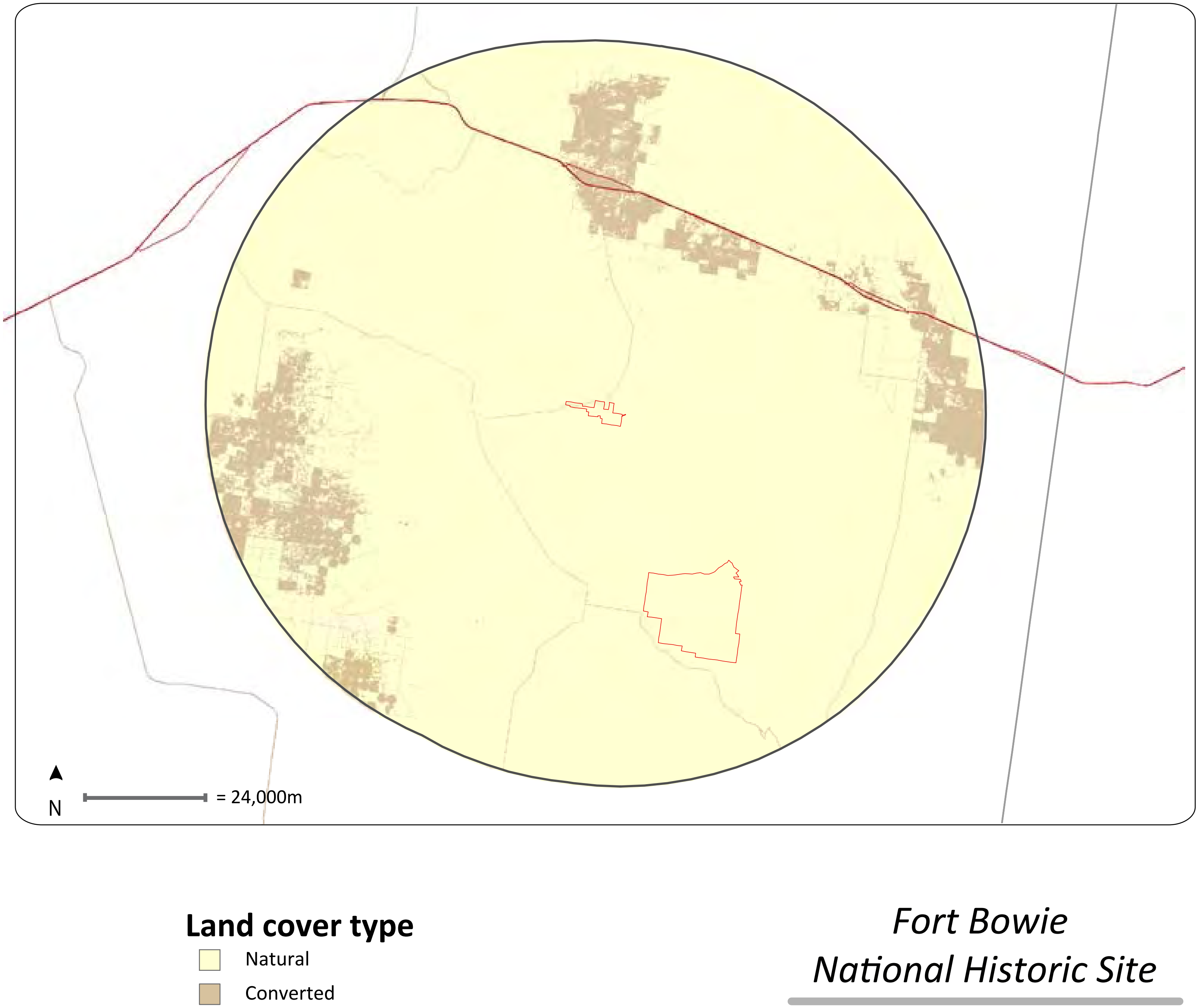


Figure 4.27. Natural versus converted land cover within 30 kilometers of Fort Bowie NHS (NPS 2010d; Homer et al. 2004; Fry et al. 2009).

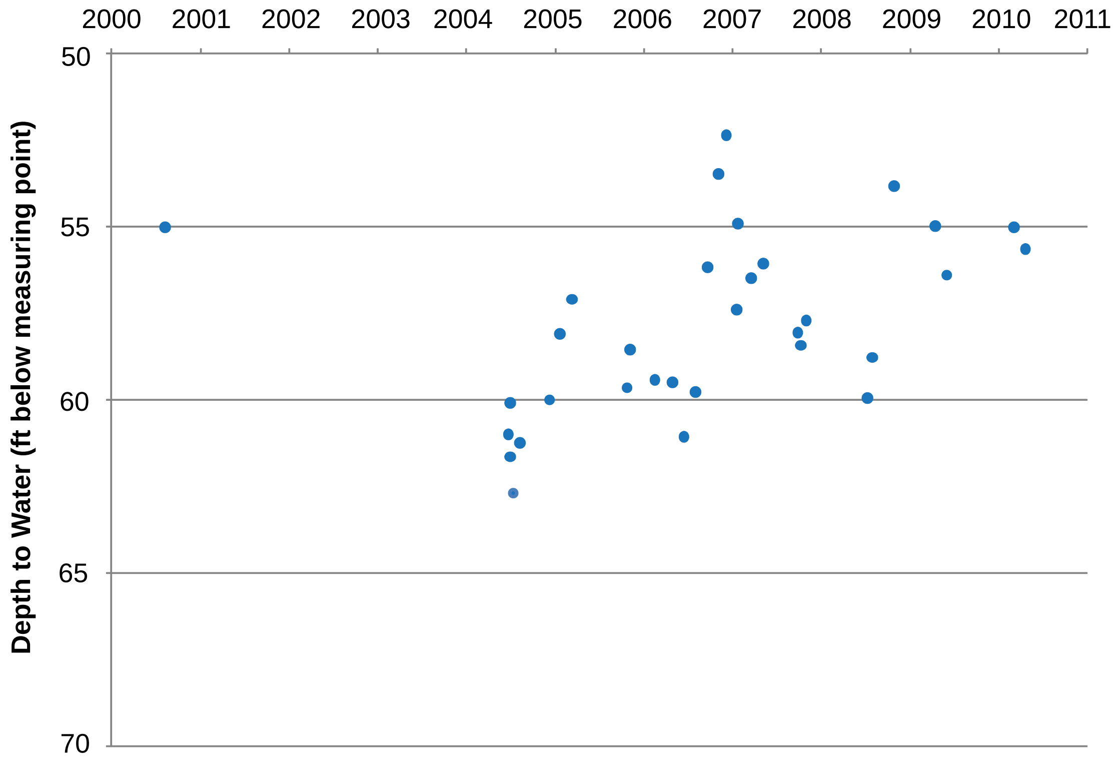


Figure 4.28. Depth to water measurements at Fort Bowie NHS, Well 55-582902 (NPS SODN 2011).

when intense rainfall damaged piping and water meters. Total flow at the spring was measured by a timed catch method and with a portable flume. Maximum total flow during the study for Apache Spring was 4.8 gpm, and minimum total flow was 3 gpm (Figure 4.29). Discharge at Lower Mine Tunnel Spring is greater in magnitude by an average of 1.4 gpm (Figure 4.29).

In June 2010, the NPS Sonoran Desert and Chihuahuan Desert Networks collaborated on a seeps, springs, and tinajas inventory across their network parks. Field crews surveyed three springs at Fort Bowie NHS: Apache Spring, Lower Mine Spring, and Upper Mine Spring. The crews collected data on hydrology, geology, and invertebrates at most of the seeps and springs (NPS SWNC 2010). Abundance and diversity of invertebrates were not assessed in a quantitative fashion. The reports on these surveys also do not include species lists, so it is not possible to determine if any sensitive invertebrate species or species of management concern were encountered.

NPS field crews measured discharge at the springs using the volumetric method. Crews captured the flow by constructing a small earthen dam using local materials, inserting a tube into the dam, and collecting the water flowing from the tube in a container with known volume. The total amount of time required to completely fill the container was recorded and then flow rate was calculated (NPS SWNC 2010).

Water was observed flowing at all three of the springs. Discharge was measured 0.21 liters/second (3.3 gpm) at Upper Mine Spring, 0.23 liters/second (3.6 gpm) at Apache Spring and 0.36 liters/second (5.7 gpm) at Lower Mine Spring (Table B.10; NPS SWNC 2010). Data from 2010 has not undergone quality assurance/quality control, so the author's confidence in the exact discharge results is low. However, the author's confidence that the data represent presence of flow in June, prior to the monsoon, is moderate.

Water Quality

Water quality sampling was conducted at Fort Bowie NHS as part of the Baseline

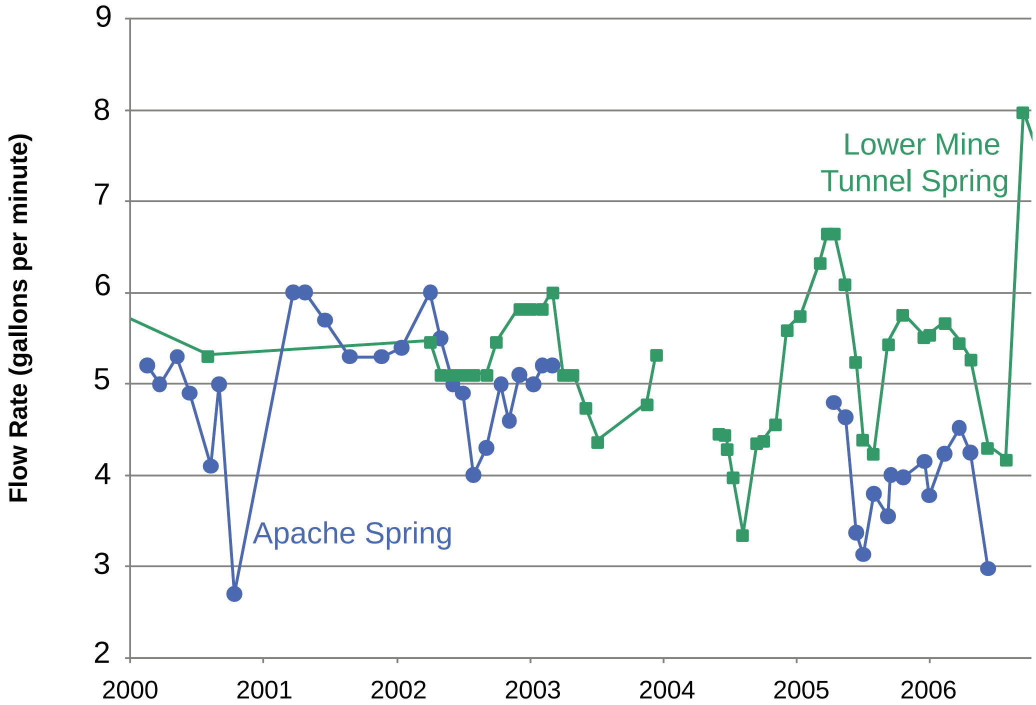


Figure 4.29. Discharge at Apache Spring and Lower Mine Tunnel Spring, Fort Bowie NHS (Filippone 2009).

Water Quality Inventory (Brown 2005). In addition to the analysis of the samples collected for the baseline inventory, analyses for one additional site, Lower Mine Tunnel spring, at Fort Bowie NHS was included in the review (NPS 2009). For the purpose of establishing applicable water quality criteria, designated use classifications are prescribed in Arizona Administrative Code Title 18, Ch. 11 Department of Environmental Quality – Water Quality Standards. All of the surface waters sampled in the SODN Level I Baseline program are designated as Aquatic and Wildlife waters (A&W).

Analyses of three water samples from Apache Spring (Brown 2005) and one sample from Lower Mine Tunnel Spring (NPS SODN 2009) were reviewed. These perennial springs are located very near the top of their respective watersheds and both discharge along the Apache Pass fault zone from the same aquifer. Since the elevation of these springs is between 4,900 and 4,950 ft, the designated use classification of these two springs is A&Ww. Major ion compositions of the samples are plotted in Figures B.4 and B.6. Figure B.4 illustrates the similarity in major ion composition of these samples, both of which are calcium-bicarbonate (Ca-HCO_3) type waters (Table B.12). As shown in Figure B.8, pH at these springs ranges from 6.5 to 7.3. Figure B.9 shows low dissolved oxygen at Apache Spring. Low dissolved oxygen may be to some degree attributed to the presence of iron-oxidizing bacteria in groundwater at Fort Bowie NHS, which has been well documented as a result of problems these bacteria have caused to the water system at the park.

Figure B.4 shows that the relative concentrations of major ions are higher for these two springs at Fort Bowie NHS than for the two Chiricahua NM springs discussed earlier. Average total dissolved solids for the four Fort Bowie NHS samples is 345 mg/L. The elevated dissolved solids, conductance, alkalinity and hardness (Figures B.10 and B.11) are attributed to higher mineral solubility within the primary contributing aquifer for water to these springs, which is a fractured fossiliferous limestone (Drewes 1984). Figure B.15 illustrates the difference in calcium, magnesium and sodium proportions in these samples relative to those at Chiricahua NM.

Figure B.16 presents nitrate levels for all of the samples. Among the results shown in B.16, Fort Bowie NHS shows higher levels of nitrate than would be typical for most groundwater springs in the area. Sources of nitrogen compounds to groundwater at the park are limited, and application of fertilizers or introduction of nitrogen via the park's wastewater leach field may be responsible. When groundwater is strongly oxidizing (contains high concentrations of dissolved O2), denitrification does not occur, and nitrogen present in reduced states, such as ammonia, will oxidize to nitrate. Under oxidizing conditions, nitrate is stable and very mobile, and dissolved oxygen is known to persist into groundwater flow systems in areas with minimal soil cover overlying fractured rock (Freeze and Cherry 1979). These conditions are widely present in the upper reaches of the watersheds for these two springs, and may be exacerbated by soil losses in the upper watershed area where human use has been intensive for the past 150 years. There is no A&Ww standard for nitrate.

The NPS water quality baseline report (NPS WRD 1997b) reviewed water quality data from six stations located within Fort Bowie NHS boundaries and two stations outside the park. Within that cohort, no reported parameters were identified that exceeded applicable water quality standards.

In summary, natural water sources sampled at Fort Bowie NHS were reviewed and compared to State of Arizona standards for Aquatic and Wildlife warm water designated use. Apache Spring failed to meet the standard for dissolved oxygen. However, natural processes are reasonable explanations for the presence of low dissolved oxygen levels in the springs sampled; therefore the presence of dissolved oxygen in these waters below state criteria is not considered to be problematic or requiring attention. All of the remaining samples were in compliance with A&Ww criteria for surface waters. For these reasons, water quality at Fort Bowie NHS is considered to be in good condition.

Soils

As described in Section 4.1.1, dynamic soil characteristics and soil biota can change over relatively short periods of time and are directly influenced by management actions. Soil surface cover, biological soil crust composition and cover, and surface soil aggregate stability are important dynamic soil properties and relate to soil and site stability and hydrologic function. While biological soil crusts are an important component of the vegetation and soil community at Fort Bowie NHS, reference conditions for biological soil crust composition and cover are undetermined for the Madrean Archipelago. Therefore, biological soil crusts are not included as an indicator in this assessment.

However, Hubbard et al. (2010) proposed reference conditions for soil cover and surface soil aggregate stability for Fort Bowie NHS. The soil cover reference condition focuses on the percent cover of bare ground and adopts work done by the Bureau of Land Management and The Nature Conservancy at Las Cienegas National Conservation Area. Gori and Schussman (2005) set the desired amount of bare ground cover at 30% to minimize erosion potential. In this assessment, we use a stricter reference condition of 30% bare ground cover regardless of vegetative cover. Hubbard et al. (2010) propose a reference condition for surface soil aggregate stability, as measured using a modified wet aggregate stability field method, based on professional judgment and Herrick et al. (2005). In the soil aggregate stability field method, samples are scored from 1 to 6, with 6 being the most stable. Hubbard et al. set the reference condition as the percentage of soil aggregates in the "6" class should be greater than 20%.

The University of Arizona Student Chapter, Society for Range Management, collected soil cover data at eight sites in 1994 as part of a rangeland assessment (Ruyle 2001). The students used a point-quadrat method for determining soil cover by class (bare ground, litter, live vegetation, rock, and gravel). The quadrats were places one-pace apart along four parallel 25-pace transects. Because the data was collected more than 15 years ago, data from Ruyle (2001) is not included here.

Hubbard et al. (2010) summarize results of the NPS Sonoran Desert Network's of terrestrial vegetation and soils monitoring in upland areas of Fort Bowie NHS. Ten permanent field-monitoring sites and three test sites were established and sampled in 2008 (Figure B.22). At each site, the Sonoran Desert Network established permanent, 20 × 50-m sampling plots. Vegetation sampling was done in conjunction with soil cover and stability measures along six 20-m transects within a plot utilizing the line-point intercept method with points spaced every 0.5m. Soil cover was recorded by substrate class (e.g., rock, gravel, litter, bare ground, etc.), with biological soil crust cover recorded to morphological group (e.g., light cyanobacteria, dark cyanobacteria, lichen, moss). Surface soil aggregate stability was measured using a modified wet aggregate stability method (Herrick et al. 2005) at up to 48 locations per plot. Samples were scored from 1 to 6, with 6 being the most stable.

NPS Sonoran Desert Network terrestrial vegetation and soils plots were allocated through a Reversed Randomized Quadrant-Recursive Raster (RRQRR) spatially balanced design using strata based on a combination of elevation intervals and soil rock fragment classes. The sampling frame for Fort Bowie NHS includes all terrestrial areas within park boundaries, except for areas with slopes ≥45° (for crew safety), within 100-m of roads and buildings, within 50-m of washes and trails (including Butterfield Stage Road), and selected cultural features (such as the first and second forts, cemetery, Indian Agent and Butterfield stations) . The total area excluded from the sampling frame was 543 acres, or approximately 56% of the park area (Hubbard et al. in review). None of the NPS Sonoran Desert Network plots fell within the Apache Spring watershed. Therefore, inference from the plots at Fort Bowie NHS is to all terrestrial areas of the park, except for the areas described above.

Due to the timeliness of the data collection, data from by the NPS Sonoran Desert Network is used in this condition assessment. Comparisons between Ruyle (2001) and the NPS Sonoran Desert Network (Hubbard et al. 2010) are difficult due to the use of different field methods, different sampling locations, and 14-year gap in data collection.

Based on the 13 plots collected by the NPS Sonoran Desert Network, soil substrate cover was dominated by gravel and plant litter. Less than 5% of the soil surface was bare soil (Table 4.19; Hubbard et al. 2010). See Table B.17 for plot-specific results.

Overall, about one-third of the samples were in the 6 (very stable) category. Samples collected under vegetation tended to have higher stability values than those collected in open spaces (Table 4.20; Hubbard et al.

Table 4.19. Park-wide soil surface cover (mean % cover by class and standard error), Fort Bowie NHS. Summary of thirteen plots of data from 2008 Sonoran Desert Network monitoring (Hubbard et al. 2010).

Soil Substrate	% Cover Mean ± SE
Bare ground	4.4% ± 0.82
Gravel	49.1% ± 3.4
Litter and Duff	31.7% ± 2.1
Rock and Bedrock	9.1% ± 2.1
Plant base	5.6% ± 0.7
Biological Soil Crust	0.064% ± 0.043

Table 4.20. Park-wide soil surface aggregate stability class (mean and standard error) and proportion of samples in "very stable" (=6) category, Fort Bowie NHS. Summary of thirteen plots of data from 2008 Sonoran Desert Network monitoring (Hubbard et al. 2010).

	Average Soil Stability[1] Mean ± SE	% samples in category 6[1] Mean ± SE
All samples (n=591)	3.80 ± 0.09	36.1% ± 4.1
Under vegetation (n=526)	3.94 ± 0.09	37.8% ± 4.2
No vegetation (n=65)	2.63 ± 0.26E	21.5% ± 4.8

[1]Samples rated on stability scale from 1-6. Category 1 = very unstable; category 6 = very stable

2010). However, greater than 20% of the samples collected in open spaces were in the 6 (very stable) category. Significantly more samples were collected under vegetation than were collected in open spaces. All thirteen of the NPS Sonoran Desert Network sites had an average surface soil stability rating of at least 3 (somewhat stable). Eight of the sites had a surface stability rating of at least 3.5, the midpoint between "very stable" and "very unstable." See Table B.18 for plot-specific results.

As a whole, Fort Bowie NHS soil indicators meet their respective reference conditions. The areas of the park included in the NPS Sonoran Desert Network 2008 monitoring effort appear to be well-protected from soil erosion. The overall soil aggregate stability of the sites was moderate to high, indicating that the sites can resist erosion and that the soil-biotic system is functioning. Total cover of the sites was very high, with little exposed bare soil. However, a large amount of cover comes from annual grass plant bases, litter, and duff, which could leave the sites susceptible to erosion if fire or drought removed those materials. While the data was collected recently using peer-reviewed data collection methods, the area of inference was less than half of the park. Therefore, our confidence in the data and its ability to assess current is moderate.

4.2.3.2 Biological Integrity

Major Biomes

Most of Fort Bowie NHS area is in a transitional zone between desert grassland and oak woodland. Which of these dominates has probably changed in historic and prehistoric times in response to minor climatic fluctuations and human land use. Chihuahuan desertscrub occurs within a few miles of the park, and Fort Bowie NHS's hillsides could permanently convert to desert if the thin soils erode away.

Biological Diversity

Fort Bowie NHS is quite diverse considering its tiny area (Table ES.2). Compared to the Arizona portion of the Sky Island Archipelago, Fort Bowie NHS has more than a quarter of its plants (572), more than half of the amphibians and reptiles (73, one fewer than larger Coronado NMem and many more than much larger Chiricahua NM), well over half of the mammals (61), and nearly 40% of the birds (188).

Biological Corridors

Because of its relatively low elevation, Fort Bowie NHS is part of the northward migratory corridor for birds and bats (section 4.1.2.9).

Exotic Species

Although there are numerous exotic species established in the parks, the great majority do not appear to be invasive (e.g., they are not causing significant ecological harm or posing a health hazard). Some are invasive, but are already so widespread and well established that control is probably not feasible, e.g., Bermuda grass and London rocket. Most of these species also seem to have attained their maximum invasive potential; they probably are not increasing further, at least not into undisturbed habitats. Those that should be monitored and may need management action are: Lehmann lovegrass (management techniques can reduce its dominance) and curly dock.

Rare and Endemic Biocommunities and Species

Fort Bowie NHS has no known rare or endemic plants. The list of possibilities is in Table 4.4. Rare vertebrates that are currently or were historically present are grizzly bear, jaguar, lesser long-nosed bat, and Chiricahua leopard frog (Table 4.16). The lists are probably incomplete. See the discussion of data gaps in Section 5.1

Ecosystem Health

The grassland northeast of Fort Bowie NHS is shrub-invaded nonnative grassland, while the area to the southwest is native grassland with low shrub cover. The condition of the grassland within Fort Bowie NHS is not classified on the available GIS layers. The AZ veg gap layer categorizes it as mixed grass-mixed scrub with some mixed grass-yucca-agave.

Our site visit revealed that a shrub invasion appears to be under way.

Fort Bowie NHS is in the ecotonal zone between grassland, woodland, and Chihuahuan Desert (which is a few miles from the boundary). The vegetation is therefore very sensitive to climate change and human disturbance, so significant shifts in community structure and floristic composition may occur in the future. Such change does not necessarily indicate a health problem.

4.2.3.3 Special Themes

Erosion

Erosion within the Apache Spring watershed was identified by resource staff at Fort Bowie NHS as a threat to the cultural and natural resources of the site. The impact of erosion on infiltration and recharge and on potential vegetation are concerns (Nauman 2010). Recently, Nauman (2010) mapped erosion features and estimated soil losses in the Apache Spring watershed. The NPS Sonoran Desert Network vegetation and soils monitoring efforts does not have any plots within the Apache Springs watershed so dynamic soil properties are not available for the watershed (Hubbard et al. 2010). There are no established reference conditions for erosion.

Nauman (2010) mapped 551 active erosion features within the Apache Springs watershed. Features mapped fell into one of three categories: sheet erosion, rills and gullies. Sheet erosion begins with raindrops dislodging soil particles from the surface. As runoff travels over the surface, it picks up and transports the particles dislodged by the raindrops. Rills are small water courses that are a few centimeters deep. Gullies are larger channels that are typically deeper than 0.5 meters. Of the 551 erosion features mapped, 163 were classified as sheet erosion, 212 as rills, and 176 as gullies (Nauman 2010). Overall, 54,000 square meters within the Apache Springs watershed were affected by erosion. Nauman (2010) estimates that the 551 mapped erosion features represent nearly 59,000 cubic meters (m^3)of soil loss. The majority of soil loss occurred in gullies (approximately 57,000 m^3).

Nauman (2010) posits that the rills and sheet erosion features were between five and ten years old. However, determining the age of gullies is more difficult and the gullies likely represent erosion over the past 150 to 200 years. Erosion over the past 200 years affected the ground level at Apache Spring. Since the early 19th century, the ground level at Apache Spring has decreased 6-12 feet (Nauman 2010).

Soil losses within the Apache Spring watershed have been identified as key to significant decreases in spring discharge at the spring in recent decades (Filippone 2009). Decades of human use and abuse concentrated in the second fort area have taken their toll on the natural vegetation and soils that were once present. As soils are lost, reduced infiltration and storage of precipitation within the upper reaches of the watershed occurs, surface runoff increases, soil losses are accelerated, and a cycle of ever-diminishing water availability occurs. Mitigation of soil losses within the Apache spring watershed is deemed extremely important to the long-term viability of Apache spring as a perennial resource at the park, particularly during periods of long term drought.

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5.1 Data Gaps

We identified several data gaps during the condition assessment, listed below.

Invertebrate inventory

Two major areas are chronically overlooked in biological assessments. One is the invertebrate fauna. Invertebrates comprise about 90% of all species in most communities, yet are rarely given more than cursory attention. In most regions the state of knowledge is still in the alpha taxonomy phase (discovering and naming new species). The Sky Islands Region is no exception, although some groups have been fairly well documented thanks to researchers who have worked at the Southwestern Research Station and elsewhere in the region. The life cycles and ecological functions of the vast majority of species are still unknown. Forty-five invertebrate species that occur, or could occur, in Chiricahua NM, Coronado NMem and Fort Bowie NHS are listed by federal agencies for protection or as "species to guide management decisions" (e.g., US Forest Service; see Table C.5).

Soil biology

The other major neglected area is soil science. Soils are often mapped from a geological perspective, but their status as biological communities is usually ignored. These living substrates are the foundations of the ecological web, and are thus of crucial importance in understanding the health of the macrobiotic communities above ground. Most soil organisms belong to poorly studied groups, i.e., non-insect invertebrates and the kingdoms of small to microscopic organisms such as bacteria, fungi, cyanobacteria, and lichens.

One readily visible component of the soil community is biological soil crusts. Field guides for identifying the major organisms of biological soil crusts are beginning to appear (e.g., Rosentreter et al 2007). While the NPS Sonoran Desert Network includes biological soil crusts as part of its vegetation and soils monitoring program, there is limited information on the distribution, abundance and ecological role of biological soil crusts in the Madrean Archipelago. Further research is needed in this area.

Ephemeral/Intermittent Washes

We have limited information on the channel morphology and streamflow of ephemeral washes within the three park units. The NPS Sonoran Desert Network continues to develop a wash monitoring protocol that should address this data gap.

Seeps and Springs

We have limited information on the flow and biodiversity of seeps and springs at the parks and within the region. The NPS Sonoran Desert Network is developing a seeps, springs, and tinajas monitoring protocol that should address a portion of this data gap but more research is needed.

Other species inventories

The National Park Service and other land management agencies generally lack sufficient data on biological diversity to prevent, and even to recognize, the loss of species from protected lands (Swann et al. 2010). Thorough and regularly updated inventories are essential baselines from which to monitor the effectiveness of conservation programs. A useful inventory is more than a species list; it must include long-term distribution and abundance data in order to detect significant population trends.

The Inventory and Monitoring (I&M) database is several years out of date with respect to Karen Krebbs' bat inventories. Other inventories may also be out of date. The difficulty of maintaining the inventories is exacerbated by the ever increasing rate of taxonomic revisions, which make the comparison of biotas between parks particularly troublesome. (An example is the claret cup cacti *Echinocereus triglochidiatus*, *E. coccineus*, and *E. arizonicus*. Until recently they were regarded as a single species. After the recent splitting and subsequent partial recombining, it is not known whether one, two, or all three entities occur in the three parks. Certain identification requires chromosome counts.) The current I&M database is a monumental accomplishment, but still more work to complete it and keep it up to date is needed to make it fully useful.

Fire history

According to available GIS data, only Coronado NMem has spatial fire data, and only for two fires in the 2000s. There is a fire intensity map for Coronado NMem but the time period covered is not indicated. Data for Chiricahua NM and Fort Bowie NHS identify only ignition points, with no areal extent mapped. Only Fort Bowie NHS has a fuel density map. Table 4.6 contains fire data found in printed records; the data appears to be incomplete.

Grazing history

We have no detailed data on grazing intensity over time. This is important to know, because grazing can alter the composition of biological communities.

Impacts of border activities

We have limited information on the impacts of border activity; they need to be researched and monitored more precisely. While studies are currently underway, this is a critical data gap for the region.

Vegetation maps

National Vegetation Classification Standard (NVCS) mapping is incomplete for the Sky Island Archipelago. We could not find a map that covers the region at the formation level, which is roughly equivalent to the extensively used Brown-Lowe-Pase vegetation map (BLP map, 1980). Several federal land management agencies are currently mapping their respective areas to the Alliance and Association levels, but without interagency coordination (Todd Esque, USGS, pers. comm. 2010). As detailed as the protocol is, the NVCS system is not sufficiently standardized to produce consistent classification by different teams. The result is that regional maps by one agency or survey team are not comparable to those of adjacent lands managed and classified by other agencies and teams. Therefore it is not possible to use existing (and probably future) NVCS maps to assess the abundance and distribution of vegetation types throughout the region. The three parks have almost no associations in common, which seems unlikely to us.

The most detailed map we found for Chiricahua NM is the GIS layer chir_veg_3BLP_poly; it was found on the NPS website, but its origin is unknown. The map does not conform to the current monument boundary. It maps the vegetation to the levels of Association and Subassociation (the latter category is not in the NVCS 2008 hierarchy).

Historic photographs

A preliminary inquiry revealed that there are numerous photos of likely value to NPS that are scattered among several agencies, including the Arizona State Historical Society and the Desert Laboratory on Tumamoc Hill (repeat photography project). Many of them are not cataloged under subjects that clearly identify them as valuable to NPS purposes. It will require considerable research to locate and catalog them in a central database, but it is probably worth doing. Some photos are kept at Fort Bowie NHS headquarters, reportedly not under archival storage conditions.

Species of conservation concern

There appear to be no existing lists for the three parks. We have compiled some tentative lists based on our experience and on lists for adjacent lands. There are probably omissions in these lists. The list of vertebrates of management concern is especially weak except for the charismatic megafauna.

Rare and Endemic Biocommunities and Species

The Arizona Gap Analysis Project (Gebow 2001) identified 4 at-risk plant communities in the Sky Islands Archipelago. But none of the park maps compiled in the GIS product identify any of them under the Gap names. There may be a mismatch in naming, or perhaps none occur in the three parks. Even though there are relatively few endemic species in the Sky Island Archipelago, lists of rare and endemic species we found seem short to us. They are probably incomplete. We found no list of rare and endemic vertebrates, other than the well-known charismatic megafauna.

5.2 Recommendations and Conclusions

Based on our review of existing information about the Madrean Archipelago, Chiricahua NM, Coronado NMem, and Fort Bowie NHS and our professional experience, we make the following recommendations and conclusions:

1. It is easier and biologically wiser to manage ecosystems than to manage individual species. The number of species of management concern in southeastern Arizona is large and continually growing. Realistically, park resources will never be sufficient to deal with each species as a separate management issue. Focusing attention on maintaining healthy biological communities will assure the well being of nearly all of their component species, leaving only a small number of highly specialized species that may require individual attention.

2. There is little need to fight most naturally caused fires in areas where there is not excessive fuel accumulation or human structures. But forests and shrublands that have unnaturally dense biomass are at risk of being damaged by fires. Before the 20th century frequent ground fires burned throughout most biological communities in the Madrean Archipelago. These fires had a neutral to positive long-term impact on the communities, because they are adapted to periodic burning. The policy of aggressive fire suppression begun in the early 1900s has resulted in fuel accumulation that has in turn led to catastrophic crown wildfires (Swetnam 2005). With the added stresses of climate change in the 21st century, crown fires are more likely than ever to cause type conversion (permanent replacement of one community by another) of large tracts of land to more arid and perhaps less stable communities.

3. Many of the ecosystems in the Sky Island Archipelago (and all over the planet) are characterized as fragile. We encourage the adoption of a different perspective. In fact, most ecosystems are robust and resilient. That so many of them are threatened is not so much a result of fragility as an indication of the enormous magnitude of damage that humans are inflicting upon them. If we develop an understanding of their functions and learn their limitations, they should thrive with modest management efforts.

4. Park management should monitor large predators, which as a group are essential to a healthy ecosystem. Three of the region's four largest predators (grizzly bear, Mexican gray wolf, and jaguar) have been extirpated, leaving only the mountain lion. The structure of sky island communities is probably changing because of their absence. Smaller predators (bobcat, coyote, bats, etc.) are also important indicators of healthy ecosystems and should be monitored.

5. Continue to inventory and monitor bat species in parks; they make up nearly a third of the mammals of the region. There are few (if any) long-term bat-monitoring projects at Arizona National Parks other than the Krebbs' (2000 to present) summer bat surveys at Chiricahua NM and Fort Bowie NHS. Winter bat surveys are also recommended. Acoustic monitoring would provide additional information. Continue to monitor the transient roost (State of Texas Mine) and small adits for the endangered lesser long-nosed bats and Mexican long-tongued bats at Coronado NMem during the summer months.

6. Participate in reintroductions of extirpated species such as prairie dogs, black-footed ferrets, aplomado falcons, thick-billed parrots, Mexican gray wolves, etc. Habitat is available for these species in the parks.

7. Anticipate and embrace the possible immigration of animals from Mexico (jaguar, thick-billed parrots, ocelot, etc.) and other tropical animals and plants into the border parks. Global warming also should support the northward extension of the ranges of other tropical species. Similarly, climate change may drive mesic and cold-tolerant species higher in elevation and farther north, perhaps beyond park boundaries.

8. Digitize and share climate data from Fort Bowie NHS with the National Oceanic and Atmospheric Administration, National Weather. Sharing the data requires quality assurance/quality control measures, allows for 30-year historic average calculations, and enables data sharing.

9. Continue to monitor spotted owl nests and populations in the Chiricahua and Huachuca Mountains.

10. Facilitate research on the distribution, abundance and ecological function of biological soil crusts in the Madrean Archipelago.

11. The Apache Spring watershed is the source of the area springs and water supply for the park and should be proactively managed to restore vegetative cover and to enhance infiltration and soil retention.

12. All efforts should be made to protect biological corridors from northern Mexico (i.e.-Ajos-Bavispe Federal Reserve) to southeastern Arizona. Corridors provide connectivity and improve animal populations, health, and enhance adaptation in the face of widespread environmental change (e.g., climate change).

13. Identify species of management concern including invertebrates, and initiate surveys and monitoring efforts (several dozen species of insects are listed as of special concern to federal agencies – see Table C.5).

14. Develop cooperative management polices with the neighboring US forest Services, for habitats and species that cross park boundaries, such as vegetative communities, riparian corridors, and large and/or vagile animal species. The "Landscape Conservation Cooperative" program of the Department of the Interior (Nature 2011; DOI Secretarial Order 3289) might be a good model for such cooperation.

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Appendix A: Documentation for GIS Data Products

GIS spatial database

Basic data acquisition and pre-processing

Data needs were determined from initial project documents and in consultation with NPS project personnel and this augmented with other available data that seemed relevant to the purpose of the project. Representative originating data sources include the National Park Service, US Geological Survey, USDA Forest Service, the Bureau of Land Management, the Nature Conservancy, US Fish & Wildlife Service, US Bureau of the Census, Instituto Nacional de Estadística y Geografía, and many others.

These data were obtained primarily online, from a variety of primary or secondary sources (data repositories or aggregators; layer metadata will indicate original source and may indicate distribution source). Some data was delivered directly (USB drive, DVD) and some originated from GPS output or were created specifically for this project.

Project data collection began with the National Park Service Data Store, accessed online for individual Park data. Data varied substantially in content, coverage, age, completeness, and accuracy. Additional internal NPS data supplemented this. Depending on the desired extent and content, other data was then located to build on what NPS had available. See layer metadata for specific information on data source.

Data was obtained in a variety of projections, file formats, and extent, and in different levels of completeness, accuracy, etc. Many data layers had to be re-projected, clipped, or otherwise manipulated. Some data was not usable because of corrupt files, errors, or other issues significant enough to make it unusable (or untrustworthy). After data was obtained and examined for error, extent, relevance, etc., all projections were verified and standardized. In addition, at this point mapping extents for the various components of the project were standardized.

Once all data were in the same projection, layers were clipped (subsetted) to the appropriate area. Park-specific data was sometimes limited, due to original collection or recording, to the actual Park boundary, in other cases data was clipped to a 3000m buffer area around the boundary. This was done so as not to lose relevant coverage at a non-natural boundary. In other instances, data was extended past this buffer area to encompass the data itself (watersheds for example) where another artificial boundary (the buffer) would have limited the usefulness of the data. For the regional context mapping, a somewhat arbitrary frame (see frame metadata for specific criteria) was used to clip less detailed data.

Both vector and raster data were processed for the different mapping units. Raster images were clipped or in many cases mosaiced (combining image tiles to one raster) and then clipped. For better compatibility with image processing and design software, most imagery was retained or converted to .tif format. The exception was the very large combined 2010 National Agricultural Imagery Program 1m color imagery. These high-resolution images were processed in ERDAS IMAGINE and saved in ERDAS .img format. This format is specifically structured for image analysis, saves smaller than a comparable .tif, and is natively read by ArcGIS.

All project work was done with ArcGIS 9.3 on a Windows 7 Ultimate 64-bit system. More involved image processing was done in ERDAS IMAGINE 9.2, and maps created with Adobe Photoshop and Illustrator CS4 (initial data layout, symbolization, etc. were done in ArcGIS).

Basic data theme processing

Once data was projected and clipped, any editing was performed. Editing tasks included, as examples, correcting obvious errors (e.g., realignment tracing of roads from 2010 high-resolution aerial imagery), adding attributes (fields), adding missing attribute information or correcting or clarifying existing attribute data, adding records, and creating new layers.

When similar layers such as roads exist for all Parks, these were standardized to the extent that they all carry the same minimum fields. Additional fields may be present if these were in the original data (these differ for each Park). As far as practicable, symbolization of these layers was standardized as well.

When editing was complete, field geometry values were verified or recalculated (length, area, perimeter, centroid, latitude (y values), and longitude (x values)). Unless otherwise specified, all measurements (length, perimeter, area) are metric. Length measures are in meters or kilometers (some tables, such as roads, have a miles or feet field as well); area measures are in hectares and/or square meters (some datasets have acres as well). Once all measure fields were updated, layer geometry was verified to detect errors (ArcGIS Check Geometry tool run on all relevant layers) and any adjustments or corrections made. Typical examples of these types of errors are self-intersecting lines or polygons and overlapping polygons. Finally, Set Data Source(s) was run to verify and ensure proper data source pointers.

For maximum flexibility with existing data, all operations were done on or using the ESRI shapefile format. Concurrently, the structure for a geodatabase for each project component was developed and this populated once layers were processed and complete. Final project spatial database deliverables will include some original data, complete shapefile-based ArcGIS file sets, and folder geodatabases as well as ancillary files such as map products and documentation. All project GIS files will be delivered in DVDs. For archival purposes, the contractor will retain copies of all project GIS products and files for a minimum of two years. Please see the data disclaimer at the end of this section.

General notes on data and data applicability

As noted, data varied in quality and coverage and, therefore, to or for what and where it can be reasonably applied. In many cases layer metadata will note a specific scale or range in which the data can be considered valid (or a “validity threshold” that defines an upper or lower limit for which the data would be considered acceptable for some particular use). All data is acceptable for display purposes but not all data can be used for analysis—either examine layer metadata for applicability or make a decision based on specific needs and data limitations.

The project calls for four sets of data, three at the unit level for each Park, and a larger, less-detailed, regional presentation for context and location. For our purposes the Park-level data would be considered large-scale and the regional data small-scale, and the selected and processed data for each would reflect the scale ((while the regional frame extends into Mexico, little data is found in typically-available theme datasets so little is presented).

Data at these different scales is more or less detailed depending on intent, acquisition technique, instrument, etc. and hence may be applicable at one level and not another. For instance, data at the Park level is usually not appropriate for display or use at the regional (context) level. In some cases this data may be generalized for incorporation in the regional product but would not be intended for analysis (generally, layer metadata will carry a note about applicability in these cases).

At the regional level (data covers approximately 11,000,000 acres) a fair amount of data is available but it is probably of limited use for Park management purposes. This data is intended to provide some context and setting or location information for the Parks. Some regional layers might be usable at the Park level but, again, would not be suitable for analysis (many layers carry scale constraints). These layers are simply less-detailed or smaller-scale versions of Park data—if something of Park interest is found at the regional level, always check individual Park data. If a layer exists in the data for a particular Park but not in another it means that comparable data does not exist for the other Park.

Specific data notes and comments

For GIS data purposes, NPS Park unit coding is adopted

CHIR = Chiricahua National Monument

CORO = Coronado National Memorial

FOBO = Fort Bowie National Historic Site

Similarly, REGN = Region for the project regional context extent. REGN metadata will note either Region or REGN to refer to this area.

All layers are NAD 83 UTM Zone 12, and data is clipped to either REGN, CHIR, CORO, or FOBO boundaries; to a 3000m buffer area around each Park; or, in cases where clipping would substantially disrupt the data extent or intent (such as watersheds), data was clipped to the smallest unit(s) that maintained data integrity. Note that in some cases clipping would have altered geography but not field contents. In these few cases the affected values or data would not be used for analysis and can be ignored.

As already noted above but worth repeating, much of the data at the regional level is only usable at the REGN scale or context (e.g., night lights data—too coarse for individual Parks). Also as noted above, each Park carries different assemblies of data and if a Park has a layer that another does not have, then data was not available for the latter OR clipping to unit boundaries or 3000m buffer areas resulted in no data being retained (e.g., there is no Forest Service polygon fire data for CHIR, this because the nearest recorded polygon fire event fell well outside the 3000m buffer area).

Some data may be redundant or overlap (for instance, REGN_canals_ditches_pipelines is essentially a subset of REGN_hydrologic_line). These different layers may be from different sources or carry different information. It may be that attribute tables or number of records differ and carry more or less data depending on the layer. It is not always possible, or time-effective, to structure or populate all features the same way but a subset of records or attributes may add valuable information.

Parks may not have similar data coverage. Layers or data may apply to one Park and not another, or, in some cases, data relevant for one Park is not relevant for another. For instance, FOBO has a flood zone layer because flood zone data intersects the 3000m buffer area around the Park. CORO has no flood zone layer because there is no corresponding intersection with the original FEMA data.

Layer files (which hold symbolization information) do not exist for a quite a few layers. This is because many layers carry a number of attributes and rather than taking a guess as to which is more important or simply pick one, it is best left to NPS personnel to select a layer of interest and symbolize it in a way that makes sense for them and the circumstances. One such layer, better custom-symbolized, is habitat potential, for which an analyst could pick one or more species with which to symbolize the data.

Other themes have a common data source but may have two symbolization layers. The REGN_ management _category and the REGN_ management _name are an instance of two layers referencing one data source. It was felt that both management category and management name were important (the REGN_stewardship layer is similar but contains different attributes). If two layers have the same name but a differing number suffix, they are the same theme but different sources or detail—two surface geology layers, for example, may portray different geologic surveys but the topic is the same. They are different portrayals of the same or very similar data although they may or may not have the same data source.

Some layers have display scales enforced such that beyond a certain scale (zoom) in or out they will not show. If layers do not seem to display when checked, try zooming in or out or examine the display scale under layer Properties, Display. Similarly, if a layer has labeling activated but no labels show, check under layer Properties, Labels, Scale Range to see if a scale has been set for labels. There should be no need to alter these settings although they are arbitrary and certainly can be changed to suit purposes.

Although effort were made to obtain the newest appropriate data, some data, depending on source, update timetable, etc. will be old and some will not be the latest. For example, Census 2010 products are being released right now (as of February 2010) but project-relevant tables are not yet available for southeastern Arizona.

CHIR and CORO were both visited with a GPS to help determine and complete some data points and as a trial-run for possible more-detailed work (see below). Features recorded included points such as trash receptacles, restrooms, trailheads, fire hydrants, and others, and line features such as trails. See XXXX_Park_facilities_pnts for details (for CHIR and CORO only at this time).

For many layers, the attribute tables, or most or many of the attribute entries, were left as-is. We do not know to what extent these layers need to be kept compatible with existing projects, products, or processes, or in many cases exactly what the fields represent or are presenting (such as internal NPS coding). We felt it best to retain data at this point in time rather than discard something that may be important later on.

All layers carry metadata. However, metadata is of varying completeness depending on original source, understanding of the data, etc. There was a great deal of variability in the metadata even among data sources. Some Park Service layers, for instance, carried no metadata, a few had metadata that noted the unknown nature of data attributes, and some had very complete metadata.

The schema under which the layers are grouped is based on ESRI's Basemap Data Model*. This seemed to be a convenient and logical model for structuring project data. See the generalized flowchart below for layer structure. Note, however, that data groupings—ArcGIS table of contents entries—are not identical to folder structure.

* Information and templates available at resources.arcgis.com/content/basemap-data-model. From the Web site description: "In every GIS project there are many layers that serve as the basemap. These layers provide context for multiple GIS workflows, such as editing data or producing cartographic products. Basemap layers include themes such as hydrography, physiography, boundaries, transportation, cultural features, and elevation. You will find features such as these on topographic maps. Other maps may use some or all of these features as the geographic base for showing operational layers, such as soils, geology, zoning, and utilities. Many of these same layers also appear in base for maps that overlay satellite imagery or orthophotography."

Next-steps

The project team believes strongly in the utility of detailed data for Park units. Such data should be available and as much as practical and useful, should be compatible between Parks.

In addition, since Parks lands do not function within an artificially-bounded ecosystem, data should extend beyond Park boundaries sufficiently to add context and to help present and model the relationships and elements of the wider environment in which Park management decisions should be considered.

There are many opportunities for refining or extending this project, from relatively simple to long-term and complex. The first steps, regardless, would be to review all data, if possible with originating source input, to correct, update, and further standardize and structure data. A final data update should be accompanied by a review and standardization of metadata, and the development of a GIS and data collection, processing and management protocol.

Another important task to consider is making the different datasets compatible between Parks. Finding a best-practices set of attributes, domains/values, database structure, naming conventions, etc. would, once established, allow the Park Service to better compare and analyze Park built and natural environments. Beyond this, however, a uniform system of recording, archiving, and manipulating data simplifies personnel training and skills transfer, streamlines data entry, avoids duplication, and helps ensure appropriate and standardized data projection, extent, and content. For example, a geodatabase can be set up to enforce the entry of only the appropriate or relevant road types, these dependent on NPS criteria or needs.

Once there is an established comfort level with the GIS and data, a good, logical next-step could be to spend some time in the Parks with a survey-grade GPS instrument recording the locations of facilities or anything of management interest. These could include anything from electrical boxes to water lines, buildings, or natural features. Recording is essentially limited by time, funds, and need. Depending on how ambitious one is, a basic survey of a Park would be relatively easy and inexpensive and can be built upon as funds become available or as needs arise (keeping the recording method, format, and storage standard). This has been done in a more-rudimentary fashion (consumer-grade GPS but points then referenced to aerial imagery) for CHIR and CORO, as noted above.

A step up in complexity would be to link geodatabase features with archived or current imagery. A reasonable project might spatially integrate Park Service archival images—extensive for some Parks, with current locations and conditions. This would enforce standardized and accessible image treatment, simplify and consolidate some before-after analysis, and provide a more-complete and "better picture" of the resource or condition. Images can be accessed directly in ArcGIS by linking or embedding and would allow one to view both a location and data associated with it at the same time and in the same place. Besides archival or comparison uses, images of Park facilities (electrical boxes, fire hydrants, culverts, buildings, etc.) or natural resources (trailheads, invasive plant infestations, springs, erosion areas, etc.) could be attached for identification and management purposes.

Still more complex "cloud computing," taking advantage of on-demand self-service Internet infrastructure, could be linked directly to NPS ArcGIS installations. Data is maintained, with an explicit, periodic, update submission and change procedure, on NPS servers somewhere and accessed as-needed. This is much like the NPS Data Store but with refinements/enhancements (such as direct GIS server links) and a renewed emphasis and commitment to data quality, timeliness, and persistence. Remote, centralized (in affect if not in physical space) data storage and access is rapidly becoming more common.

There are many more possibilities for additional uses and functionality, limited mainly by imagination and resources. If the GIS is carefully tailored, structured, integrated, and maintained, the product should be usable and valuable well into the future.

Data disclaimer

The data on which this GIS product is based were obtained from a variety of digital and other sources and these sources were evaluated for relative accuracy, relevance, and temporal applicability. Any derived layers or mapping products were created carefully but may carry errors inherent in the underlying data.

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Layer groups and contents

See appropriate layer metadata for specific details

Layer groups and layers as arranged and displayed in the ArcGIS table of contents (does not model the folder structure).

Data is believed current as of Feb 2011

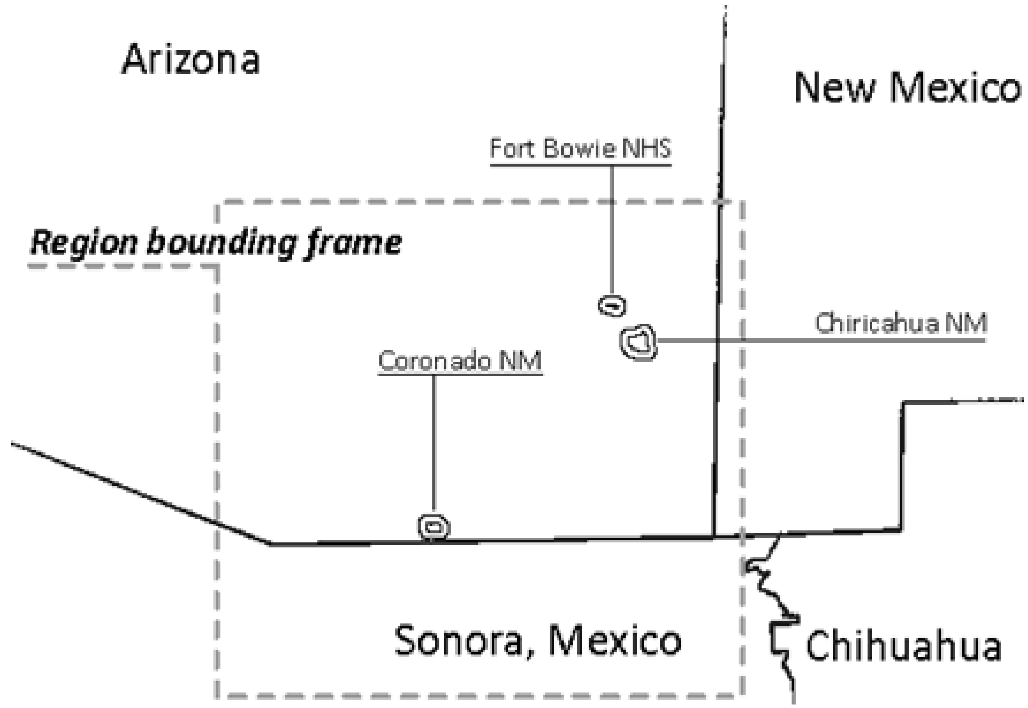
Region/regional mapping extent (REGN)

Chiricahua National Monument (CHIR)

Coronado National Memorial (CORO)

Fort Bowie National Historic Site (FOBO)

Region (REGN)



REGN

Boundaries	
CHIR_3000m_buffer	3000m buffer around Chiricahua NM
CHIR_boundary	Boundary of Chiricahua National Monument
CORO_3000m_buffer	3000m buffer around Coronado NM
CORO_boundary	Boundary of Coronado National Memorial
FOBO_3000m_buffer	3000m buffer around Fort Bowie NHS
FOBO_boundary	Boundary of Fort Bowie National Historic Site
REGN_frame	Region bounding frame
REGN_frame_pnts	Region frame corner points
REGN_states_portion	Country and state border lines (portions) showing region location
Cultural	
REGN_2000_housing_density	Projected regional housing density for 2000
REGN_2100_housing_density	Projected regional housing density for 2100
REGN_Census_2000	2000 US Census data
REGN_cities	20 principal region cities
REGN_landfills	Landfills
REGN_RCRIS_sites	EPA hazardous waste tracking database sites
REGN_TDSFs	Treatment, Storage, and Disposal facilities

Hydrography	
REGN_ADEQ_wells	Arizona Dept. of Environmental Quality wells
REGN_SODN_wells	NPS_SODN monitoring wells
REGN_aquifers	Principal aquifers
REGN_canals_ditches_pipelines	Linear hydrologic features
REGN_dams	Dams
REGN_floodzones	FEMA floodzones
REGN_gauging_stations	Stream gauging stations
REGN_HUC4-digit	Hydrologic Unit Code – 4-digit
REGN_HUC8-12-digit	Hydrologic Unit Code – 8–12-digit
REGN_hydrologic_line	Hydrologic line features
REGN_hydrologic_point	Hydrologic point features
REGN_springs	Springs and seeps
REGN_streams_principal	Primary named streams
REGN_washes	Washes (dry)
REGN_waterbodies	Lakes, reservoirs, ponds—polygon features
REGN_wells	Wells
Hypsography	
REGN_contours_90m	90m contours (USGS National Elevation Dataset (NED) Digital Elevation Models (DEMs))
REGN_contours_30m	30m contours generated from DEMs
Image_base	
REGN_30m_DEM	NED (USGS) 30m DEM
REGN_ETM	Landsat Enhanced Thematic Mapper satellite imagery
REGN_hshade	Hillshade image created from 30m DEMs
REGN_painted	Image created from combined hillshade and classed 30m DEM rasters
REGN_MX_DRG_50k	INEGI 50k DRG topographic imagery
REGN_US_DRG_250k	USGS 250k Digital Raster Graphics (DRG) topographic imagery
REGN_US_DRG_100k	USGS 100k DRG topographic imagery
Reference	
REGN_24k_DRG_index	Index of USGS 24k DRG tiles
REGN_100k_DRG_index	Index of USGS 100k DRG tiles
REGN_250k_DRG_index	Index of USGS 250k DRG tiles
REGN_AMAs	Arizona Active Management Areas (hydrology)
REGN_Congressional_Districts	Region Congressional Districts
REGN_Legislative_Districts	Region Legislative Districts
REGN_grazing_allotments	Grazing allotments

REGN_MDP_boundary	Cochise County Master Development Plan
REGN_ownership_name	Land ownership/management by entity name
REGN_ownership_category	Land ownership/management by category
REGN_PADUS	USGS Protected Areas Database for the US
REGN_PLSS	Public Land Survey System grids
REGN_places	Feature place names for location reference
REGN_Landbird_monitoring_sites	NPS-SODN Landbird monitoring locations
REGN_stewardship	Land stewardship (SW-GAP)
REGN_USGS_photopoints	USGS photo-point locations
REGN_Turner_photopoints	Turner (USGS) photo-point locations
REGN_urban_buffers	1- to 3-mile urban buffer areas
REGN_wilderness	Designated wilderness areas
REGN_WUIs	Wildland-Urban Interface zones
Surface_overlays	
Climate	
Air quality	
REGN_ IMPROVE07	Interagency Monitoring of Protected Visual Environments (IMPROVE) aerosol visibility monitoring site, CHIR and near Douglas (2007; locations)
REGN_ Ozone07	Ozone monitoring site
REGN_ NADP07	National Atmospheric Deposition Program, CHIR, (2007; site location only)
REGN_ GPMN07	EPA Clean Air Status and Trends Network (CASTNET), CHIR (2007; site location and specifications only)
REGN_weather_stations	National Climate Data Center weather station data
REGN_SODN_weather_stations	NPS-SODN weather monitoring locations
REGN_precip	Average annual precipitation
REGN_temp_precip_avgs	Average temperature and precipitation
REGN_temp_avg	Average annual temperature
REGN_temp_min	Average annual temperature minimums
REGN_temp_max	Average annual temperature maximums
Fauna	
REGN_amphibians_habitat	Habitat suitability by species
REGN_amphibians_potential	SW-GAP Species Richness Potential (count ranges)
REGN_birds_habitat	Habitat suitability by species
REGN_birds_ potential	SW-GAP Species Richness Potential (count ranges)
REGN_mammals_habitat	Habitat suitability by species
REGN_mammals_ potential	SW-GAP Species Richness Potential (count ranges)
REGN_reptiles_habitat	Habitat suitability by species
REGN_reptiles_ potential	SW-GAP Species Richness Potential (count ranges)

REGN_critical_habitat	US F&WS general critical habitat areas
REGN_habitat_blocks	Potential wildlife habitat zones (derived)
REGN_potential_link_zones	Potential wildlife link zones (similar to corridors, link habitat zones; derived)
Geology	
REGN_faults	Regional faults
REGN_mines	Mines
REGN_minerals_favorability	Locatable Known Mineral Deposit Areas
REGN_seismic_hazard	Potential for seismic hazard activity
REGN_landslide	Potential susceptibility to landslide events
REGN_soils_GSM	US General Soil Map
REGN_soils_SSURGO	USDA Soil Survey Geographic soils data
REGN_geology_1	Surface geology, 1980 tectonic map
REGN_geology_2	Surface geology, 1983 Geologic Map of Arizona
Land_cover	
REGN_agri	Agricultural land use (NLCD)
REGN_biomass	USDA Forest Service live forest biomass estimates
REGN_BL_veg1	Brown & Lowe vegetation community type
REGN_BL_veg2	B & L-derived vegetation type, sub-associations
REGN_canopy	Vegetation canopy cover, percent
REGN_impervious	Impervious land cover (surface), percent
REGN_landcover1	National Land Cover Dataset (NLCD) land cover, 2001
REGN_landcover2	NLCD land cover
REGN_landuse	NLCD land use, 2006
REGN_arsenic	Arsenic levels
REGN_biotic_communities	The Nature Conservancy (TNC) biotic communities
REGN_conservation_areas	TNC conservation areas
REGN_ecoregions	TNC ecoregions
REGN_grassland	TNC grasslands survey (delineation and condition)
REGN_natural_infrastructure	TNC natural infrastructure composite (index)
REGN_night_lights	Visible impact, night lights/lighting
REGN_topography	Topographic classes
Transportation	
REGN_powerlines	Powerlines
REGN_roads	US and Mexican primary roads
REGN_railroad_lines	Rail lines

Chiricahua National Monument

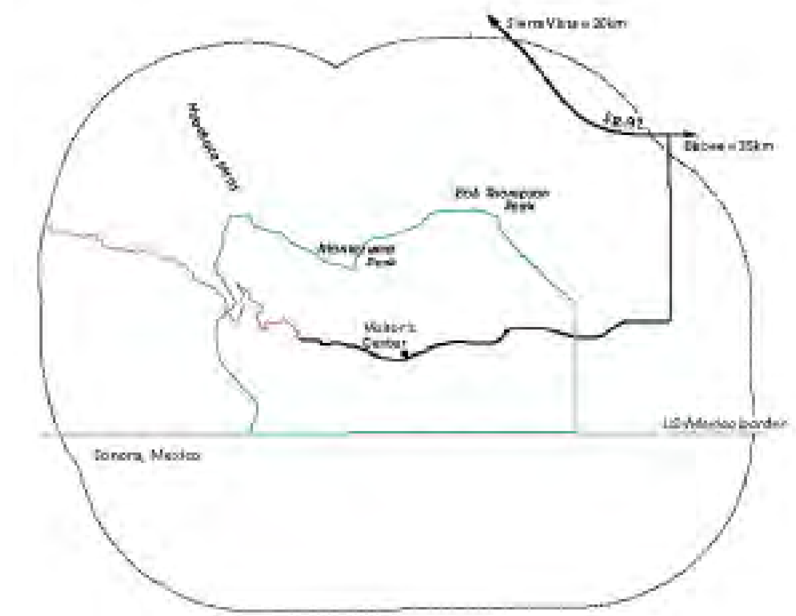
CHIR

Boundaries	
CHIR_boundary	Park boundary
CHIR_3000m_buffer	3000 meter buffer area around Park
Cultural	
CHIR_2000_housing_density	Projected housing density for 2000 (3000m buffer area)
CHIR_2100_housing_density	Projected housing density for 2100 (3000m buffer area)
CHIR_cemetary	Community cemetery, outside Park boundary
CHIR_Park_facilities	NPS and public facilities within the Park, polygons
CHIR_Park_facilities_pnts	NPS and public facilities within the Park, point markers
CHIR_misc_pnts	Misc point markers
CHIR_trails	Designated trails within the 3000m buffer area
CHIR_FS_trailhead	Forest Service trailheads, Coronado National Forest
Hydrography	
CHIR_ADEQ_wells	Arizona Dept. of Environmental Quality wells
CHIR_NPS_springs	Springs (2010 NPS survey)
CHIR_springs	Springs
CHIR_streams	Streams
CHIR_washes	Major washes
CHIR_waterbodies	Lakes, reservoirs, ponds, tanks (polygon)
CHIR_HUC8-12-digit	Hydrologic Unit Code (HUC) 8–12-digit catchment classes

Hypsography	
CHIR_10m_contours	10m contours (USGS Digital Elevation Models (DEMs))
CHIR_elevation_points	Select point elevations (may include landmarks, spot elevations, or benchmarks)
Image_base	
CHIR_10m_DEM	NED (USGS) 10m DEM
CHIR_24k_DRG	USGS 24k DRG topographic imagery
CHIR_aerial	USDA National Agriculture Imagery Program (NAIP) 2010 1m color aerial imagery
CHIR_hshade	Hillshade image created from 30m DEMs
CHIR_painted	Image created from combined hillshade and classed 30m DEM rasters
Reference	
CHIR_grazing_allotments	Grazing allotments
CHIR_FS_grazing_allotments	Forest Service grazing allotments
CHIR_FS_pasture	Forest Service pasturing allotments
CHIR_GDI_station	Generic Diatom Index, water quality metric
CHIR_management_areas	NPS management areas/themes
CHIR_PADUS	Protected Areas Database for the US
CHIR_water_quality	Water quality monitoring stations
CHIR_places	Feature place names for location reference
CHIR_upland plots	NPS vegetation and soils monitoring plots
CHIR_tracts	NPS tract and boundary data
CHIR_wilderness	Designated Wilderness areas
CHIR_USGS_photopoints	USGS photo-point locations
Surface_overlays	
Climate	
CHIR_SODN_weather_stations	NPS-SODN weather monitoring locations
CHIR_precip	Average annual precipitation
CHIR_temp_precip_avgs	Average temperature and precipitation
CHIR_temp_avg	Average annual temperature
CHIR_temp_min	Average annual temperature minimums
CHIR_temp_max	Average annual temperature maximums
Fauna	
CHIR_amphibians_habitat	Habitat suitability by species
CHIR_amphibians_potential	SW-GAP Species Richness Potential (count ranges)
CHIR_birds_habitat	Habitat suitability by species
CHIR_birds_potential	SW-GAP Species Richness Potential (count ranges)
CHIR_mammals_habitat	Habitat suitability by species
CHIR_mammals_potential	SW-GAP Species Richness Potential (count ranges)

CHIR_reptiles_habitat	Habitat suitability by species
CHIR_reptiles_potential	SW-GAP Species Richness Potential (count ranges)
Geology	
CHIR_faults	Faults
CHIR_mines	Mines
CHIR_minerals_favorability	Locatable Known Mineral Deposit Areas
CHIR_soils	NPS soils data
CHIR_surface_geology_1	Surface geology
CHIR_surface_geology_2	Generalized surface geology
Landcover	
CHIR_BL_veg	Brown & Lowe vegetation types
CHIR_BLP_veg	NPS legacy vegetation classification
CHIR_canopy	Canopy cover
CHIR_impervious	Relative surface imperviousness
CHIR_landuse	NLCD land use, 2006
CHIR_fires	Fires
CHIR_fire_ignitions	NPS CHIR fire ignitions
CHIR_fires_1980to2003	Fires, various agencies reporting
CHIR_FS_fires_pnt	Forest Service fire events, point
CHIR_fuels	NPS fire fuels models
CHIR_Landbird_monitoring_locations	NPS SODN Landbird monitoring locations
CHIR_exotic_plants	Exotic/invasive plants
CHIR_slope	DEM-derived terrain slope
CHIR_aspect	DEM-derived direction of terrain slope
CHIR_insolation	DEM-derived ground solar energy
CHIR_topography	Topographic classes
Transportation	
CHIR_roads	Roads
CHIR_airfield	Private dirt strip outside Park
CHIR_road_features	Road-related features (gates, pullouts, low-water crossings, etc.)

Coronado National Memorial



CORO

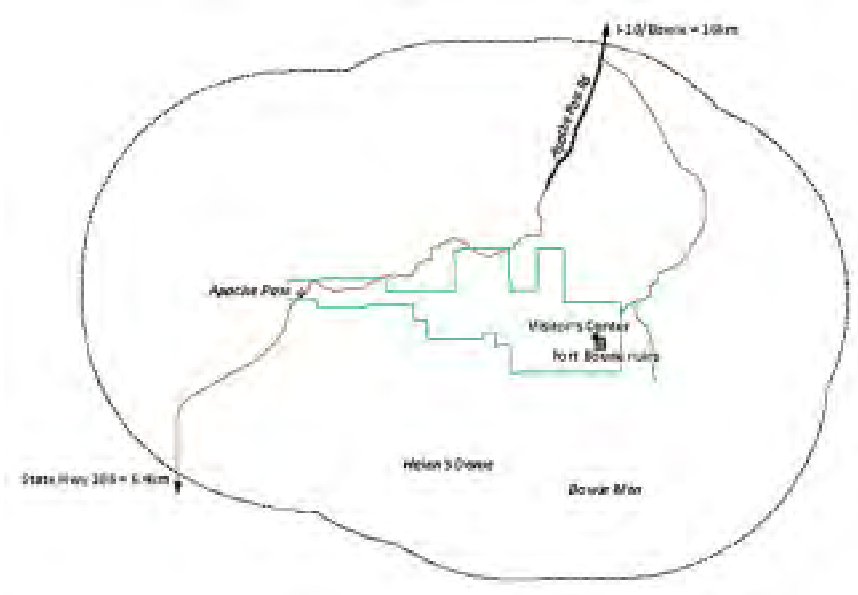
Boundaries	
CORO_boundary	Park boundary
CORO_3000m_buffer	3000 meter buffer area around Park
CORO_survey_markers	NPS survey points
CORO_border	US-Mexico border
Cultural	
CORO_2000_housing_density	Projected housing density for 2000 (3000m buffer area)
CORO_2100_housing_density	Projected housing density for 2100 (3000m buffer area)
CORO_buildings_pnt	Building point markers
CORO_buildings_poly	Building polygons
CORO_Park_facilities	NPS and public facilities within the Park, polygons
CORO_Park_facilities_pnts	NPS and public facilities within the Park, point markers
CORO_graveyard	Graveyard
CORO_trails	Designated trails within the 3000m buffer area
CORO_FS_trailhead	Forest Service trailheads, Coronado National Forest
CORO_grazing_fences	Grazing allotment fences
CORO_ranch_structures	Montezuma Ranch structures
CORO_Trailmaster_cameras	Trailmaster remote camera locations
Hydrography	
CORO_ADEQ_wells	Arizona Dept. of Environmental Quality wells

CORO_windmills	Windmills (pump)
CORO_NPS_springs	Springs (2010 NPS survey)
CORO_springs	Springs
CORO_streams	Streams
CORO_waterbodies	Lakes, reservoirs, ponds, tanks (polygon)
CORO_HUC8-12-digit	Hydrologic Unit Code (HUC) 8–12-digit catchment classes
Hypsography	
CORO_10m_contours	10m contours (USGS National Elevation Dataset (NED) Digital Elevation Models (DEMs))
CORO_elevation_points	Select point elevations (may include landmarks, spot elevations, or benchmarks)
Image_base	
CORO_10m_DEM	NED (USGS) 10m DEM
CORO_24k_DRG	USGS 24k DRG topographic imagery
CORO_aerial	USDA National Agriculture Imagery Program (NAIP) 2010 1m color aerial imagery
CORO_hshade	Hillshade image created from 30m DEMs
CORO_painted	Image created from combined hillshade and classed 30m DEM rasters
Reference	
CORO_FMUs	NPS Fire Management Areas
CORO_FS_grazing_allotments	Forest Service grazing allotments
CORO_FS_pasture	Forest Service pasturing allotments
CORO_FS-RMUs	Forest Service Rangeland Management Units
CORO_grazing_allotments	Grazing allotments
CORO_mammal_trapping_grid	NPS mammal trapping grid
CORO_upland_plots	NPS vegetation and soils monitoring plots
CORO_management_areas	NPS management areas/themes
CORO_PADUS	Protected Areas Database, US
CORO_places	Feature place names for location reference
CORO_tracts	NPS tract and boundary data
CORO_USGS_photopoints	USGS photo-point locations
CORO_water_quality	Water quality sample points
CORO_wilderness	Designated Wilderness areas
Surface_overlays	
Climate	
CORO_SODN_weather_stations	NPS-SODN weather monitoring locations
CORO_precip	Average annual precipitation

CORO_temp_precip_avgs	Average temperature and precipitation
CORO_temp_avg	Average annual temperature
CORO_temp_min	Average annual temperature minimums
CORO_temp_max	Average annual temperature maximums
Fauna	
CORO_amphibians_habitat	Habitat suitability by species
CORO_amphibians_potential	SW-GAP Species Richness Potential (count ranges)
CORO_birds_habitat	Habitat suitability by species
CORO_birds_potential	SW-GAP Species Richness Potential (count ranges)
CORO_mammals_habitat	Habitat suitability by species
CORO_mammals_potential	SW-GAP Species Richness Potential (count ranges)
CORO_reptiles_habitat	Habitat suitability by species
CORO_reptiles_potential	SW-GAP Species Richness Potential (count ranges)
Geology	
CORO_caves	Caves
CORO_dikes	Dikes
CORO_faults	Faults
CORO_folds	Folds
CORO_mines	Mines
CORO_minerals_favorability	Locatable Known Mineral Deposit Areas
CORO_soils	NPS soils data
CORO_surface_geology_1	Surface geology
CORO_surface_geology_2	Generalized surface geology
Landcover	
CORO_GAP_veg	USGS SW GAP vegetation types
CORO_ruf_veg	NPS general vegetation classification
CORO_canopy	Canopy cover
CORO_impervious	Relative surface imperviousness
CORO_landuse	NLCD land use, 2006
CORO_fires	Fires
CORO_fires_1980to2003	Fires, various agencies reporting
CORO_FS_fires_pnt	Forest Service fire events, point
CORO_FS_fires_poly	Forest Service fire events, polygon
CORO_fuels	NPS fire fuels models
CORO_exotic_plants	Exotic/invasive plants
CORO_slope	DEM-derived terrain slope
CORO_aspect	DEM-derived direction of terrain slope
CORO_insolation	DEM-derived ground solar energy
CORO_topography	Topographic classes
CORO_wildfire_intensity	Fire intensities for the 1988 Peak Fire

Transportation	
CORO_culverts	Culverts point data along unpaved portion of Montezuma Pass Road
CORO_pipelines	Pipeline features
CORO_road_features	Road-related features (gates, pullouts, low-water crossings, etc.)
CORO_road_miles	Road mile markers
CORO_road_pnts	Misc road points
CORO_roads	Roads

Fort Bowie National Historic Site



FOBO

Boundaries	
FOBO_boundary	Park boundary
FOBO_3000m_buffer	3000 meter buffer area around Park
Cultural	
FOBO_2000_housing_density	Projected housing density for 2000 (3000m buffer area)
FOBO_2100_housing_density	Projected housing density for 2100 (3000m buffer area)
FOBO_classified_structures	NPS building inventory
FOBO_NPS_structures	Building polygons
FOBO_original_buildings	Structure traces from 2007 NAIP imagery
FOBO_Park_facilities	NPS and public facilities within the Park, poygons
FOBO_trails	Designated trails within the 3000m buffer area
Hydrography	
FOBO_wells	Wells
FOBO_ADEQ_wells	Arizona Dept. of Environmental Quality wells
FOBO_NPS_springs	Springs (2010 NPS survey)
FOBO_springs	Springs
FOBO_streams	Streams
FOBO_tanks_pnt	NPS tanks, ponds, troughs - point
FOBO_tanks_poly	NPS ponds, tanks, troughs - polygon
FOBo_waterbodies	Lakes, reservoirs, ponds, tanks (polygon)
FOBO_floodzone	FEMA flood zones
FOBO_washes	Major washes

FOBO_HUC8-12-digit	Hydrologic Unit Code (HUC) 8–12-digit catchment classes
Hypsography	
FOBO_10m_contours	10m contours (USGS National Elevation Dataset (NED) Digital Elevation Models (DEMs))
FOBO_elevation_points	Select point elevations (may include landmarks, spot elevations, or benchmarks)
Image_base	
FOBO_10m_DEM	NED (USGS) 10m DEM
FOBO_24k_DRG	USGS 24k DRG topographic imagery
FOBO_aerial	USDA National Agriculture Imagery Program (NAIP) 2010 1m color aerial imagery
FOBO_hshade	Hillshade image created from 30m DEMs
FOBO_painted	Image created from combined hillshade and classed 30m DEM rasters
Reference	
FOBO_grazing_allotments	Grazing allotments
FOBO_Silverstrike_allotment	NPS grazing allotments
FOBO_management_areas	NPS management areas/themes
FOBO_PADUS	Protected Areas Database, US
FOBO_places	Feature place names for location reference
FOBO_tracts	NPS tract and boundary data
FOBO_USGS_photopoints	USGS photo-point locations
FOBO_veg_plot	NPS vegetation plots
FOBO_upland_plots	NPS vegetation and soils monitoring plots
FOBO_water_quality	NPS water quality monitoring locations
Surface_overlays	
Climate	
FOBO_SODN_weather_stations	NPS-SODN weather monitoring locations
FOBO_precip	Average annual precipitation
FOBO_temp_precip_avgs	Average temperature and precipitation
FOBO_temp_avg	Average annual temperature
FOBO_temp_min	Average annual temperature minimums
FOBO_temp_max	Average annual temperature maximums
Fauna	
FOBO_amphibians_habitat	Habitat suitability by species
FOBO_amphibians_potential	SW-GAP Species Richness Potential (count ranges)
FOBO_birds_habitat	Habitat suitability by species
FOBO_birds_potential	SW-GAP Species Richness Potential (count ranges)
FOBO_mammals_habitat	Habitat suitability by species
FOBO_mammals_potential	SW-GAP Species Richness Potential (count ranges)

FOBO_reptiles_habitat	Habitat suitability by species
FOBO_reptiles_potential	SW-GAP Species Richness Potential (count ranges)
Geology	
FOBO_dikes	Dikes
FOBO_faults	Faults
FOBO_folds	Folds
FOBO_mines	Mines
FOBO_minerals_favorability	Locatable Known Mineral Deposit Areas
FOBO_primary_soil_type	Generalized soil surface type
FOBO_soils	NPS soils data
FOBO_surface_geology_1	Surface geology
FOBO_surface_geology_2	Generalized surface geology
Landcover	
FOBO_BL_veg	Brown & Lowe vegetation types
CORO_canopy	Canopy cover
CORO_impervious	Relative surface imperviousness
CORO_landuse	NLCD land use, 2006
FOBO_fires	Fires
FOBO_fires_1980to2003	Fires, various agencies reporting
FOBO_FS_fires_poly	Forest Service fire events, polygon
FOBO_fuels	NPS fire fuels models
FOBO_exotic_plants	Exotic/invasive plants
FOBO_slope	DEM-derived terrain slope
FOBO_aspect	DEM-derived direction of terrain slope
FOBO_insolation	DEM-derived ground solar energy
FOBO_topography	Topographic classes
FOBO_riparian	Park riparian locations
Transportation	
FOBO_roads	Roads
FOBO_pipeline	Pipeline features

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Appendix B: Supplementary Information on Physical Resources

Table B.1. Historic climate averages (1971-2000) for weather stations in region that meet the World Meteorological Organization's standard for historic climate calculations (NOAA 2002).

Station Number	Station Name	Elevation (ft)	Climate Characteristic	Month												Annual
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
8	Animas 3 ESE	4437	Max. Temp. (°F)	58.1	63.4	69.9	77.7	86.4	95.4	94.4	91.3	87.3	78.0	65.9	57.7	77.1
			Min. Temp. (°F)	26.8	29.8	34.0	39.3	48.2	57.2	63.4	61.9	56.2	44.5	32.7	27.0	43.4
			Precipitation (in)	0.7	0.5	0.5	0.2	0.3	0.6	2.2	2.5	1.4	1.3	0.8	1.1	12.0
21	Bowie	3760	Max. Temp. (°F)	60.5	65.8	72.0	79.9	88.1	97.4	97.1	94.2	90.3	80.1	68.5	60.2	79.5
			Min. Temp. (°F)	31.9	35.1	39.3	44.8	53.1	62.2	68.0	66.1	60.3	49.1	37.5	31.7	48.3
			Precipitation (in)	1.0	0.8	0.7	0.3	0.4	0.5	2.0	2.2	1.0	1.4	0.8	1.3	12.3
26	Canelo 1 NW	5010	Max. Temp. (°F)	58.3	61.8	66.3	73.6	81.4	90.7	88.8	86.0	83.8	75.7	65.5	58.5	74.2
			Min. Temp. (°F)	28.3	30.1	33.1	37.6	45.1	53.7	60.4	59.1	53.7	43.4	33.3	28.6	42.2
			Precipitation (in)	1.4	1.2	1.1	0.5	0.2	0.6	3.7	3.7	1.8	1.5	1.0	1.4	18.0
31	Cascabel	3145	Max. Temp. (°F)	64.7	68.6	73.6	82.0	90.5	100.0	99.7	96.9	93.7	84.2	72.8	64.9	82.6
			Min. Temp. (°F)	30.6	32.8	35.7	39.7	46.7	55.6	65.2	64.6	58.0	46.9	35.1	30.3	45.1
			Precipitation (in)	1.3	1.2	0.9	0.3	0.4	0.4	2.4	2.8	1.4	1.3	0.7	1.2	14.3
36	Cliff 11 SE	4776	Max. Temp. (°F)	55.6	60.1	65.8	73.4	81.9	91.6	91.8	89.0	84.8	75.2	63.7	55.4	74.0
			Min. Temp. (°F)	20.1	22.8	27.0	31.9	39.8	48.6	56.9	55.6	48.1	35.9	24.3	19.1	35.8
			Precipitation (in)	1.2	1.1	0.9	0.4	0.5	0.5	2.8	2.8	1.9	1.6	1.0	1.3	15.8
37	Chiricahua NM	5300	Max. Temp. (°F)	57.5	60.5	66.1	73.3	81.4	90.2	89.1	86.2	83.5	75.3	64.8	57.8	73.8
			Min. Temp. (°F)	30.4	32.1	35.2	40.0	47.2	56.4	60.5	59.6	55.8	46.7	36.2	30.8	44.2
			Precipitation (in)	1.6	1.3	1.3	0.5	0.4	0.9	4.1	3.8	1.9	1.7	1.3	2.0	21.0
41	Coronado NM HQ	5242	Max. Temp. (°F)	58.3	62.3	67.5	74.7	82.1	91.6	89.8	86.9	84.7	76.0	65.8	58.7	74.9
			Min. Temp. (°F)	32.3	34.2	37.0	42.5	50.0	58.1	60.9	59.2	56.1	47.8	38.2	32.9	45.8
			Precipitation (in)	1.9	1.6	1.2	0.5	0.3	0.6	4.5	3.7	1.8	2.0	1.1	2.0	21.2

Table B.1. Historic climate averages (1971-2000) for weather stations in region that meet the World Meteorological Organization's standard for historic climate calculations (NOAA 2002).

Station Number	Station Name	Elevation (ft)	Climate Characteristic	Month												Annual
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
45	Douglas Bisbee Airport	4098	Max. Temp. (°F)	62.2	66.3	71.4	78.7	86.3	95.1	93.5	91.3	88.4	80.1	69.8	62.4	78.8
			Precipitation (in)	0.8	0.6	0.5	0.2	0.3	0.6	3.1	2.9	1.6	1.3	0.7	1.1	13.8
			Min. Temp. (°F)	29.4	32.1	36.4	41.9	50.2	59.2	64.4	63.3	58.5	47.1	35.2	29.4	45.6
46	Duncan	3660	Max. Temp. (°F)	60.0	65.0	71.0	79.3	87.7	96.9	97.1	94.4	90.1	80.3	68.2	59.6	79.1
			Min. Temp. (°F)	23.7	26.5	31.0	35.6	44.6	53.6	63.3	62.2	54.2	41.0	28.5	22.9	40.6
			Precipitation (in)	1.0	0.9	0.6	0.2	0.4	0.4	2.3	2.2	1.1	1.3	0.8	1.2	12.3
83	McNeal	4170	Max. Temp. (°F)	Station does not record temperatures												
			Min. Temp. (°F)													
			Precipitation (in)	0.7	0.6	0.4	0.2	0.2	0.4	2.6	2.9	1.2	1.1	0.7	1.0	11.9
85	Lordsburg 4 SE	4250	Max. Temp. (°F)	59.3	64.5	70.9	79.6	88.8	98.1	97.9	95.1	90.5	80.5	67.7	59.1	79.3
			Min. Temp. (°F)	25.1	27.6	32.1	37.6	46.9	57.0	63.9	62.3	55.3	42.7	30.1	25.2	42.2
			Precipitation (in)	0.9	0.8	0.8	0.3	0.4	0.5	2.0	1.9	1.3	1.3	0.8	1.3	12.2
91	Nogales 6 N	3560	Max. Temp. (°F)	63.9	67.1	71.3	78.3	86.2	95.7	94.2	92.2	90.2	82.1	71.6	64.5	79.8
			Min. Temp. (°F)	27.1	29.8	34.0	38.4	45.2	54.3	63.5	62.9	55.7	43.5	32.6	27.7	42.9
			Precipitation (in)	1.3	1.1	1.0	0.5	0.3	0.5	4.3	4.2	1.7	1.8	0.8	1.5	19.0
93	Oracle 2SE	4510	Max. Temp. (°F)	56.2	59.8	64.5	72.3	82.0	91.9	92.1	89.4	85.9	76.3	64.2	56.2	74.2
			Min. Temp. (°F)	35.0	36.8	39.6	45.4	53.8	63.8	66.8	65.6	61.5	51.1	40.6	34.8	49.6
			Precipitation (in)	2.5	2.6	2.5	0.9	0.6	0.4	3.3	4.1	2.0	2.0	1.8	2.3	24.9
109	Portal 4 SW	5390	Max. Temp. (°F)	52.9	57.5	63.1	70.4	78.1	86.6	85.2	82.0	78.5	70.7	60.4	53.0	69.9
			Min. Temp. (°F)	23.4	25.3	29.4	33.8	40.8	48.6	55.6	54.4	48.3	38.3	28.4	23.6	37.5
			Precipitation (in)	1.4	1.2	1.0	0.5	0.5	1.1	4.4	3.7	2.4	2.0	1.4	1.9	21.6

Table B.1. Historic climate averages (1971-2000) for weather stations in region that meet the World Meteorological Organization's standard for historic climate calculations (NOAA 2002).

Station Number	Station Name	Elevation (ft)	Climate Characteristic	Month												Annual
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
112	Redrock 1 NNE	4050	Max. Temp. (°F)	58.1	62.9	69.0	76.9	85.0	94.4	94.5	91.5	87.3	77.3	65.9	58.0	76.7
			Min. Temp. (°F)	25.3	28.4	32.1	36.7	44.3	53.2	62.6	62.2	55.0	42.5	30.2	24.9	41.5
			Precipitation (in)	1.0	0.9	0.7	0.2	0.5	0.5	2.4	2.6	1.7	1.5	0.8	1.2	13.9
114	Redington	2940	Max. Temp. (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Min. Temp. (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Precipitation (in)	1.5	1.4	1.3	0.4	0.4	0.2	2.9	2.6	1.4	1.5	0.9	1.3	15.6
116	Rucker Canyon	5730	Max. Temp. (°F)	Station does not record temperatures												
			Min. Temp. (°F)													
			Precipitation (in)	1.4	1.2	1.1	0.4	0.4	1.1	4.4	3.9	1.7	1.8	1.2	1.7	20.2
123	San Manuel	3460	Max. Temp. (°F)	Station does not record temperatures												
			Min. Temp. (°F)													
			Precipitation (in)	1.3	1.3	1.2	0.4	0.5	0.4	2.4	2.8	1.3	1.2	0.8	1.2	14.8
125	Santa Rita Experimental Range	4300	Max. Temp. (°F)	60.4	64.3	68.6	76.0	83.8	93.3	92.0	89.1	86.5	78.6	67.7	60.7	76.8
			Min. Temp. (°F)	37.5	39.7	43.2	48.3	55.8	64.6	66.8	65.2	62.3	54.5	42.8	37.5	51.5
			Precipitation (in)	1.7	1.7	1.8	0.7	0.3	0.6	4.8	4.3	2.4	2.1	1.3	1.9	23.4
145	Tombstone	4610	Max. Temp. (°F)	59.5	63.5	68.8	76.6	85.0	94.5	93.3	90.5	87.6	78.3	67.6	59.8	77.1
			Min. Temp. (°F)	36.1	38.5	41.9	47.3	54.8	63.1	66.5	65.2	61.4	52.4	42.6	36.7	50.5
			Precipitation (in)	1.0	0.7	0.7	0.2	0.3	0.6	2.8	3.1	1.5	1.3	0.7	1.1	14.1
150	Tucson Camp Ave Exp Fm	2330	Max. Temp. (°F)	66.6	70.2	75.0	82.7	91.3	100.6	100.7	98.8	95.7	86.1	74.7	66.9	84.1
			Min. Temp. (°F)	34.6	37.3	41.5	46.4	54.9	64.2	71.8	70.9	65.0	52.6	39.8	34.6	51.1
			Precipitation (in)	1.1	1.1	1.0	0.4	0.2	0.3	1.8	2.1	1.2	1.3	0.8	1.3	12.4
152	Tucson	2478	Max. Temp. (°F)	66.0	70.0	74.7	82.4	90.9	100.3	100.5	98.6	95.1	85.3	73.8	66.2	83.7
			Min. Temp. (°F)	41.9	44.8	48.7	54.4	62.8	71.9	76.5	75.3	70.9	59.8	47.9	42.1	58.1
			Precipitation (in)	1.0	1.0	0.9	0.3	0.2	0.3	1.9	2.2	1.2	1.2	0.7	1.0	12.0

Table B.1. Historic climate averages (1971-2000) for weather stations in region that meet the World Meteorological Organization's standard for historic climate calculations (NOAA 2002).

Station Number	Station Name	Elevation (ft)	Climate Characteristic	Month												Annual
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
154	Tucson International Airport	2549	Max. Temp. (°F)	64.5	68.4	73.3	81.5	90.4	100.2	99.6	97.4	94.0	84.0	72.3	64.6	82.5
			Min. Temp. (°F)	38.9	41.6	45.1	50.5	58.6	68.0	73.4	72.4	67.7	57.0	45.1	39.2	54.8
			Precipitation (in)	1.0	0.9	0.8	0.3	0.2	0.2	2.1	2.3	1.5	1.2	0.7	1.0	12.2
155	Tumacacori NM	3267	Max. Temp. (°F)	65.0	68.6	72.4	79.8	87.8	97.8	96.2	93.4	90.9	82.7	72.1	65.4	81.0
			Min. Temp. (°F)	31.8	33.7	37.0	41.6	48.4	58.0	65.9	64.6	58.6	47.8	36.6	31.9	46.3
			Precipitation (in)	1.2	1.1	1.0	0.4	0.2	0.5	3.8	4.0	1.7	1.4	0.7	1.4	17.4
165	Willcox	4175	Max. Temp. (°F)	60.5	65.3	71.0	78.7	86.6	95.5	95.2	92.7	89.0	79.5	68.3	60.3	78.6
			Min. Temp. (°F)	27.7	30.0	34.0	38.8	46.8	55.4	63.8	62.8	55.7	43.8	32.3	27.2	43.2
			Precipitation (in)	1.1	1.0	0.7	0.3	0.4	0.4	2.4	2.6	1.3	1.4	0.7	1.3	13.4
171	Y Lightning Ranch	4590	Max. Temp. (°F)	Station does not record temperatures												
			Min. Temp. (°F)													
			Precipitation (in)	1.1	0.8	0.6	0.3	0.2	0.6	3.5	3.2	1.6	1.5	0.8	1.2	15.3

Table B.2. Recent precipitation record for Chiricahua NM weather station (station number 37). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010b) and NOAA (2010).

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	0.06	0.39	0.8	0	0	4.7	2.52	4.59	0.09	6.19	2.23	0.34	21.91
2001	1.91	0.82	0.66	1.01	0.39	0.36	4.87	5.56	1.42	0.62	0.37	1.68	19.67
2002	0.98	0.83	0.09	0.08	0	0	2.97	7.31	1.14	0.65	0.3	2.25	16.6
2003	0.07	1.65	0.68	0	0	0.22	1.31	1.36	0.3	0.43	1.38	0.28	7.68
2004	1.56	2.17	1.14	1.21	0.14	1.18	3.39	3.61	1.83	0.39	1.34	1.3	19.26
2005	2.02	1.93	0.53	0.51	0.49	0.00 z	0.36	3.47	0.89	1.62	0.00 z	0.72	12.54
2006	0.11	0.2	0.82	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	1.13
2007	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0
2008	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	5.79	0.4	0.26 a	1.24	0.6	8.29
2009	1.03 c	0.66 c	0.75	0.16	1.11	2.49	1.24	1.67	1.87 b	0.81	1.11	1.58	14.49
2010	5.1	2.75 d	2.33	0.58	0.02	0.26	4.25	2.38 r	0.00 z	0.00 z	0.00 z	0.00 z	15.29
Historic Average (1971-2000)	1.56	1.34	1.34	0.47	0.44	0.94	4.12	3.83	1.91	1.73	1.31	1.96	20.95

Table B.3. Recent temperature record for Chiricahua NM weather station (station number 37). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010b) and NOAA (2010).

Year	Climate Characteristic	Month												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	Max. Temp. (°F)	63.32	65.66	67.52	79.13	89.06	88.9	89.52	87.13	87.93	71.06	58.03	61.74	75.75
	Mean Temp. (°F)	47.79	49.45	50.73	61.03	69.68	73.2	74.48	72.68	72.93	59.34	45.03	46.65	60.25
	Min. Temp. (°F)	32.26	33.24	33.94	42.93	50.29	57.5	59.45	58.23	57.93	47.61	32.03	31.55	44.75
2001	Max. Temp. (°F)	53.5	59.79	63.97	74.17	84.65	90.8	85.42	85.74	85.67	78	66.83	57.03	73.8
	Mean Temp. (°F)	41.57 a	46.41	50.48	58.57	67.74	74.28	72.97 a	72.89	71.55	63.13	53.48	42.34	59.62
	Min. Temp. (°F)	29.87	33.04	37	42.97	50.84	57.77	60.33 a	60.03	57.43	48.26	40.13	27.65	45.44
2002	Max. Temp. (°F)	57.55 a	60.57	67.1	78.7	84	94.63	89.58	86.68	84.57	73.26	66.17	55.16	74.83
	Mean Temp. (°F)	42.98	46.2	49.85	60.97	65.94	76.67	75.53	72.48	70.77	59.26	51.57	42.56	59.56
	Min. Temp. (°F)	28.42	31.82	32.61	43.23	47.87	58.7	61.48	58.29	56.97	45.26	36.97	29.97	44.3
2003	Max. Temp. (°F)	63.97	58.32	63.87	72.43	84.39	91.07	95.1	89.68	87.67	81.68	66.23	59.61	76.17
	Mean Temp. (°F)	48.89	45.84	49.26	55.18	66.82	72.97	77.4	75.71	72.38	65.68	51.23	44.79	60.51
	Min. Temp. (°F)	33.81	33.36	34.65	37.93	49.26	54.87	59.71	61.74	57.1	49.68	36.23	29.97	44.86
2004	Max. Temp. (°F)	55.87	56.62	68.1	70.4	83.71	91.43	90.48	86.35	83.7	75.87	61.53	57.87	73.5
	Mean Temp. (°F)	44.52	41.93	54.68	55.22	66.05	73.47	74.56	72.58	69.38	61.85	47.5	44.06	58.82
	Min. Temp. (°F)	33.16	27.24	41.26	40.03	48.39	55.5	58.65	58.81	55.07	47.84	33.47	30.26	44.14
2005	Max. Temp. (°F)	58.23	55.36	63.23	74.9	84.1	----- z	95.35	86.74	87.4	77.71	----- z	62.68	74.57
	Mean Temp. (°F)	45.56	46.14	49.05	58.35	67.13	----- z	79.53	73.56	72.63	63.5	----- z	47.98	60.34
	Min. Temp. (°F)	32.9	36.93	34.87	41.8	50.16	----- z	63.71	60.39	57.87	49.29	----- z	33.29	46.12
2006	Max. Temp. (°F)	62.87	65.18	65.58	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	64.54
	Mean Temp. (°F)	47.48	49.59	51.39	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	49.5
	Min. Temp. (°F)	32.1	34	37.19	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	34.43

Table B.3. Recent temperature record for Chiricahua NM weather station (station number 37). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010b) and NOAA (2010).

Year	Climate Characteristic	Month												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2007	Max. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Mean Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Min. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
2008	Max. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Mean Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Min. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
2009	Max. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Mean Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Min. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
2010	Max. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Mean Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
	Min. Temp. (°F)	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z
Historic Average (1971-2000)	Max. Temp. (°F)	57.5	60.5	66.1	73.3	81.4	90.2	89.1	86.2	83.5	75.3	64.8	57.8	73.8
	Mean Temp. (°F)	44	46.3	50.7	56.7	64.3	73.3	74.8	72.9	69.7	61	50.5	44.3	59
	Min. Temp. (°F)	30.4	32.1	35.2	40	47.2	56.4	60.5	59.6	55.8	46.7	36.2	30.8	44.2

Table B.4. Recent precipitation record for Coronado NM weather station (station number 41). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010c) and NOAA (2002).

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	0.14	0.2	0.93	0	0.05	3.28	4.78	6.56	0.12	12.69	1.86	0	30.61
2001	2.29	0.61	0.74	1.25	0.18	0.48	4.94	5.42 b	1.22	0.86	0.05	1.18	19.22
2002	1.21	1.22	0	0	0	0.01	4.05 a	3.81	3.41	0.48	0.23 a	2.22	16.64
2003	0.04	1.98	0.76	0	0.01	0.31	4.89	5.46	2.59	1.21	1.3	0.13	18.68
2004	2.76	1.31	1.82	2.45	0	0.82	3.31	3.79	2.17	0.8	1.31	1.91	22.45
2005	2.7	3.01	0.07	0.22	1.59	0.00 z	3.43	4.44	1.54	0.54	0.00 z	0.18 b	17.72
2006	0.02	0.17	1.22	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	0.00 z	1.41
2007	0.00 z	0.37	0.00 z	0	0.01	1.51	5.94 b	5.90 a	1.67	0.36	0.00 z	3.10 b	18.86
2008	0.97	0.61	0.00 z	0.00 z	0.57	0.8	0.00 z	5.57	1.1	1.33	1.10 c	0.85 c	12.9
2009	0.53	0.68	0.36	0.16 a	0.76	2.36 b	3.4	4.67	1.58 a	1.26	0.62	1.92 c	17.47
2010	5.81	6.61	2.12	0.55	0	0	6.29	1.72 j	0.00 z	0.00 z	0.00 z	0.00 z	21.38
Historic Average (1971-2000)	1.87	1.63	1.21	0.45	0.32	0.64	4.49	3.74	1.79	1.95	1.11	1.98	21.18

Table B.5. Recent temperature record for Coronado NM Headquarters weather station (station number 41). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010d) and NOAA (2010).

Year	Climate Characteristic	Month												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	Max. Temp. (°F)	64.77	66.59	68.1	79.7	89.48	89.53	90.06	86.06	87.7	70.35	57.37	61.48	75.93
	Mean Temp. (°F)	49.94	52.05	52.18	62.68	72.21	74.92	76.17	73	73	59.32	45.24	47.47	61.51
	Min. Temp. (°F)	35.1	37.52	36.26	45.67	54.94	60.3	62.3 a	59.94	58.3	48.29	33.1 a	33.45	47.1
2001	Max. Temp. (°F)	52.55	59.54	66.55	73.8	85.32	92.17	86.48	87	86.53	78	66.7	57.9	74.38
	Mean Temp. (°F)	41.26	46.48	51.74	58.7	69.18	75.78	73.89	73.61	72.17	63.76	54.03	43.58	60.35
	Min. Temp. (°F)	29.97	33.43	36.94	43.6	53.03	59.52 c	61.29	60.23	57.8	49.52	41.37	29.26	46.33
2002	Max. Temp. (°F)	58.39	63	68.9	79.6	84.97	95.27	89.9	87.61	84.43	73.74	67.1	55.16	75.67
	Mean Temp. (°F)	45.11	47.82	52.44	64.07	67.81	78.37	76.26	74.45	71.2	60.65	53.43	42.63	61.19
	Min. Temp. (°F)	31.84	32.64	35.97	48.53	50.65	61.47	62.61	61.29	57.97	47.55	39.77	30.1	46.7
2003	Max. Temp. (°F)	64.97	59.93	66.03	73.73	85.42	91.7	95.03	87.94	85.27	78.9	65.7	60.61	76.27
	Mean Temp. (°F)	50.58	48.23	51.13	58.33	68.63	75.3	79.35	74.66	71.42	65.21	52.6	45.97	61.78
	Min. Temp. (°F)	36.19	36.54	36.23	42.93	51.84	58.9	63.68	61.39	57.57	51.52	39.5	31.32	47.3
2004	Max. Temp. (°F)	55.97	57.31	70.97	70.07	83.16	90.17	89.61	86.39	82.13	73.39	59.6	57	72.98
	Mean Temp. (°F)	44.77	43.41	56.89	56.58	68.29	74.02	75.27	73.52	69.98 e	60.92	47.4	45.31	59.7
	Min. Temp. (°F)	33.58	29.52	42.81	43.1	53.42	57.87	60.94	60.65	56.04 e	48.45	35.2	33.61	46.26
2005	Max. Temp. (°F)	57.26	55.61	63.7 a	74.3	83.35	----- z	93.77	84.19	85.13	76.03	----- z	62.04 e	73.54
	Mean Temp. (°F)	46.02	46.43	51.05 a	59.05	68.02	----- z	79.27	72.16	72.63	62.55	----- z	47.9 e	60.51
	Min. Temp. (°F)	34.77	37.25	38.4 a	43.8	52.68	----- z	64.77	60.13	60.13	49.06	----- z	33.77 e	47.48

Table B.5. Recent temperature record for Coronado NM Headquarters weather station (station number 41). Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from WRCC (2010d) and NOAA (2010).

Year	Climate Characteristic	Month												Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2006	Max. Temp. (°F)	62.29	65.96	64.39	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	64.21
	Mean Temp. (°F)	48.13	51.2	51.74	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	50.36
	Min. Temp. (°F)	33.97	36.43	39.1	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	----- z	36.5
2007	Max. Temp. (°F)	----- z	61.68	----- z	73.77	82.9	91.53	87.65 e	84.97	83.33	76.69 e	----- z	56.39	77.66
	Mean Temp. (°F)	----- z	48	----- z	59.53	67.6	75.9	75.1 e	73.47	70.8	63.65 e	----- z	43.47	64.17
	Min. Temp. (°F)	----- z	34.32	----- z	45.3	52.29	60.27	62.54 e	61.97	58.27	50.62 e	----- z	30.55	50.68
2008	Max. Temp. (°F)	55.52	63.24	----- z	----- z	80.87	92.8	----- z	82.52	81.73	77.52	67.8	58.9	73.43
	Mean Temp. (°F)	44.27	48.9	----- z	----- z	65.24	76.95	----- z	71.47	68.55	62.63	54.23	46.94	59.91
	Min. Temp. (°F)	33.03	34.55	----- z	----- z	49.61	61.1	----- z	60.42	55.37	47.74	40.67	34.97	46.38
2009	Max. Temp. (°F)	62.06	65.29	70.52	74.73	85.87	86.5	91.35	89.16	84.4	74.16	68.13	56.15 r	77.47
	Mean Temp. (°F)	48.31	50.27	55.5	59.13	69.68	72.85	77.08	75.79	70.88	60.6	54.42	42.31 r	63.14
	Min. Temp. (°F)	34.55	35.25	40.48	43.53	53.48	59.2	62.81	62.42	57.37	47.03	40.7	28.46 r	48.8
2010	Max. Temp. (°F)	57	57.64	65.1	72.33	80.58	92.42 f	88.83 a	89.29 j	----- z	----- z	----- z	----- z	70.25
	Mean Temp. (°F)	44.26	44.68	50.76	57.82	64.21 b	76.06 f	76.22 a	75.86 j	----- z	----- z	----- z	----- z	56.32
	Min. Temp. (°F)	31.52	31.71	36.42	43.3	48.41 b	59.71 f	63.6 a	62.43 j	----- z	----- z	----- z	----- z	42.49
Historic Average (1971-2000)	Max. Temp. (°F)	58.3	62.3	67.5	74.7	82.1	91.6	89.8	86.9	84.7	76	65.8	58.7	74.9
	Mean Temp. (°F)	45.3	48.3	52.3	58.6	66.1	74.9	75.4	73.1	70.4	61.9	52	45.8	60.3
	Min. Temp. (°F)	32.3	34.2	37	42.5	50	58.1	60.9	59.2	56.1	47.8	38.2	32.9	45.8

Table B.6. Recent precipitation record for Fort Bowie NHS weather station. Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from NPS (2010c).

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2000	0.05 b	0.48	0.85	0.00	0.00	3.61	1.17	5.15	0.12	6.81	2.61	0.31 a	21.16
2001	1.28	1.22	0.67	1.40	0.22	0.77 a	1.62	2.78	1.46	0.38	0.38	0.57	12.75
2002	0.71	1.07	0.00	0.00	0.00 a	0.00	2.98	3.87	3.49	0.69	0.24	1.97	15.02
2003	0.13	1.74	0.80	0.00	0.00	0.12	0.50	0.99	0.32 a	0.13 b	1.16	0.2 a	6.09
2004	1.37	1.71	2.14	1.79	0.00	0.56	0.81	2.49 c	2.32	0.44 c	1.3 a	1.92 b	16.85
2005	2.93	2.6	0.71	0.30	0.55	0.00 a	0.45	4.10	0.84	0.42	0.00 b	0.39	13.29
2006	0.15	0.3	0.53	0.06	0.42	0.27	10.60	4.14	1.47 b	1.25	0.00	1.64	20.83
2007	2.34	0.37	1.39	0.72	0.63	0.78	1.77	4.30	0.65 c	0.12	0.44	2.14	15.65
2008	0.74	0.78	0.10	0.00	0.29	0.08	7.48	6.90	2.04	0.12	0.98	1.2	20.71
2009	0.55	0.75	0.68	0.18	1.28	1.00	0.91	0.52	0.63	0.43	0.68	0.38	7.99
Average (1988-2009)	1.40	1.53	1.00	0.44	0.39	0.59	2.87	3.26	1.41	1.07	1.06	1.50	16.46

Table B.7. Recent temperature record for Fort Bowie NHS weather station. Letters indicate number of days in month missing data (a=1, b=2, etc.). Individual months not used for annual or monthly statistics if more than 5 days are missing (highlighted in tan). Individual years not used for annual statistic if any month in that year has more than 5 days missing (highlighted in gray). Data from NPS (2010c).

Year	Climate Characteristic	Month												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	Max. Temp. (°F)	63.45 a	66.96	69.32	81.53	91.55	92.53	94.42	90.35	89.97	72.16	56.97	59.53 a	77.40
	Min. Temp. (°F)	36.66 b	38.00 e	38.97 b	49.50	57.67 a	63.23	66.16	63.16	61.10	46.63 a	33.40	33.30 a	48.98
2001	Max. Temp. (°F)	52.29	60.14	67.52	75.13	85.03	93.21 a	90.77	90.00	88.37	80.77	67.17	54.48	75.41
	Min. Temp. (°F)	30.45	34.14	39.55	44.87	57.30 a	64.76 a	61.58	63.00	59.80	51.16	43.23	30.30 a	48.35
2002	Max. Temp. (°F)	56.13	62.14	70.45	83.03	87.43 c	93.22 u	89.57 j	89.23	86.83	75.1 a	66.23	56.27 e	76.30
	Min. Temp. (°F)	33.42	34.41 a	38.34 b	50.69 a	53.53 b	66.04 c	65.94	64.35	59.57	47.45	39.97	32.80 a	48.88
2003	Max. Temp. (°F)	62.94	61.07	68.48	76.10	85.37	95.43	98.77	93.87	90.41 c	82.38 b	66.48 a	58.97 a	78.36
	Min. Temp. (°F)	37.84	38.79	38.61	45.57	54.67	62.77	68.35	66.10	61.64 a	56.28 b	41.17 a	34.10 a	50.49
2004	Max. Temp. (°F)	57.16	59.34	72.13	73.37	87.19	95.07	95.29	89.89 c	85.07	77.07 c	62.34 a	57.69 b	75.97
	Min. Temp. (°F)	34.55	31.57 a	45.68	47.10 a	56.70	62.69 a	64.97	63.00 c	58.27	50.11 c	39.03 a	33.50 b	48.93
2005	Max. Temp. (°F)	59.68	56.82	66.48	76.43	87.68	94.62 a	98.32	89.55	90.43	78.94	70.96 b	62.81	77.73
	Min. Temp. (°F)	37.53 a	39.04	41.26	47.63	55.81	64.24 a	68.77	64.00	64.03	50.94	42.18 b	36.90	51.03
2006	Max. Temp. (°F)	63.61	67.18	67.94	81.13	91.19	97.47	95.06	87.06	83.46 b	77.42	72.53	57.61	78.47
	Min. Temp. (°F)	36.29	38.96	41.61	49.37	58.23	67.27	66.00	62.13	54.07 b	46.52	38.70	31.03	49.18
2007	Max. Temp. (°F)	51.74	63.93	71.55	79.33	87.23	96.93	96.19	91.26	89.93 c	81.90	72.53	57.74	78.36
	Min. Temp. (°F)	29.10	34.61	38.81	48.67	55.32	60.43	64.81	64.19	60.11 c	48.32	42.40	32.71	48.29
2008	Max. Temp. (°F)	58.58	64.72	71.45	79.30	84.45	97.33	89.61	87.52	86.68	85.32	71.40	61.06	78.12
	Min. Temp. (°F)	32.65	37.83	39.29	44.07	49.94	64.20	63.52	62.38	54.21	49.55	38.20	33.16	47.42
2009	Max. Temp. (°F)	64.06	68.86	74.42	77.07	88.48	90.93	98.06	94.52	90.33	79.94	70.10	55.94	79.39
	Min. Temp. (°F)	32.97	36.04	43.39	48.10	59.16	63.90	67.19	65.61	57.97	48.42	38.93	30.19	49.32
Average (1988-2009)	Max. Temp. (°F)	57.68	62.12	68.66	76.45	85.67	94.24	93.28	89.33	87.11	78.21	66.60	56.73	76.28
	Min. Temp. (°F)	33.42	36.52	40.11	46.73	54.63	63.12	65.23	63.48	59.00	49.38	39.54	32.54	48.64

Table B.8. 2004-2008 5-Year average air quality estimates. Data from NPS Air Resources Division (2009).

Park	Class	4th Highest 8-hr Ozone (ppb)	Total-N Wet Deposition (kg/ha/yr)	Total-S Wet Deposition (kg/ha/yr)	G50 Visibility minus Natural Conditions (dv)
Chiricahua NM	1	69.2	2.7	1.3	6.1
Coronado NMem	2	69.4	1.9	0.9	7.8
Fort Bowie NHS	2	69.4	2.4	1.1	5.9
Saguaro NP	2	69.8	2.1	1.0	6.8

Table B.9. National Land Cover Dataset land cover classes, and reclassification for calculating percent of natural and converted land cover (NPS 2009).

Anderson I	Anderson II	Natural / Converted
1 Open Water	11 Open Water	Natural
	12 Perennial Ice/Snow	Natural
2 Developed	21 Developed Open Space	Converted
	22 Developed Low Intensity	Converted
	23 Developed Medium Intensity	Converted
	24 Developed High Intensity	Converted
3 Barren/Quarries/Transitional	31 Barren Land	Natural
	32 Unconsolidated Shore	Natural
4 Forest	41 Deciduous Forest	Natural
	42 Evergreen Forest	Natural
	43 Mixed Forest	Natural
5 Shrub/Scrub	51 Dwarf Scrub	Natural
	52 Shrub/Scrub	Natural
7 Grassland/Herbaceous	71 Grassland/Herbaceous	Natural
	72 Sedge/Herbaceous	Natural
	73 Lichens	Natural
	74 Moss	Natural
8 Agriculture	81 Pasture/Hay	Converted
	82 Cultivated Agriculture	Converted
9 Wetlands	90 Woody Wetlands	Natural
	95 Emergent Herbaceous Wetlands	Natural

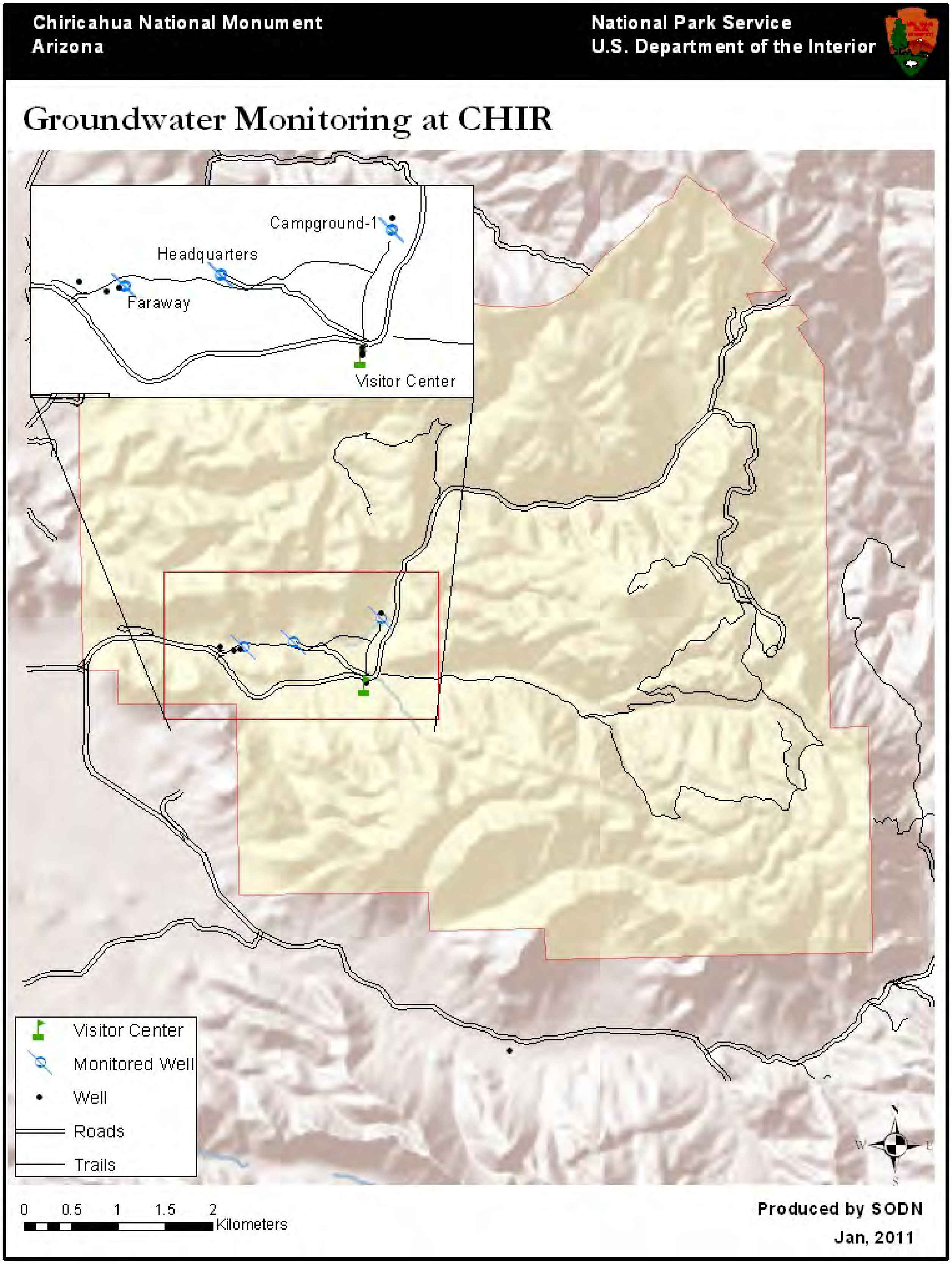

Figure B.1. Groundwater monitoring locations at Chiricahua NM (NPS SODN 2011). Figure courtesy of the NPS Sonoran Desert Network.

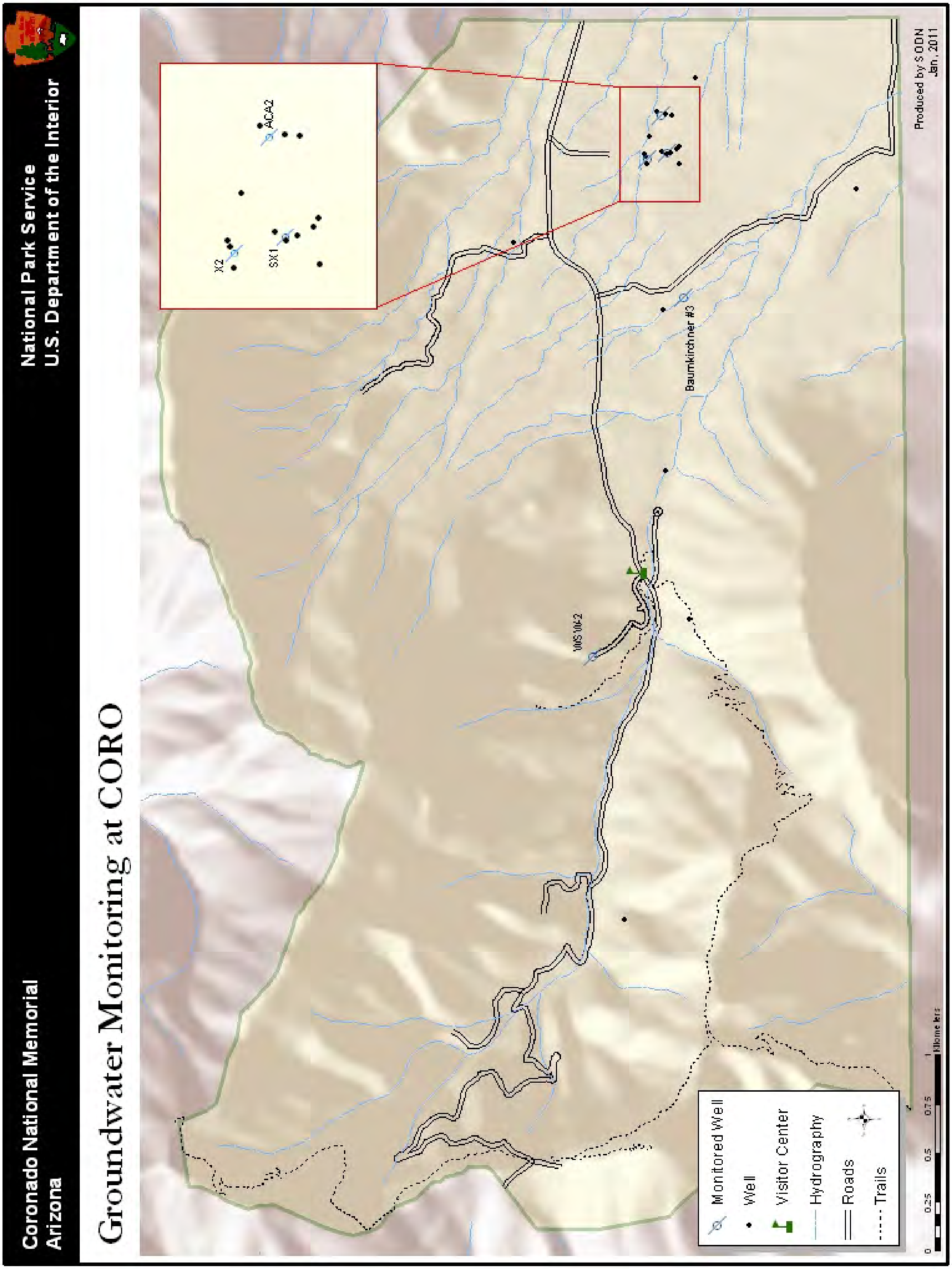

Figure B.2. Groundwater monitoring locations at Coronado NMem (NPS SODN 2011). Figure courtesy of the NPS Sonoran Desert Network.

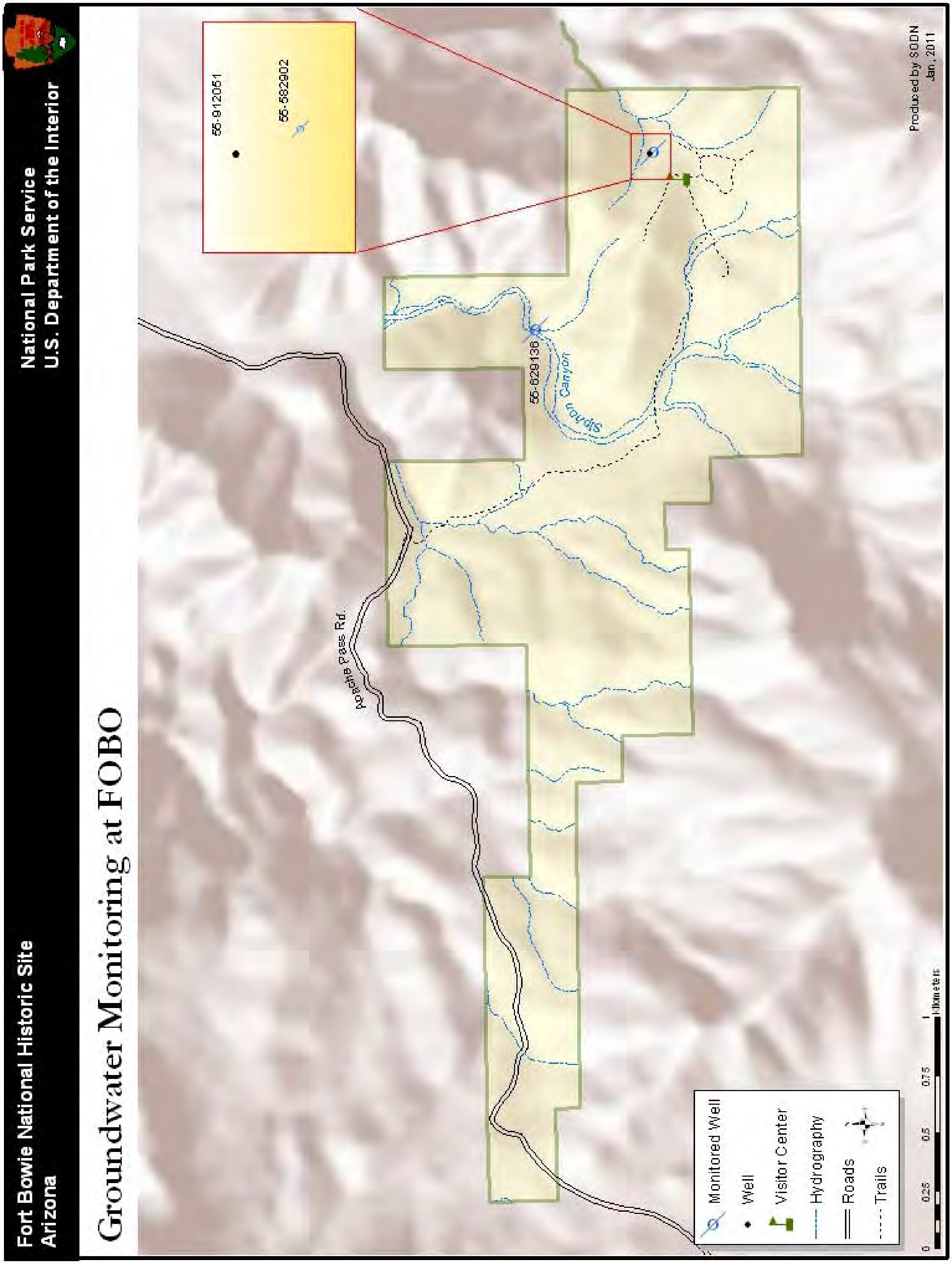

Figure B.3. Groundwater monitoring locations at Fort Bowie NHS (NPS SODN 2011). Figure courtesy of the NPS Sonoran Desert Network.

Table B.10. Seep and spring flow measurements collected by NPS Sonoran Desert Network, summer 2010 (NPS SWNC 2010).

	Visit Date	Total Discharge (Liters/second)
Chiricahua NM		
Bear Scat Spring	6/14/2010	0.0698
Bonita Park Spring	6/24/2010	0.02887
Garfield Spring	6/13/2010	0.0075
Kraft Spring	6/11/2010	none
Roadside Seep	6/24/2010	0.0396
Shake Spring	6/23/2010	0.0283
Silver Spur Spring	6/12/2010	0.0259
Superintendent Spring	6/11/2010	0.01855
Coronado NMem		
Blue Waterfall Site 1	7/24/2010	0.0165
Blue Waterfall Site 2	7/24/2010	none
East Forest Lane Seep	7/23/2010	none
Fern Grotto Site 1	7/22/2010	0.007536
Joe's Canyon Trail Site 2	7/27/2010	0.116
Joe's Canyon Trail Site 3	7/27/2010	flow visible but too low to measure
Joe's Spring	7/22/2010	0.075
Sparkes	7/25/2010	none
Swallow Spring Site 3	7/26/2010	0.022
Unknown Middle Owl	7/25/2010	0.0023
Yaqui Canyon Complex Site 1	7/23/2010	0.00724
Yaqui Canyon Complex Site 3	7/23/2010	0.0158
Fort Bowie NHS		
Apache Spring	6/10/2010	0.2283
Lower Mine Spring	6/10/2010	0.3632
Upper Mine Spring	6/25/2010	0.2136

Table B.11. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Date	Discharge, cfs	Specific Conductance (µS/cm @ 25°C)	pH	Temperature (°C)	Dissolved Oxygen (mg/L)	Calcium (dissolved, mg/L)
Chiricahua NM							
Unnamed spring above Shake Spring	11-20-2002	--	356	7.3	11.0	5.8	52.2
Unnamed spring above Shake Spring	05-06-2003	--	338	7.5	13.8	4.9	48.7
Unnamed spring above Shake Spring	09-23-2003	< .10	340	6.7	16.5	2.2	49.5
Shake Spring (Bonita Creek)	11-20-2002	--	370	7.3	12.5	4.1	53.3
Shake Spring (Bonita Creek)	05-06-2003	--	371	7.3	14.0	4.2	54.8
Shake Spring (Bonita Creek)	09-23-2003	< .10	366	7.2	17.1	3.2	53.1
Coronado NMem							
Fern Grotto (Brown allotment)	01-16-2003	--	700	7.1	15.9	8.0	123
Fern Grotto (Brown allotment)	05-01-2003	< .10	685	7.0	16.6	6.7	120
Fern Grotto (Brown allotment)	09-09-2003	< .10	728	7.2	27.0	4.8	134
Joe's Spring	01-15-2003	--	555	7.7	9.1	--	84.8
Joe's Spring	09-09-2003	< .10	406	7.0	20.2	6.3	77.3
Blue Waterfall Seep above an unnamed mine	01-15-2003	--	294	7.6	18.7	7.2	27.8
Blue Waterfall Seep above an unnamed mine	04-29-2003	< .10	363	6.7	15.7	5.6	30.4
Blue Waterfall Seep above an unnamed mine	09-11-2003	< .10	400	7.0	18.5	5.3	33.5
Blue Waterfall Seep below an unnamed mine	01-15-2003	--	350	8.1	17.0	6.7	121
Blue Waterfall Seep below an unnamed mine	09-11-2003	< .10	924	7.3	18.5	7.5	129
State of Texas Mine #11	01-15-2003	--	637	8.1	15.0	8.1	82.6
State of Texas Mine #11	04-29-2003	< .10	637	--	--	--	79.8
State of Texas Mine #11	09-10-2003	< .10	681	7.8	23.4	4.1	98.4
State of Texas Seep	01-14-2003	--	805	7.1	8.7	1.9	122
State of Texas Seep	04-29-2003	< .10	796	6.9	18.5	0.7	126
State of Texas Seep	09-10-2003	< .10	789	7.1	18.4	1.1	132
Clark-Smith Mine	01-15-2003	--	572	7.4	14.9	4.7	76.1
Clark-Smith Mine	04-30-2003	< .10	562	7.3	15.1	4.2	71.1
Clark-Smith Mine	09-10-2003	< .10	601	7.2	18.3	3.5	88.9
Yaqui Spring	05-02-2003	< .10	541	8.4	22.6	14.2	89.5
Yaqui Spring	09-11-2003	< .01	520	7.4	25.9	10.0	99.3
Fort Bowie NHS							
Apache Spring	11-20-2002	0.35	562	7.2	18.0	3.9	102
Apache Spring	05-07-2003	--	568	7.1	18.1	2.8	103
Apache Spring	09-04-2003	E .10	555	6.5	19.0	2.6	101

Table B.11. cont. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Magnesium (dissolved, mg/L)	Sodium (dissolved, mg/L)	Potassium (disolved, mg/L)	Alkalinity, water, filtrd, inc tit, field, mg/L as CaCO3	Alkalinity, water, fltrd, Gran, tit, field, mg/L as CaCO3	Sulfate (dissolved, mg/L)
Chiricahua NM						
Unnamed spring above Shake Spring	3.08	19.1	0.93	--	151	17.9
Unnamed spring above Shake Spring	2.37	19.6	0.85	143	--	15.8
Unnamed spring above Shake Spring	2.41	22.8	1.35	143	--	15.9
Shake Spring (Bonita Creek)	3.12	20.3	0.94	--	164	16.1
Shake Spring (Bonita Creek)	3.04	21.4	1.07	162	--	16.2
Shake Spring (Bonita Creek)	2.63	23.4	1.16	161	--	13.7
Coronado NMem						
Fern Grotto (Brown allotment)	8.98	18.3	0.38	--	241	114
Fern Grotto (Brown allotment)	8.54	17.1	0.49	250	--	110
Fern Grotto (Brown allotment)	10.3	19.3	0.62	237	--	114
Joe's Spring	10.4	21.1	0.32	--	215	63.0
Joe's Spring	10.2	17.7	0.92	195	--	37.3
Blue Waterfall Seep above an unnamed mine	10.7	27.5	0.30	--	75	85.5
Blue Waterfall Seep above an unnamed mine	11.2	25.0	1.02	92	--	78.1
Blue Waterfall Seep above an unnamed mine	12.5	35.7	0.22	106	--	76.5
Blue Waterfall Seep below an unnamed mine	23.7	35.6	8.13	--	145	299
Blue Waterfall Seep below an unnamed mine	26.8	41.0	0.87	104	--	373
State of Texas Mine #11	11.6	35.2	1.06	--	145	164
State of Texas Mine #11	11.2	33.2	1.22	152	--	163
State of Texas Mine #11	13.2	36.8	1.94	155	--	185
State of Texas Seep	22.8	16.1	0.53	--	339	87.0
State of Texas Seep	22.9	18.0	1.66	345	--	83.2
State of Texas Seep	22.8	17.8	1.31	359	--	79.4
Clark-Smith Mine	19.2	15.8	0.63	--	205	80.1
Clark-Smith Mine	18.1	14.9	0.75	204	--	78.3
Clark-Smith Mine	19.7	16.1	0.81	224	--	78.4
Yaqui Spring	9.57	9.06	1.28	195	--	95.1
Yaqui Spring	8.39	7.33	0.40	235	--	41.4
Fort Bowie NHS						
Apache Spring	7.10	11.1	0.95	--	243	40.8
Apache Spring	7.09	11.2	1.09	218	--	40.9
Apache Spring	7.32	11.4	1.20	234		39.4

Table B.11. cont. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Chloride (dissolved, mg/L)	Fluoride (dissolved, mg/L)	Silica (dissolved, mg/L)	Residue on evap. At 180 deg C water, fltrd, mg/L	Aluminum (dissolved, µg/L)	Antimony (dissolved, µg/L)
Chiricahua NM						
Unnamed spring above Shake Spring	5.99	2.38	54.7	256	E 1	< .30
Unnamed spring above Shake Spring	5.11	2.54	53.3	247	E 1	< .30
Unnamed spring above Shake Spring	5.03	2.7	58.8	246	2	< .30
Shake Spring (Bonita Creek)	5.92	2.41	54.9	259	E 1	< .30
Shake Spring (Bonita Creek)	5.04	2.58	57.8	269	E 1	< .30
Shake Spring (Bonita Creek)	4.98	2.8	63.9	261	2	< .30
Coronado NMem						
Fern Grotto (Brown allotment)	11.0	0.23	22.0	471	E 1	< .30
Fern Grotto (Brown allotment)	10.0	0.22	23.2	490	< 2	< .30
Fern Grotto (Brown allotment)	12.40	0.2	25.1	496	< 2	< .30
Joe's Spring	7.04	0.28	21.5	347	< 2	< .30
Joe's Spring	5.56	0.3	29.7	314	E 2	< .30
Blue Waterfall Seep above an unnamed mine	7.07	0.51	29.4	248	M	E .23
Blue Waterfall Seep above an unnamed mine	6.69	0.46	34.8	271	M	< .30
Blue Waterfall Seep above an unnamed mine	7.96	0.7	36.5	288	3	< .30
Blue Waterfall Seep below an unnamed mine	15.40	1.38	44.3	677	12	< .30
Blue Waterfall Seep below an unnamed mine	11.40	1.4	51.7	755	46	< .30
State of Texas Mine #11	7.43	0.51	30.6	443	< 2	< .30
State of Texas Mine #11	6.67	0.54	32.9	460	< 2	< .30
State of Texas Mine #11	8.86	0.6	38.2	505	E 1	< .30
State of Texas Seep	8.41	0.21	29.8	510	< 2	< .30
State of Texas Seep	8.44	0.23	34.8	537	2	< .30
State of Texas Seep	9.88	0.2	35.9	535	2	< .30
Clark-Smith Mine	7.46	0.29	37.6	375	< 2	< .30
Clark-Smith Mine	7.13	0.28	39.3	390	< 2	< .30
Clark-Smith Mine	8.74	0.3	39.9	402	E 1	< .30
Yaqui Spring	6.18	0.23	17.2	386	E 1	0.34
Yaqui Spring	4.15	0.2	15.3	325	2	E .15
Fort Bowie NHS						
Apache Spring	9.68	0.49	18.1	348	2	< .30
Apache Spring	9.83	0.44	18.4	355	< 2	< .30
Apache Spring	9.97	0.4	19.1	347	< 2	< .30

Table B.11. cont. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Barium (dissolved, µg/L)	Beryllium (dissolved, µg/L)	Boron (dissolved, µg/L)	Cadmium (dissolved, µg/L)	Chromium (dissolved, µg/L)	Cobalt (dissolved, µg/L)	Copper (dissolved, µg/L)
Chiricahua NM							
Unnamed spring above Shake Spring	11	2.16	15	< .04	< .8	0.145	0.3
Unnamed spring above Shake Spring	10	2.35	13	< .04	< .8	0.141	0.4
Unnamed spring above Shake Spring	7	2.63	21	< .04	< .8	0.221	0.2
Shake Spring (Bonita Creek)	13	0.90	17	< .04	< .8	0.179	0.2
Shake Spring (Bonita Creek)	15	0.75	18	E .02	< .8	0.133	0.4
Shake Spring (Bonita Creek)	10	1.13	23	E .03	< .8	0.211	0.4
Coronado NMem							
Fern Grotto (Brown allotment)	70	< .06	13	< .04	< .8	0.288	1.2
Fern Grotto (Brown allotment)	67	< .06	E 13	0.05	< .8	0.312	1.9
Fern Grotto (Brown allotment)	67	< .06	18	< .04	< .8	0.307	2.1
Joe's Spring	89	< .06	< 13	0.06	< .8	0.214	1.3
Joe's Spring	86	< .06	17	E .03	< .8	0.193	1.7
Blue Waterfall Seep above an unnamed mine	20	< .06	< 13	E .03	< .8	0.114	1.6
Blue Waterfall Seep above an unnamed mine	25	< .06	E 6.5	0.06	< .8	0.124	1.3
Blue Waterfall Seep above an unnamed mine	28	< .06	9.0	E .03	< .8	0.310	2.2
Blue Waterfall Seep below an unnamed mine	26	0.27	17	25.7	< .8	0.376	377
Blue Waterfall Seep below an unnamed mine	26	0.37	19	29.3	< .8	2.07	505
State of Texas Mine #11	29	E .06	E 11	< .04	< .8	0.194	1.8
State of Texas Mine #11	40	E .04	E 10	0.22	< .8	0.135	3.0
State of Texas Mine #11	36	< .06	14	0.17	< .8	0.225	9.5
State of Texas Seep	145	< .06	20	E .03	E .5	0.343	0.8
State of Texas Seep	150	< .06	24	< .04	< .8	0.399	1.0
State of Texas Seep	191	< .06	23	< .04	< .8	0.690	1.2
Clark-Smith Mine	45	E .04	23	0.23	< .8	0.174	2.8
Clark-Smith Mine	44	E .03	21	0.24	< .8	0.18	3.1
Clark-Smith Mine	48	E .04	21	0.16	< .8	0.19	1.4
Yaqui Spring	55	< .06	< 13	< .04	< .8	0.244	2.4
Yaqui Spring	68	< .06	9.2	0.04	< .8	0.256	6.5
Fort Bowie NHS							
Apache Spring	22	< .06	20	E .03	< .8	0.178	0.6
Apache Spring	24	< .06	E 12	< .04	< .8	0.198	0.4
Apache Spring	19	< .06	17	< .04	< .8	0.251	0.7

Table B.11. cont. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Cyanide (dissolved, µg/L)	Iron (disslved, µg/L)	Lead (dissolved, µg/L)	Manganese (dissolved, µg/L)	Molyb-denum (dissolved, µg/L)	Nickel (dissolved, µg/L)	Silver (dissolved, µg/L)
Chiricahua NM							
Unnamed spring above Shake Spring	< 0.01	24	< .08	44.4	1	1.99	< .2
Unnamed spring above Shake Spring	< 0.01	19	< .08	39.5	1.1	1.70	< .2
Unnamed spring above Shake Spring	< 0.01	111	< .08	88.1	1.3	0.96	< .2
Shake Spring (Bonita Creek)	< 0.01	117	< .08	103	1.0	1.93	< .2
Shake Spring (Bonita Creek)	< 0.01	< 10	< .08	11.6	1.2	1.94	< .2
Shake Spring (Bonita Creek)	< 0.01	27	< .08	122	1.2	1.00	< .2
Coronado NMem							
Fern Grotto (Brown allotment)	--	< 10	< .08	0.4	E .3	5.90	< .2
Fern Grotto (Brown allotment)	--	< 10	< .08	1.0	E .2	2.15	< .2
Fern Grotto (Brown allotment)	--	< 8	< .08	0.5	E .2	0.45	< .2
Joe's Spring	--	< 10	< .08	5.8	1.1	3.93	< .2
Joe's Spring	--	E 5	< .08	2.5	0.9	0.30	< .2
Blue Waterfall Seep above an unnamed mine	--	100	E .06	8.2	0.7	1.64	< .2
Blue Waterfall Seep above an unnamed mine	--	166	< .08	28.2	E .2	0.50	< .2
Blue Waterfall Seep above an unnamed mine	--	73	E .06	56.2	0.5	0.46	< .2
Blue Waterfall Seep below an unnamed mine	--	< 10	E .05	317	1.3	14.40	< .2
Blue Waterfall Seep below an unnamed mine	--	E 5	E .08	711	1.1	9.21	< .2
State of Texas Mine #11	--	< 10	< .08	0.5	1.7	4.06	< .2
State of Texas Mine #11	--	< 10	< .08	0.9	28.6	2.43	< .2
State of Texas Mine #11	--	< 8	E .06	22.1	2.3	0.42	< .2
State of Texas Seep	--	< 10	E .06	19.6	0.4	5.32	< .2
State of Texas Seep	--	59	E .05	112	0.5	2.35	--
State of Texas Seep	--	371	< .08	1500	E .3	0.68	< .2
Clark-Smith Mine	--	< 10	< .08	0.6	27.6	3.50	< .2
Clark-Smith Mine	--	< 10	< .08	3.4	28.0	1.41	< .2
Clark-Smith Mine	--	< 8	E .05	14.5	20.5	0.24	< .2
Yaqui Spring	--	< 10	E .07	4.3	1.0	1.60	< .2
Yaqui Spring	--	< 8	E .06	3.1	0.4	0.94	< .2
Fort Bowie NHS							
Apache Spring	--	< 10	E .05	0.9	1.5	3.72	< .2
Apache Spring	--	< 10	< .08	0.9	1.5	3.52	< .2
Apache Spring	--	< 8	E .04	1.6	1.5	1.72	< .2

Table B.11. cont. Results of water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Brown 2005; NPS 2009).

	Zinc (dissolved, µg/L)	Uranium (dissolved, µg/L)	Fecal coliform, (col/100 mL)	Ammonia as N (dissolved, mg/L)	Nitrite as N (dissolved, mg/L)	Nitrate + Nitrate (dissolved, mg/L)	Ortho-phosphate (dissolved mg/L)
Chiricahua NM							
Unnamed spring above Shake Spring	1.0	6.84	--	< .04	< .008	E .04	< .02
Unnamed spring above Shake Spring	1.6	8.38	11	< .04	< .008	E .03	< .02
Unnamed spring above Shake Spring	E .6	7.37	25	< .04	< .008	E .03	< .02
Shake Spring (Bonita Creek)	E .8	5.28	--	< .04	< .008	E .04	< .02
Shake Spring (Bonita Creek)	1.2	7.66	3	< .04	< .008	< .06	< .02
Shake Spring (Bonita Creek)	E .9	5.38	25	< .04	< .008	< .06	< .02
Coronado NMem							
Fern Grotto (Brown allotment)	1.0	11.4	--	< .04	< .008	2.51	< .02
Fern Grotto (Brown allotment)	4.3	11.7	--	< .04	< .008	2.75	< .02
Fern Grotto (Brown allotment)	1.2	10.2	4	< .04	< .008	3.05	< .02
Joe's Spring	12.1	58.6	--	< .04	< .008	< .06	< .02
Joe's Spring	E .9	13.2	39	< .04	< .008	< .06	< .02
Blue Waterfall Seep above an unnamed mine	1.9	0.21	--	< .04	< .008	< .06	0.02
Blue Waterfall Seep above an unnamed mine	2.9	0.32	--	< .04	< .008	< .06	< .02
Blue Waterfall Seep above an unnamed mine	1.9	0.43	--	< .04	< .008	< .06	< .02
Blue Waterfall Seep below an unnamed mine	2570	12.0	--	< .04	< .008	E .04	< .02
Blue Waterfall Seep below an unnamed mine	3650	12.2	--	< .04	< .008	0.14	< .02
State of Texas Mine #11	E 1.0	113	--	< .04	< .008	0.07	< .02
State of Texas Mine #11	13.1	122	--	< .04	< .008	0.36	< .02
State of Texas Mine #11	3.9	122	--	E .03	< .008	0.55	0.03
State of Texas Seep	2.1	10.2	--	< .04	< .008	< .06	0.03
State of Texas Seep	4.0	7.98	--	0.15	< .008	< .06	0.05
State of Texas Seep	E .6	7.39	--	< .04	< .008	< .06	0.02
Clark-Smith Mine	18.5	36.7	--	< .04	< .008	0.64	< .02
Clark-Smith Mine	15	37.8	--	< .04	< .008	0.70	< .02
Clark-Smith Mine	22.9	30.0	--	< .04	< .008	0.68	< .02
Yaqui Spring	2.3	23.4	28	< .04	< .008	< .06	< .02
Yaqui Spring	3.8	8.09	0	< .04	< .008	< .06	< .02
Fort Bowie NHS							
Apache Spring	2.3	9.84	--	< .04	< .008	2.12	< .02
Apache Spring	< 1.0	10.1	--	< .04	< .008	2.21	< .02
Apache Spring	< 1.0	9.60	--	< .04	< .008	2.21	< .02

Table B.12. Elevations, designated uses, station numbers and water type based on water quality sampling at Chiricahua NM, Coronado NMem, and Fort Bowie NHS. A&Wc = Aquatic and Wildlife (cold water); A&Ww = Aquatic and Wildlfie (warm water).

	Elevation (ft)	Designated Use	USGS Assigned Station Number	Date	Water Type
Chiricahua NM					
Unnamed spring above Shake Spring	5710	A&Wc	320119109201401	11-20-2002	Ca-Na-HCO_3
Unnamed spring above Shake Spring	5710	A&Wc	320119109201401	05-06-2003	Ca-Na-HCO_3
Unnamed spring above Shake Spring	5710	A&Wc	320119109201401	09-23-2003	Ca-Na-HCO_3
Shake Spring (Bonita Creek)	5690	A&Wc	320118109201701	11-20-2002	Ca-Na-HCO_3
Shake Spring (Bonita Creek)	5690	A&Wc	320118109201701	05-06-2003	Ca-Na-HCO_3
Shake Spring (Bonita Creek)	5690	A&Wc	320118109201701	09-23-2003	Ca-Na-HCO_3
Coronado NMem					
Fern Grotto (Brown allotment)	6000	A&Wc	312145110142701	01-16-2003	Ca-HCO_3-SO_4
Fern Grotto (Brown allotment)	6000	A&Wc	312145110142701	05-01-2003	Ca-HCO_3-SO_4
Fern Grotto (Brown allotment)	6000	A&Wc	312145110142701	09-09-2003	Ca-HCO_3-SO_4
Joe's Spring	6300	A&Wc	312144110152901	01-15-2003	Ca-HCO_3-SO_4
Joe's Spring	6300	A&Wc	312144110152901	09-09-2003	Ca-HCO_3
Blue Waterfall Seep above an unnamed mine	5700	A&Wc	312103110152602	01-15-2003	Ca-Na-Mg-SO_4-HCO_3
Blue Waterfall Seep above an unnamed mine	5700	A&Wc	312103110152602	04-29-2003	Ca-Na-Mg-SO_4-HCO_3
Blue Waterfall Seep above an unnamed mine	5700	A&Wc	312103110152602	09-11-2003	Ca-Na-Mg-SO_4-HCO_3
Blue Waterfall Seep below an unnamed mine	5625	A&Wc	312103110152601	01-15-2003	Ca-Mg-SO_4-HCO_3
Blue Waterfall Seep below an unnamed mine	5625	A&Wc	312103110152601	09-11-2003	Ca-Mg-SO_4
State of Texas Mine #11	5825	A&Wc	312108110162301	01-15-2003	Ca-Na-SO_4-HCO_3
State of Texas Mine #11	5825	A&Wc	312108110162301	04-29-2003	Ca-Na-SO_4-HCO_3
State of Texas Mine #11	5825	A&Wc	312108110162301	09-10-2003	Ca-Na-SO_4-HCO_3
State of Texas Seep	5575	A&Wc	312055110162201	01-14-2003	Ca-Mg-HCO_3-SO_4
State of Texas Seep	5575	A&Wc	312055110162201	04-29-2003	Ca-Mg-HCO_3-SO_4
State of Texas Seep	5575	A&Wc	312055110162201	09-10-2003	Ca-Mg-HCO_3
Clark-Smith Mine	6025	A&Wc	312123110164301	01-15-2003	Ca-Mg-HCO_3-SO_4
Clark-Smith Mine	6025	A&Wc	312123110164301	04-30-2003	Ca-Mg-HCO_3-SO_4
Clark-Smith Mine	6025	A&Wc	312123110164301	09-10-2003	Ca-Mg-HCO_3-SO_4
Yaqui Spring	6175	A&Wc	312027110165601	05-02-2003	Ca-HCO3-SO_4
Yaqui Spring	6175	A&Wc	312027110165601	09-11-2003	Ca-HCO_3
Fort Bowie NHS					
Apache Spring	4908	A&Ww	320842109252401	11-20-2002	Ca-HCO_3
Apache Spring	4908	A&Ww	320842109252401	05-07-2003	Ca-HCO_3
Apache Spring	4908	A&Ww	320842109252401	09-04-2003	Ca-HCO_3
Lower Mine Tunnel Spring	4930	undesignated	unassigned	8-25-2009	Ca-HCO_3

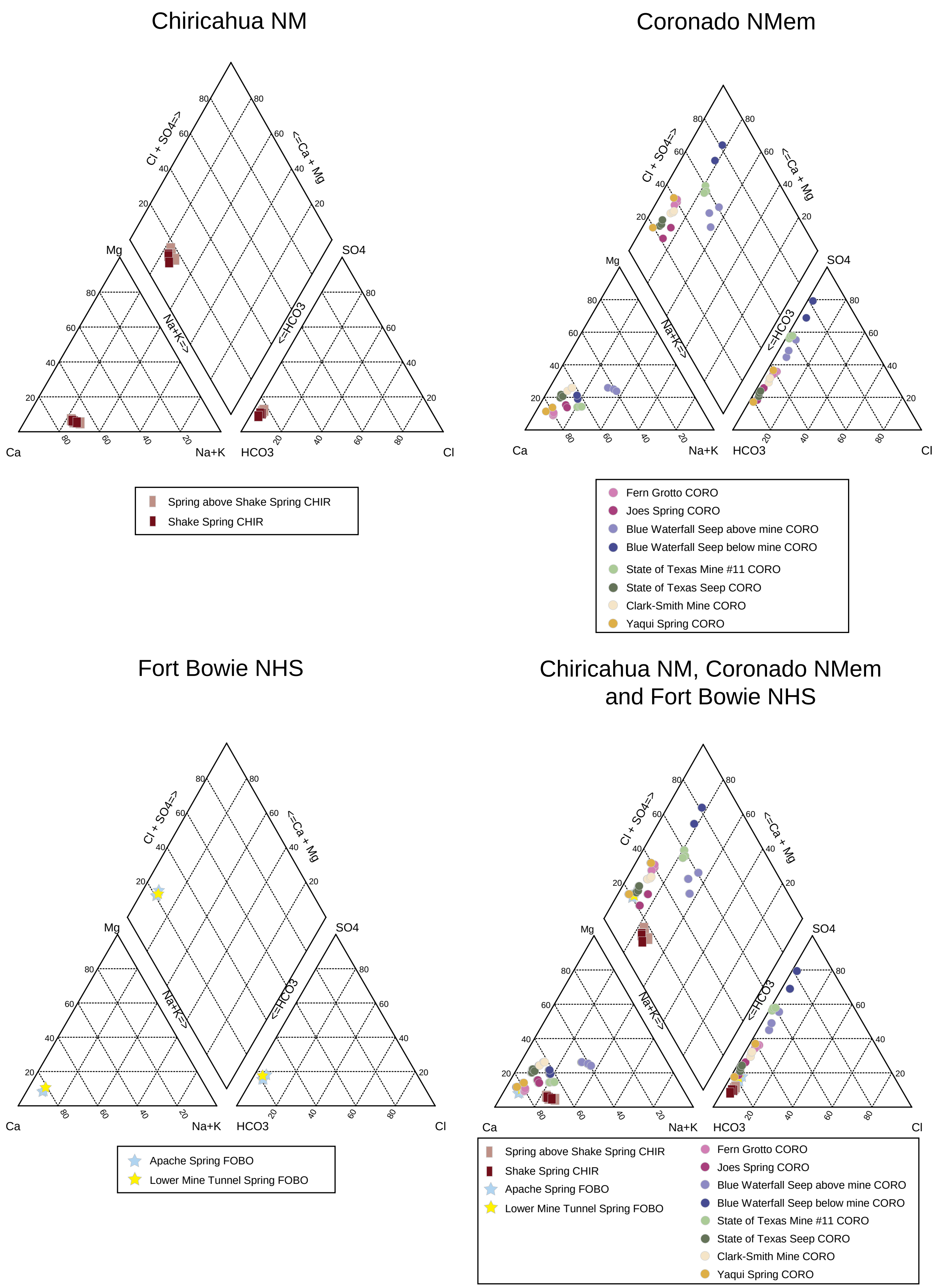

Figure B.4. Piper plots of major ions in Chiricahua NM (top left) and Coronado NMem (right) water quality samples.

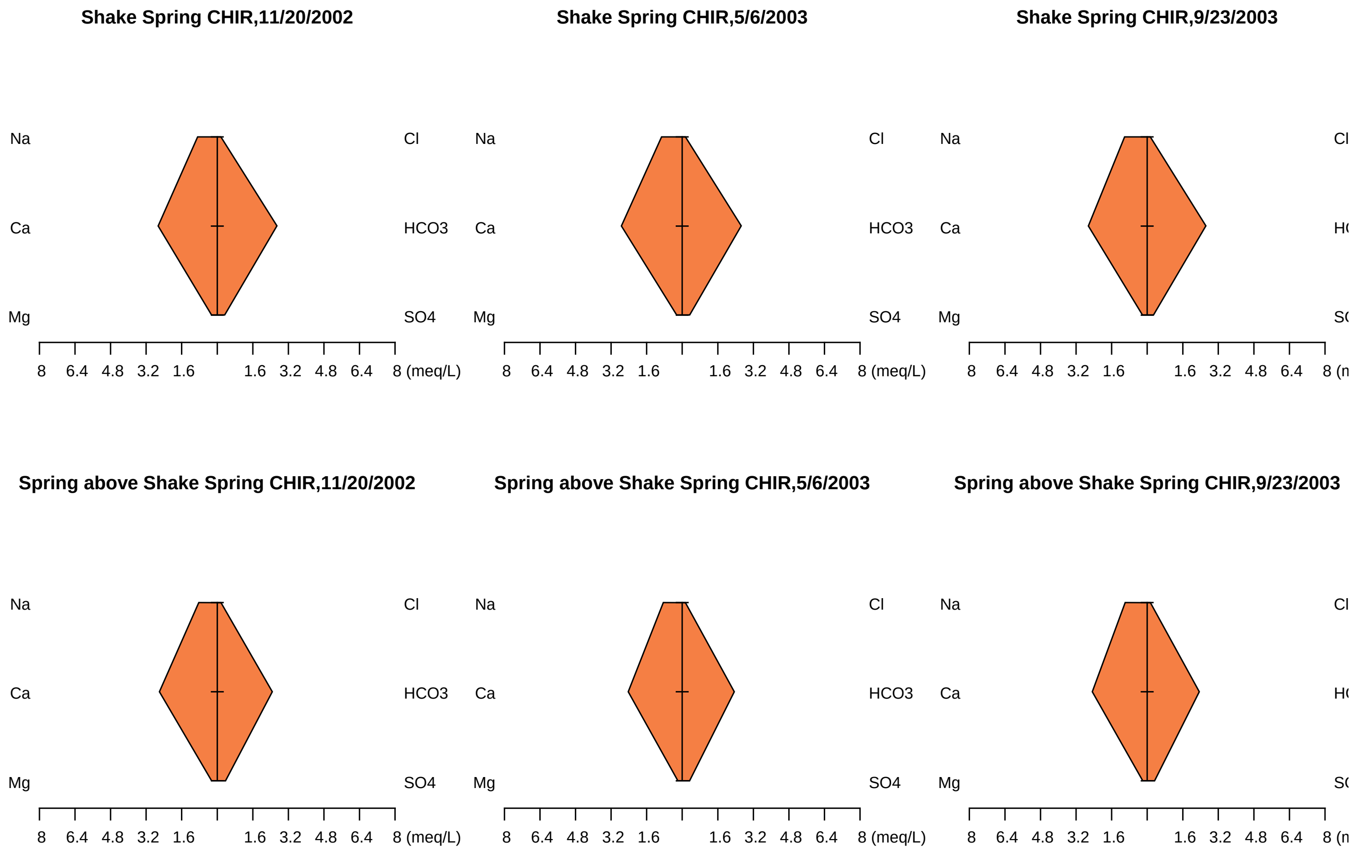

Figure B.5. Stiff diagrams of major ions in Chiricahua NM water quality samples.

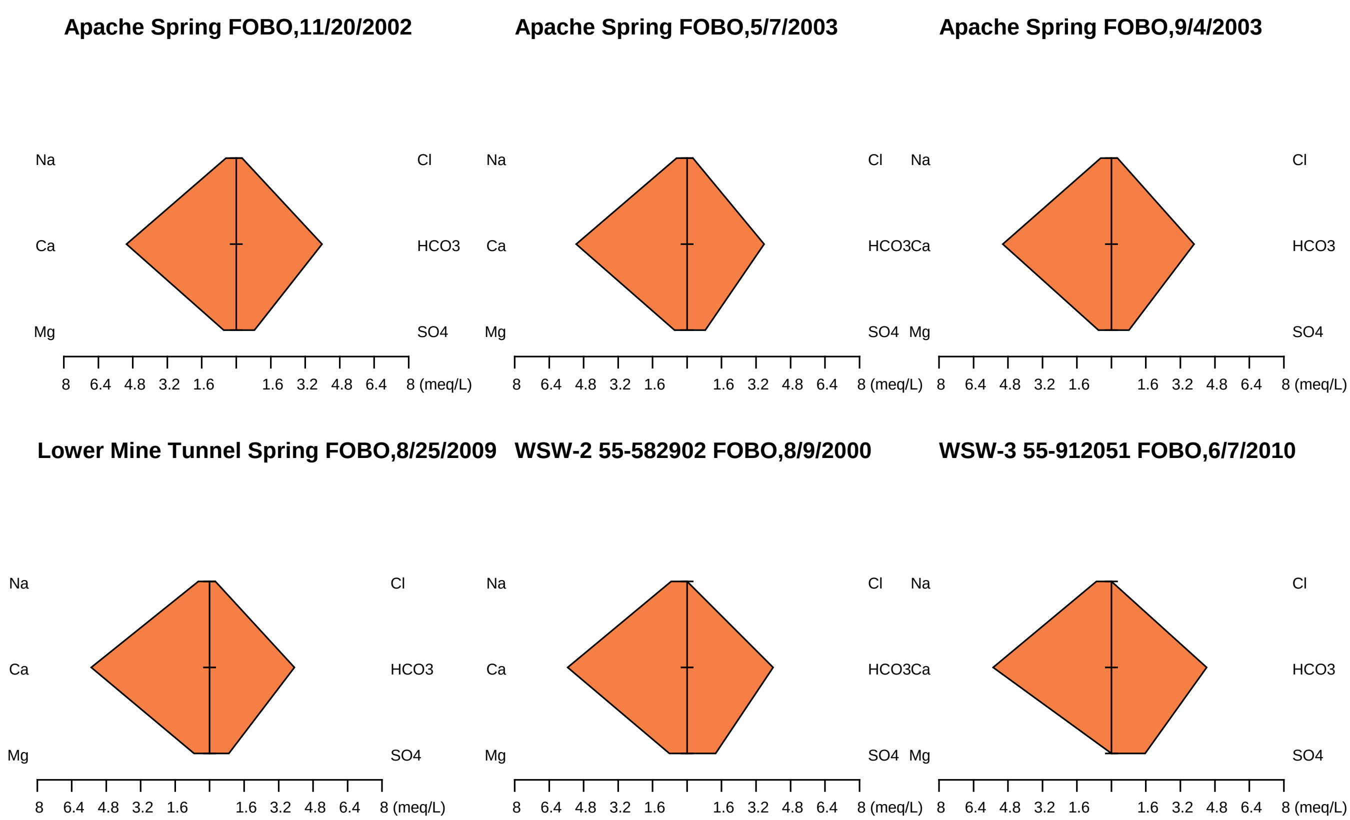

Figure B.6. Stiff diagrams of major ions in Fort Bowie NHS water quality samples.

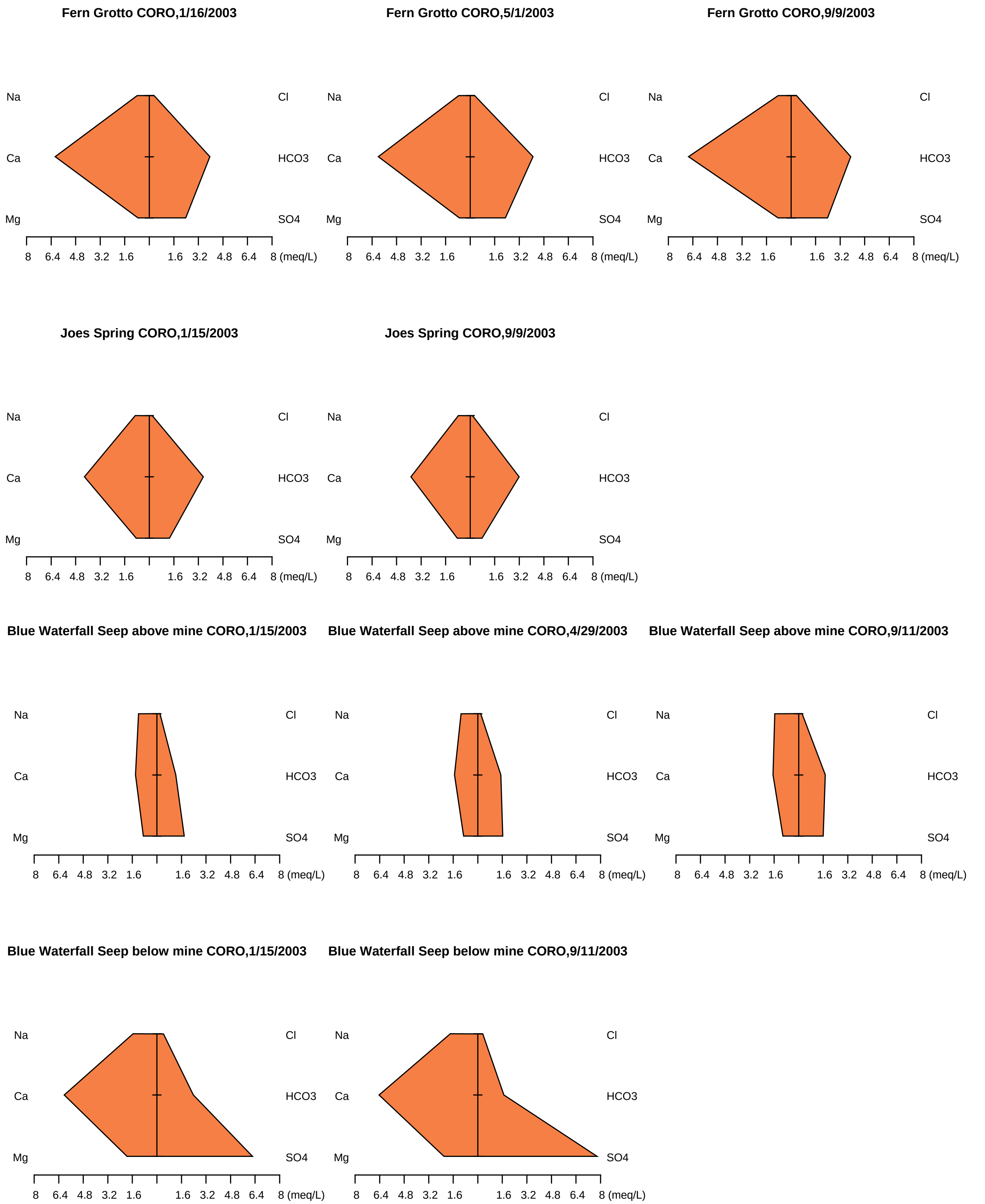

Figure B.7. Stiff diagrams of major ions in Coronado NMem water quality samples.

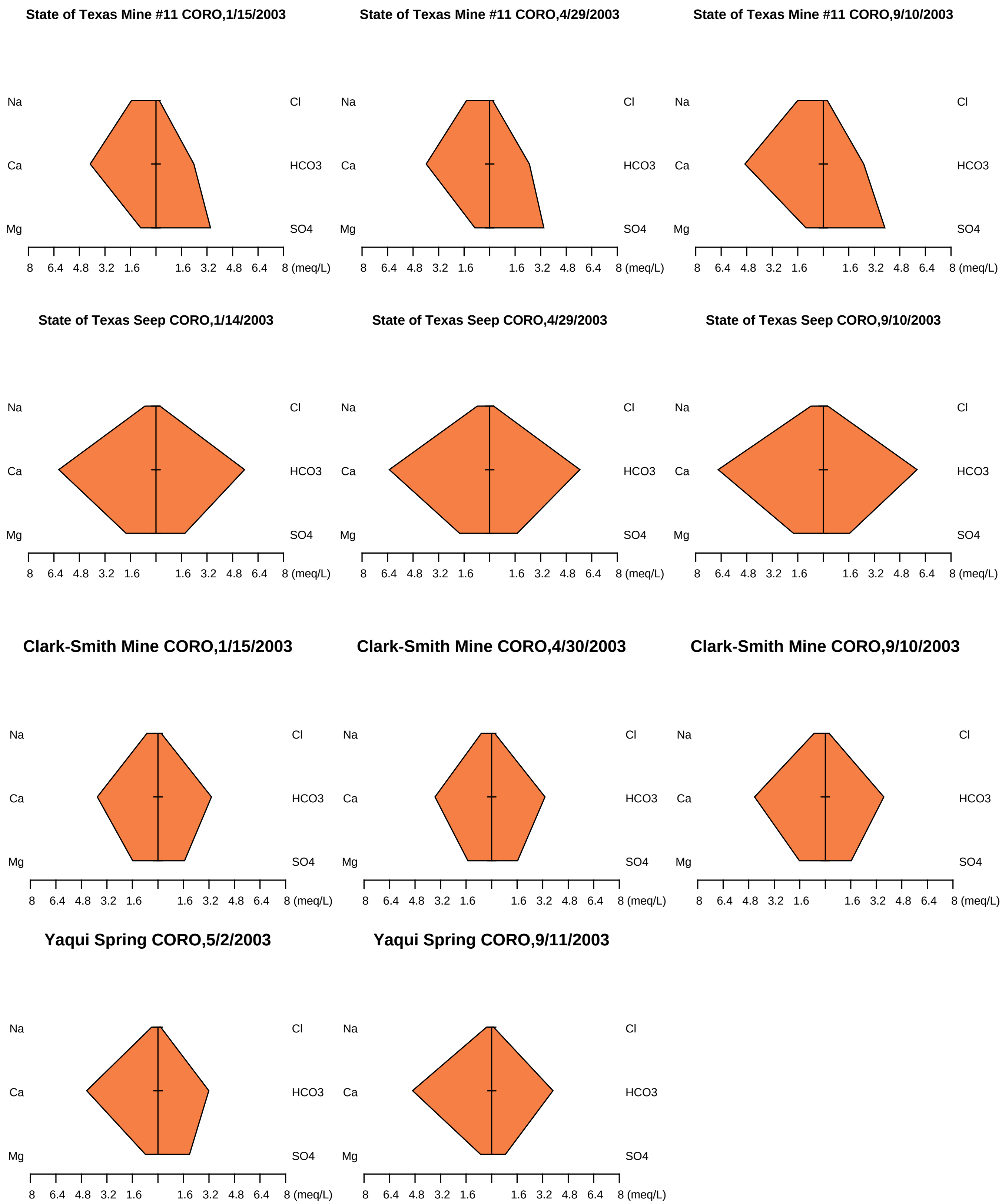

Figure B.7. cont. Stiff diagrams of major ions in Coronado NMem water quality samples.

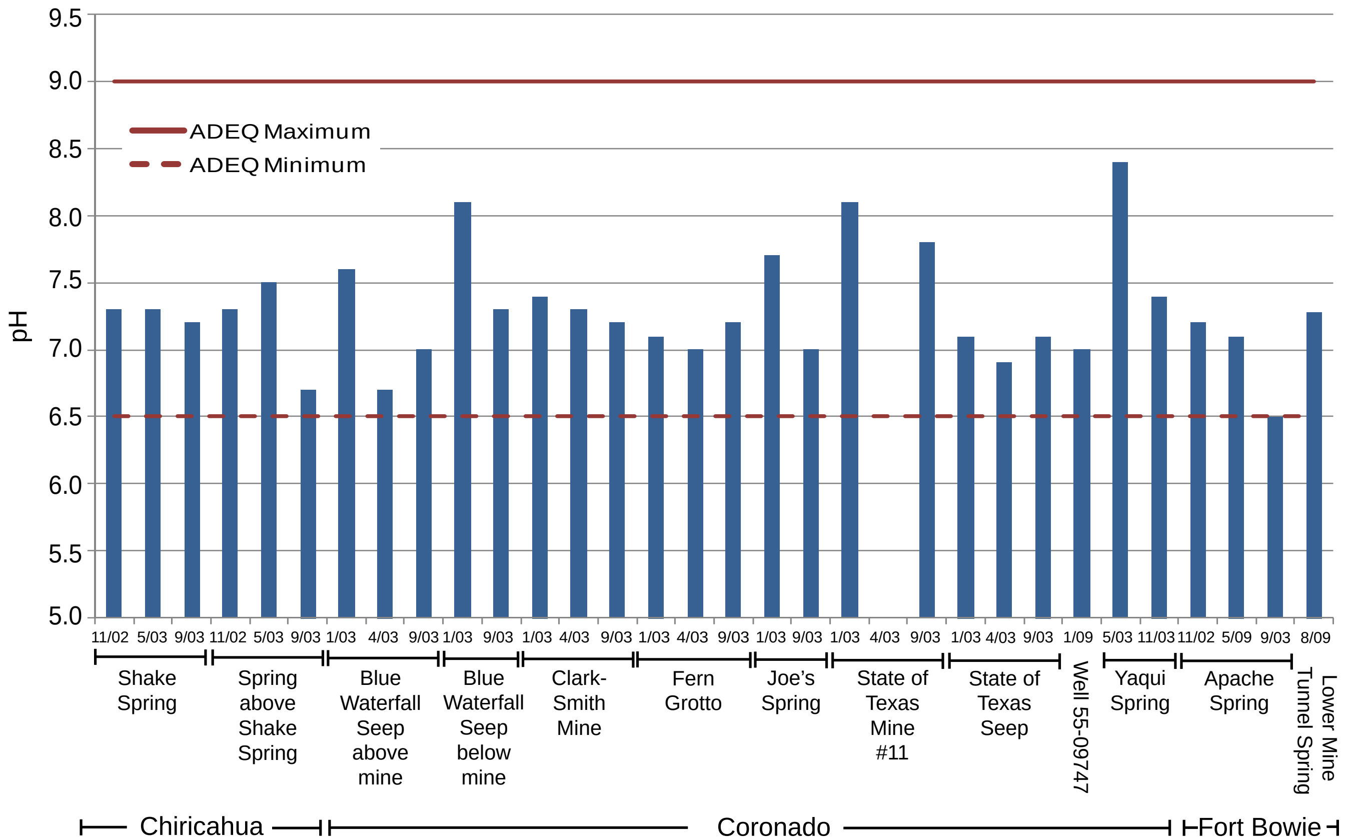

Figure B.8. pH results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

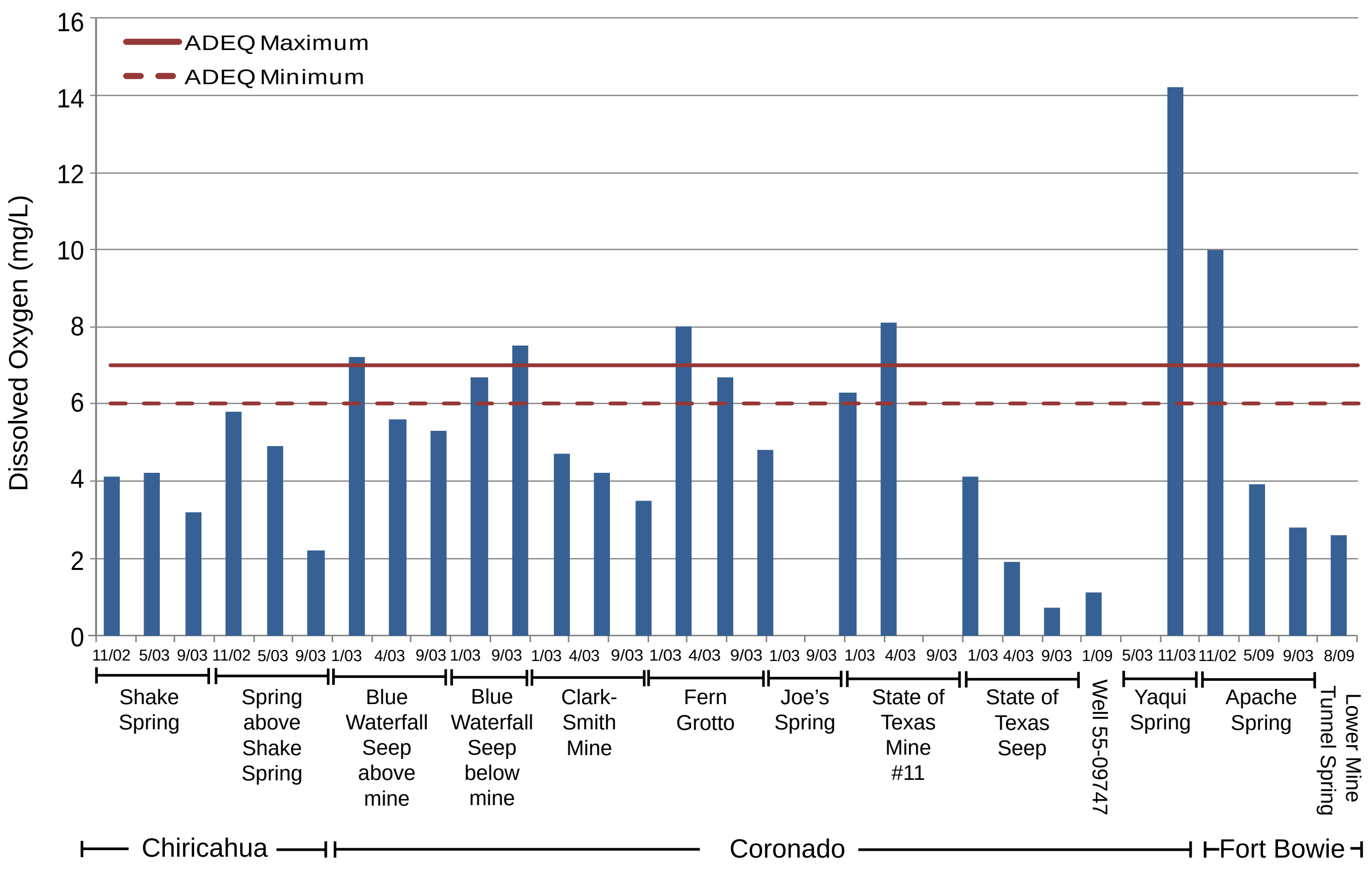

Figure B.9. Dissolved oxygen results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

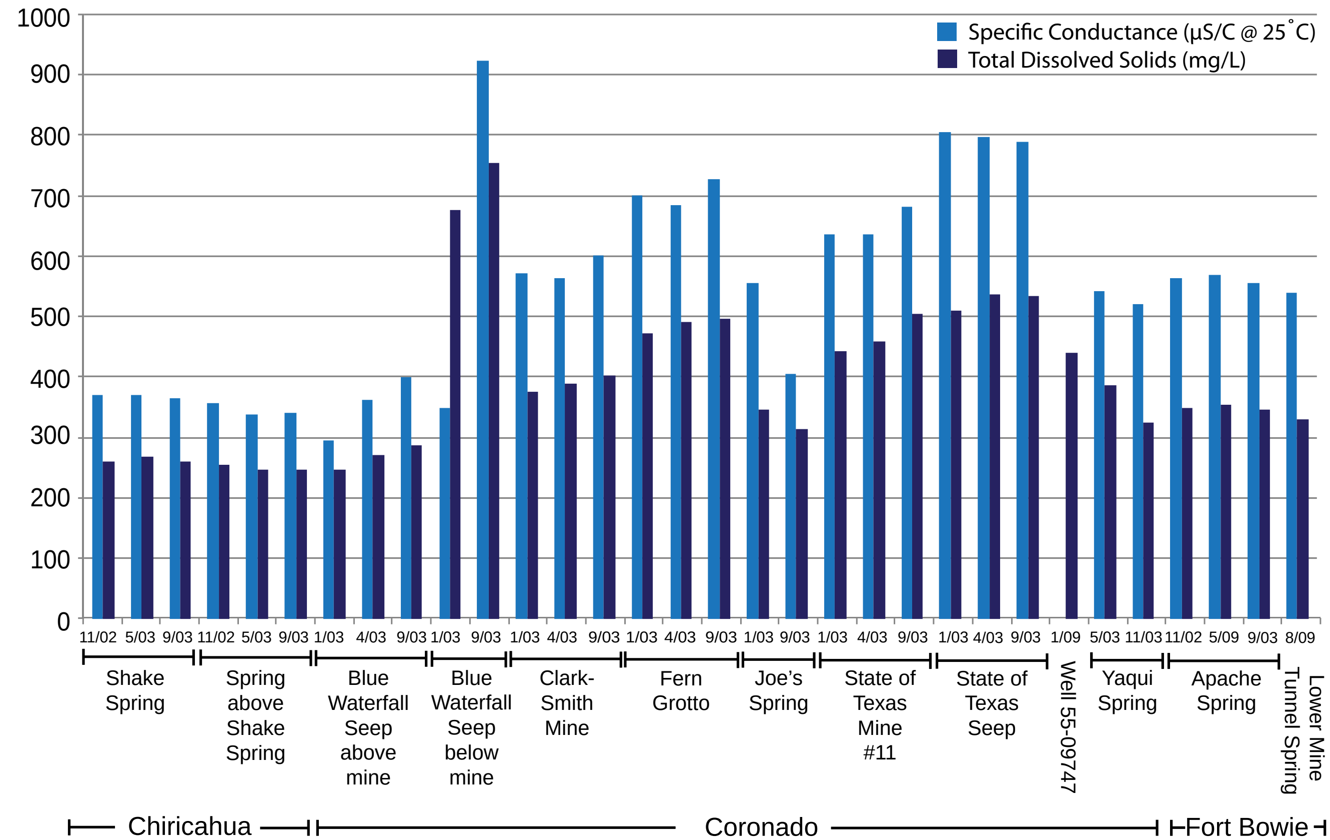

Figure B.10. Total dissolved solids and specific conductance results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

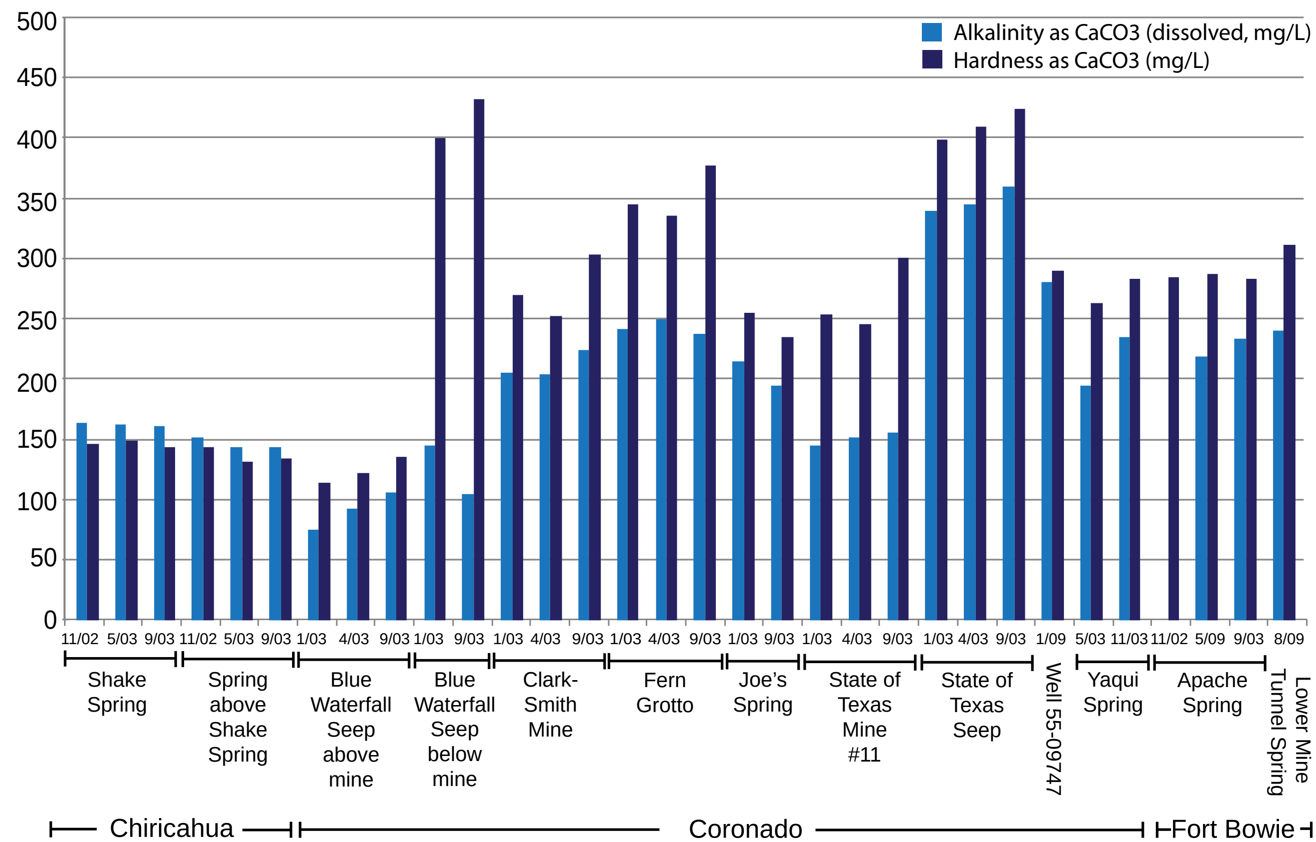

Figure B.11. Alkalinity results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

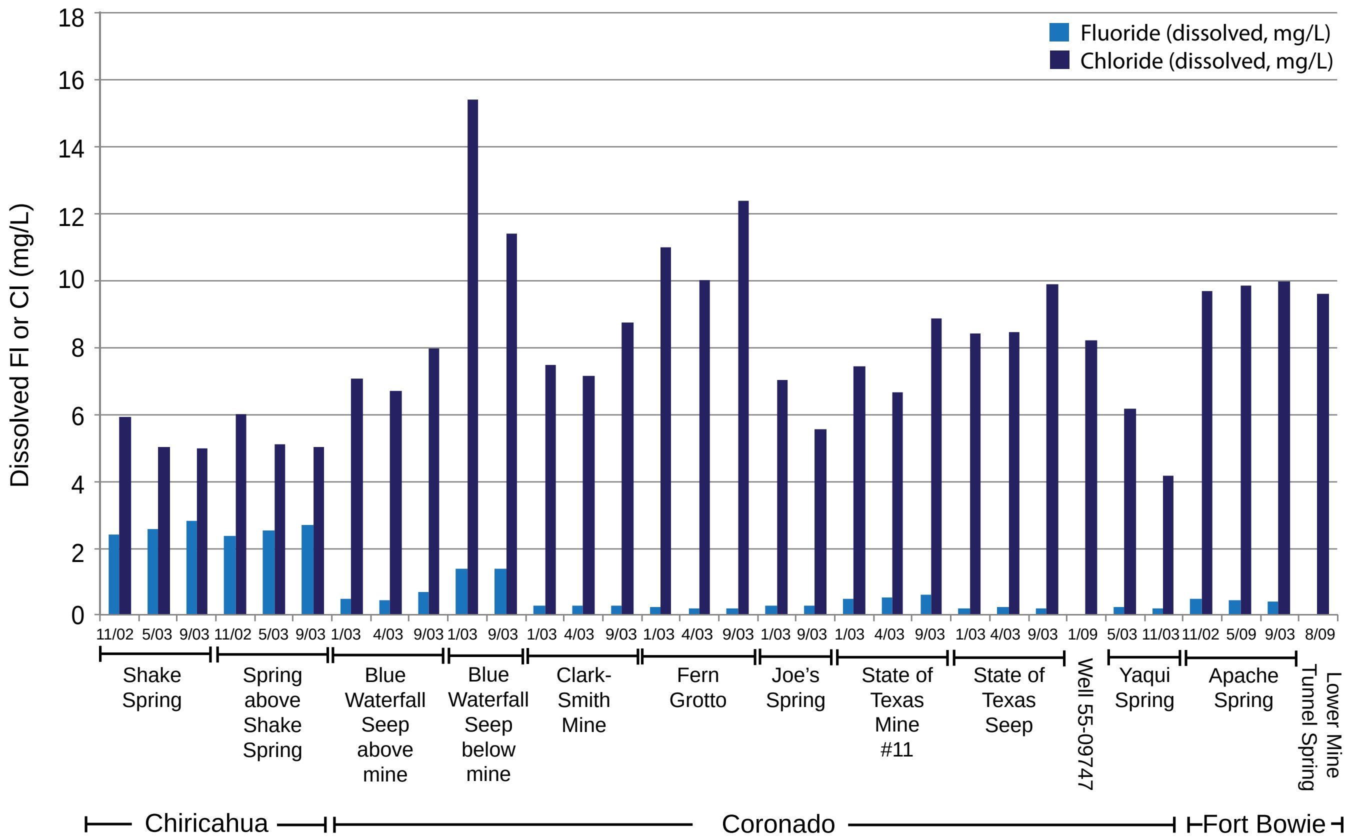

Figure B.12. Dissolved fluoride results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

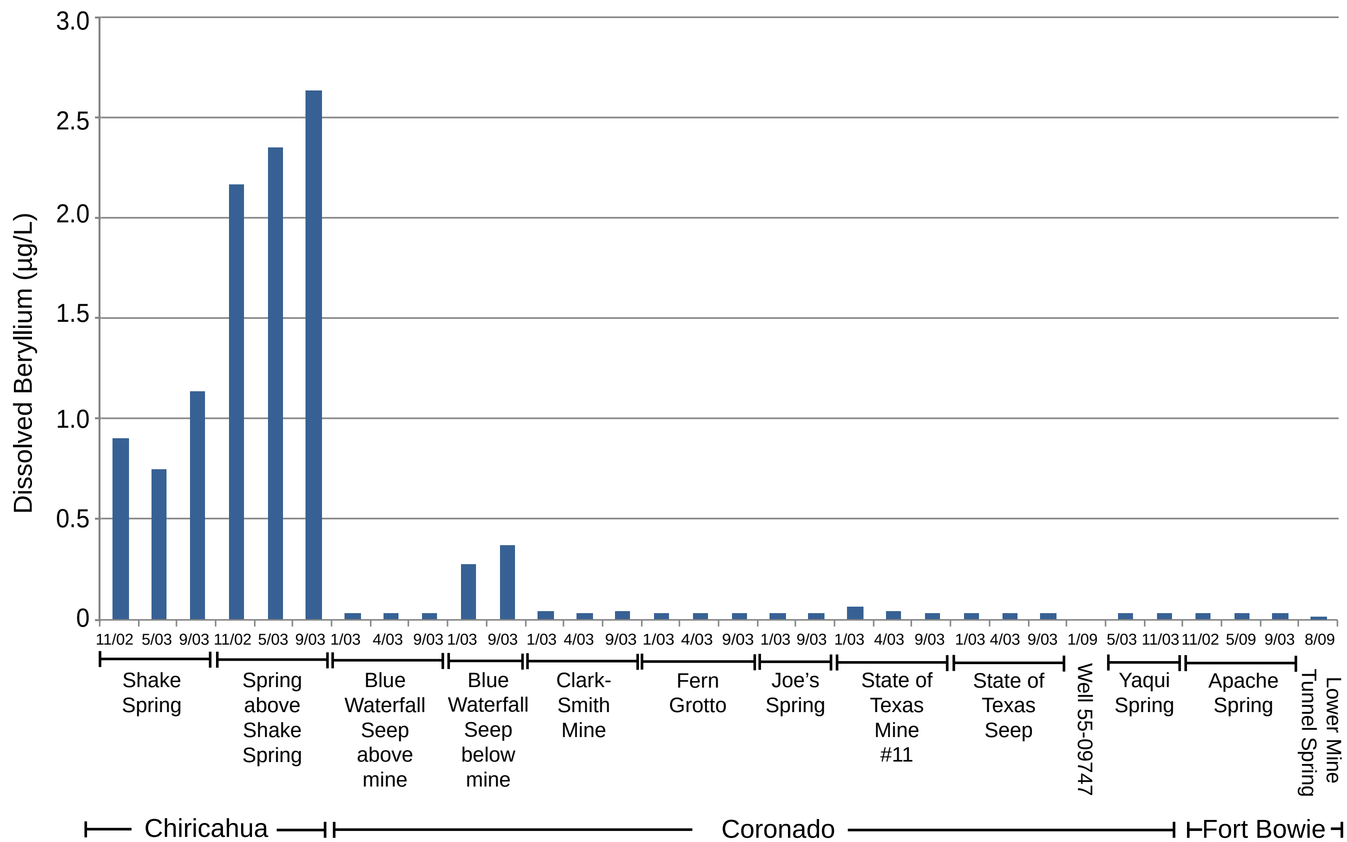

Figure B.13. Dissolved beryllium results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

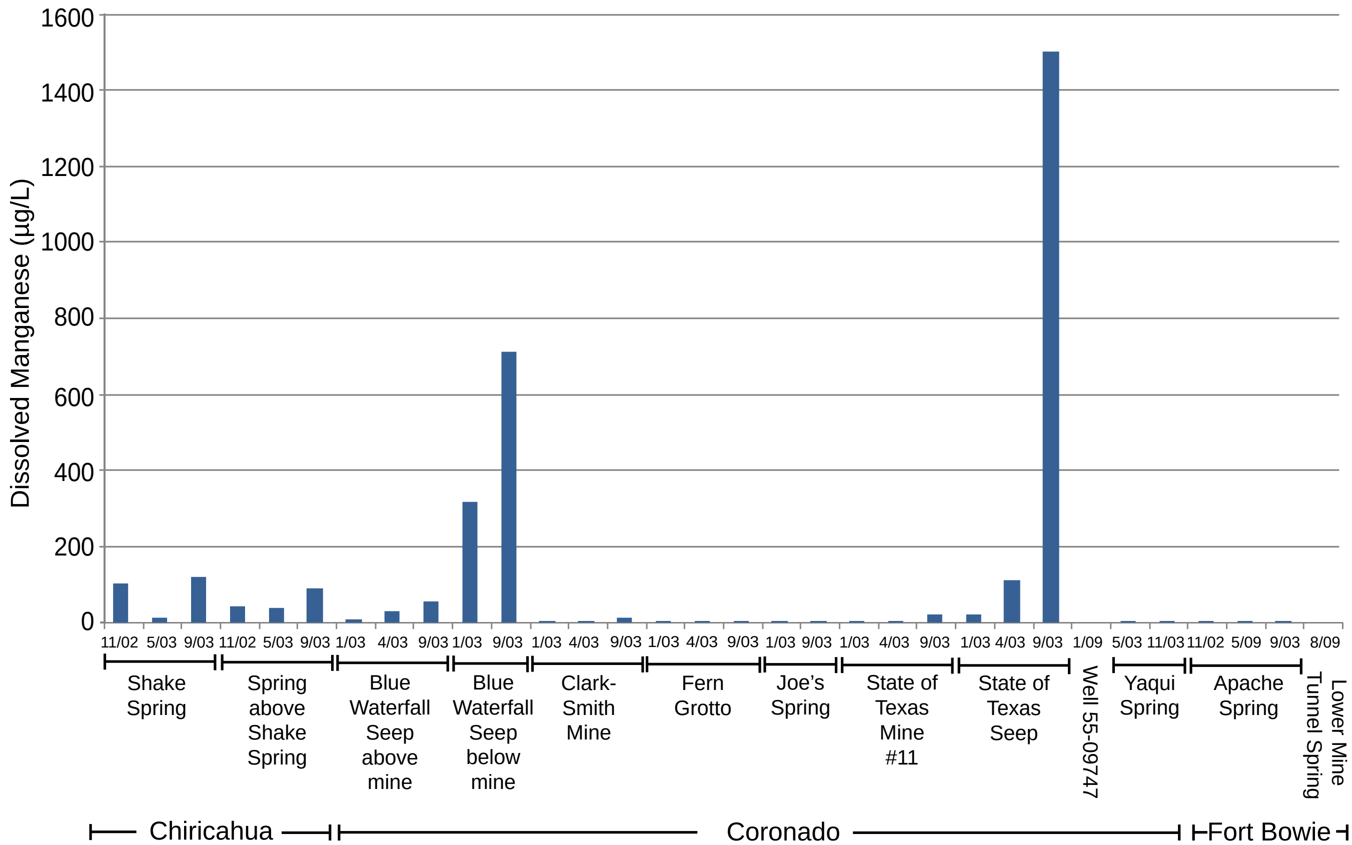

Figure B.14. Dissolved manganese results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

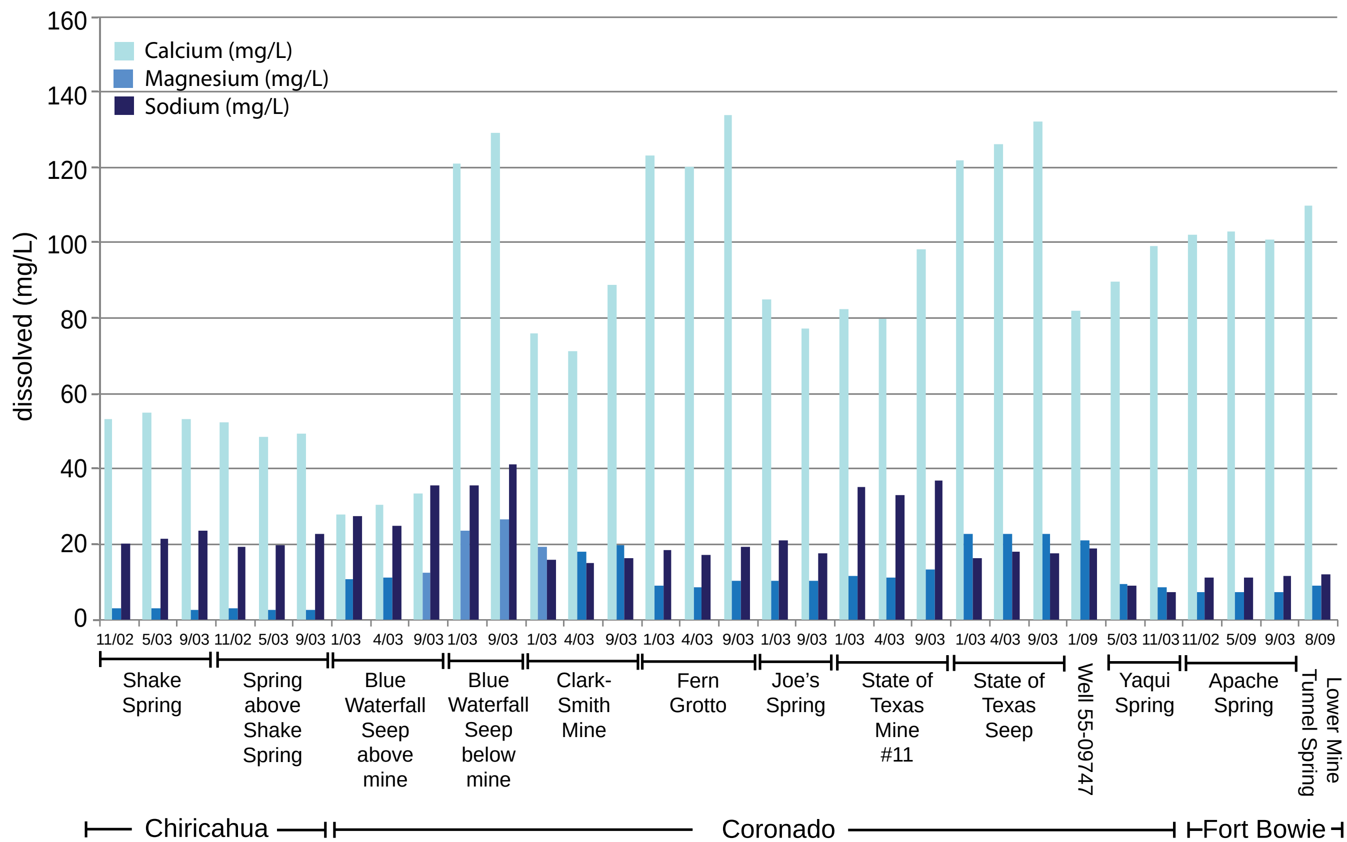

Figure B.15. Calcium, magnesium, and sodium results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

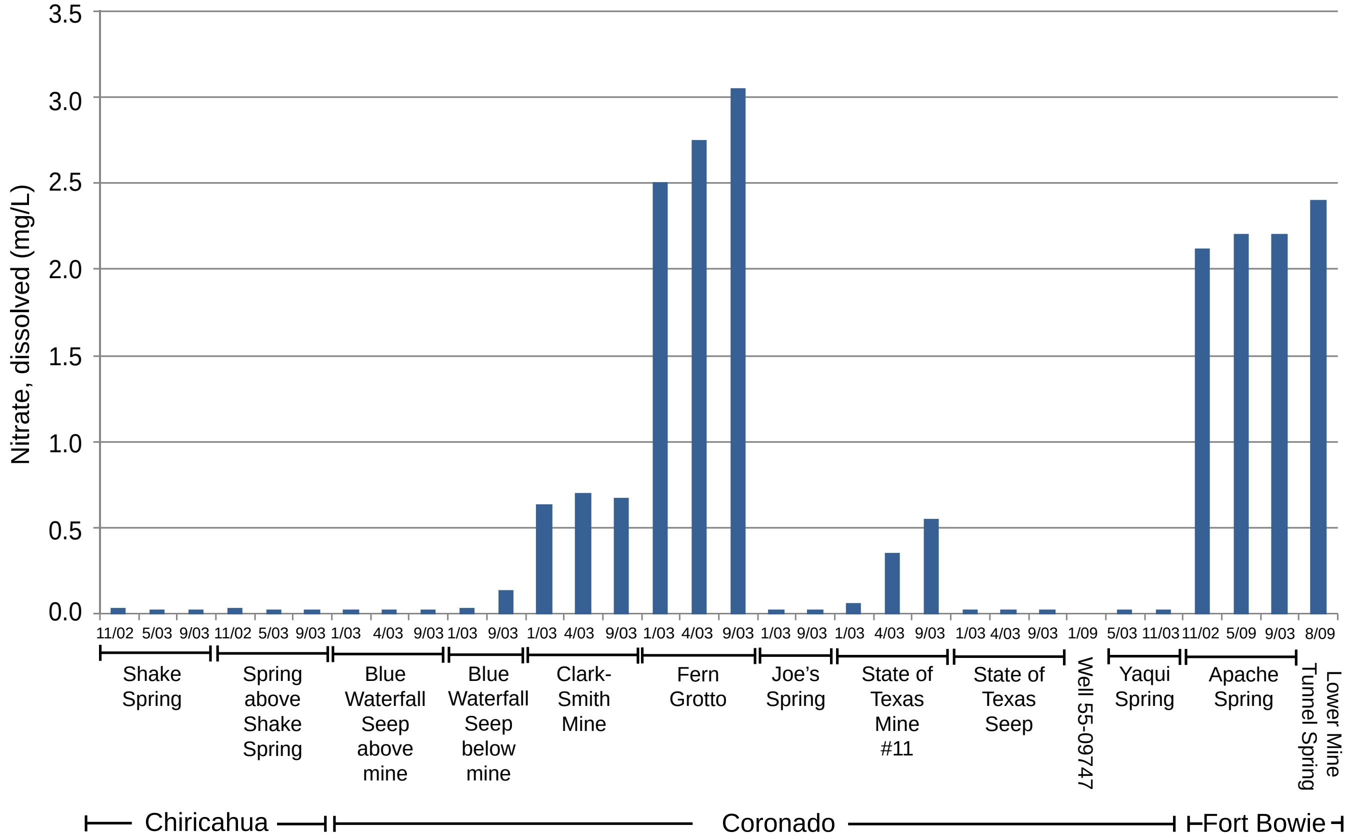

Figure B.16. Nitrate results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

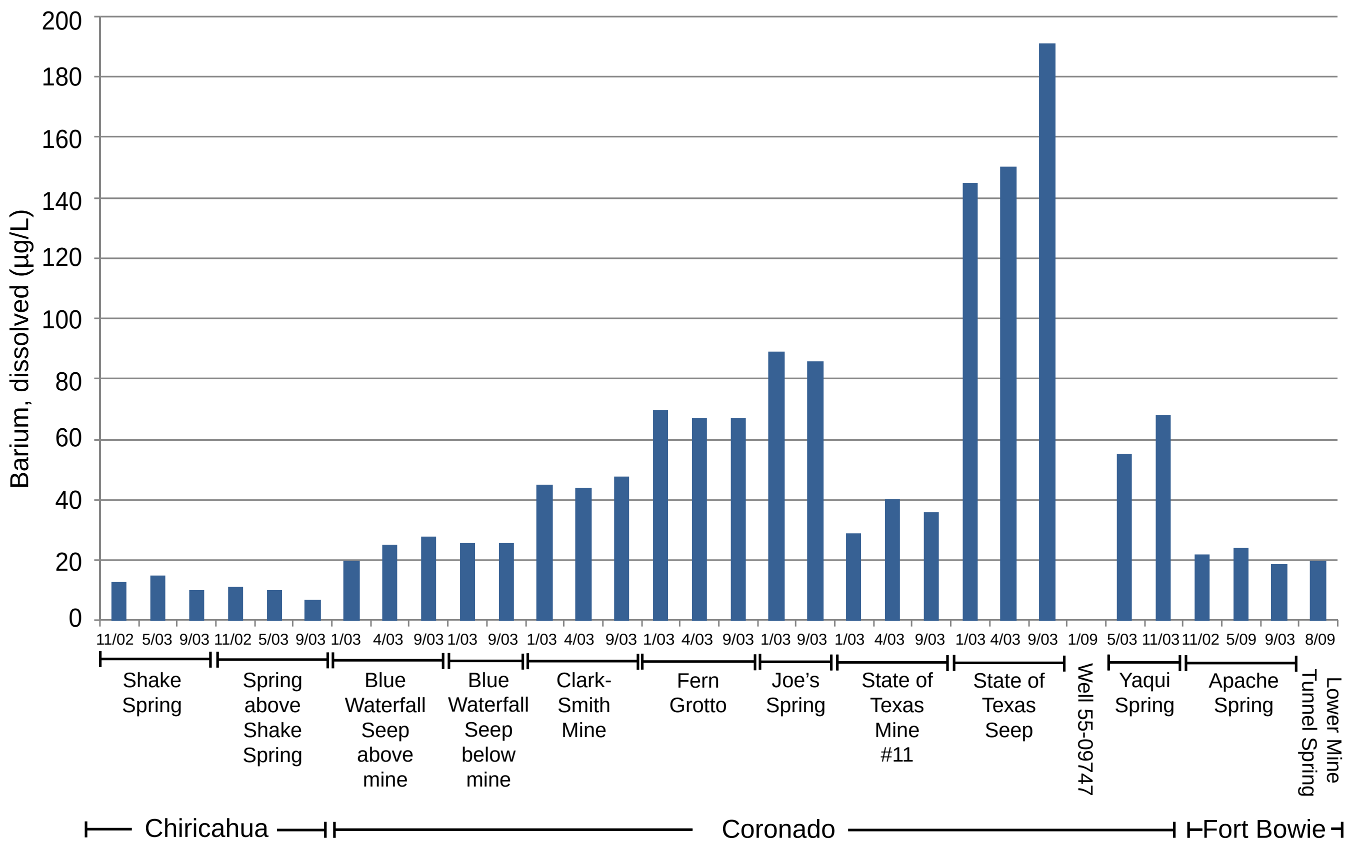

Figure B.17. Dissolved barium results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

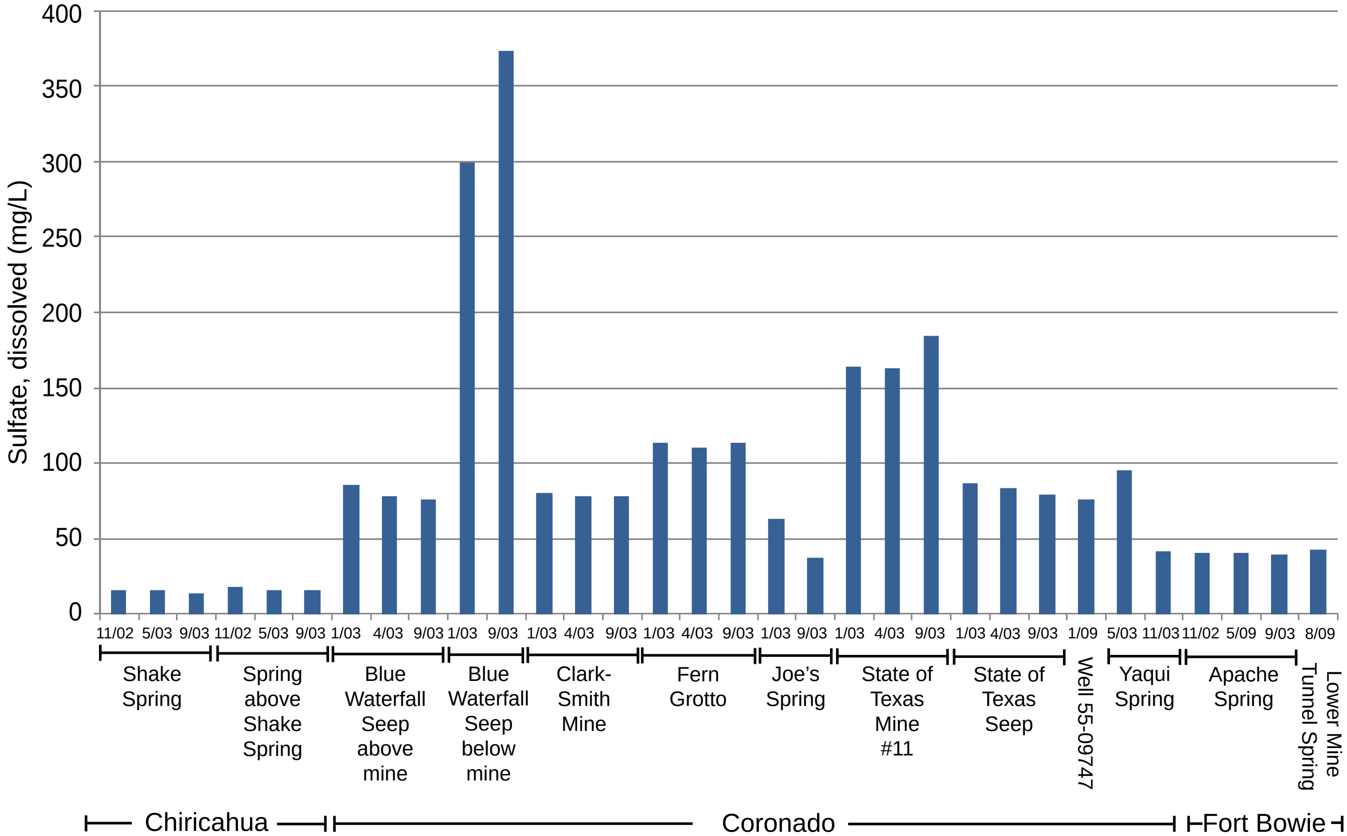

Figure B.18. Dissolved sulfate results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

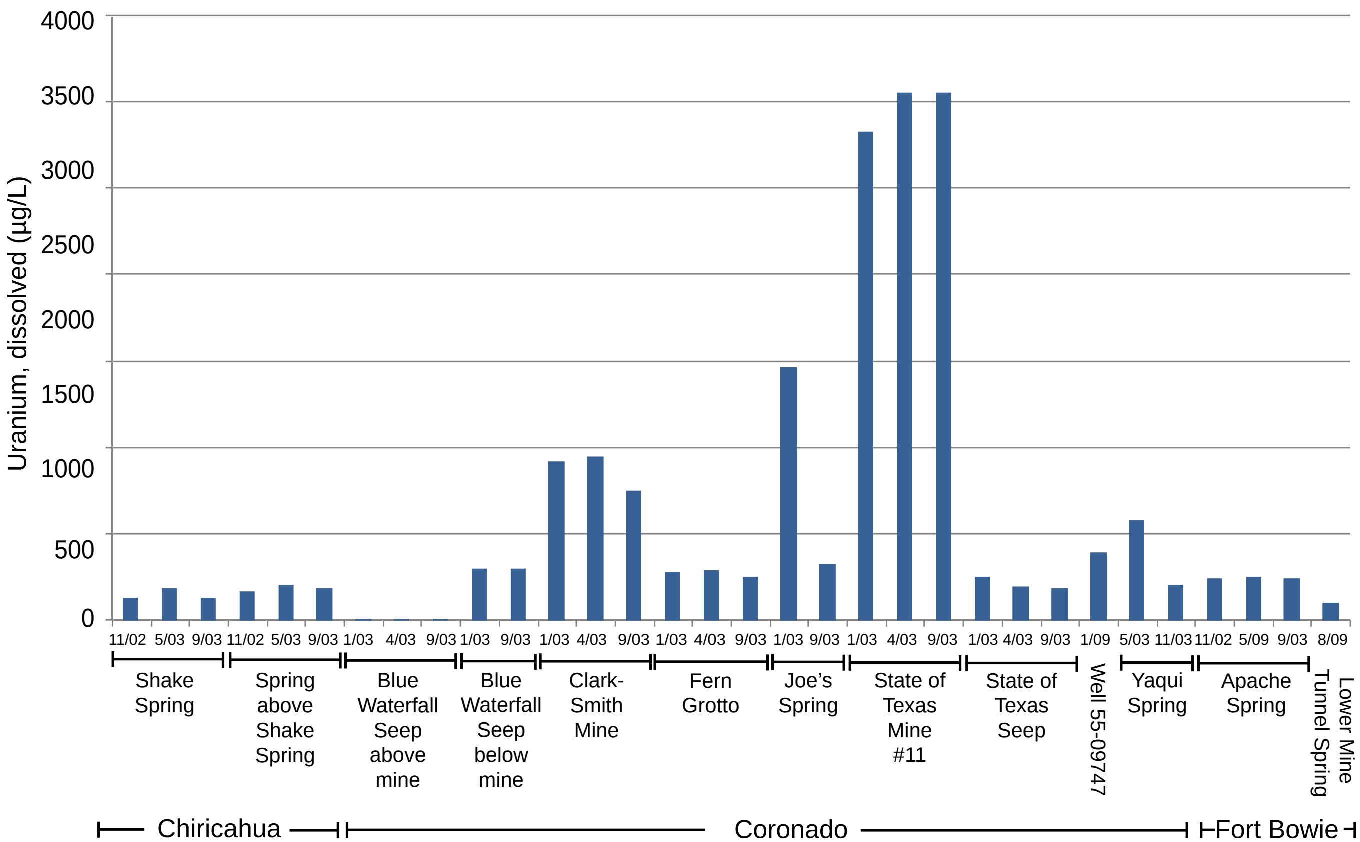

Figure B.19. Dissolved uranium results from Chiricahua NM, Coronado NMem, and Fort Bowie NHS water quality samples.

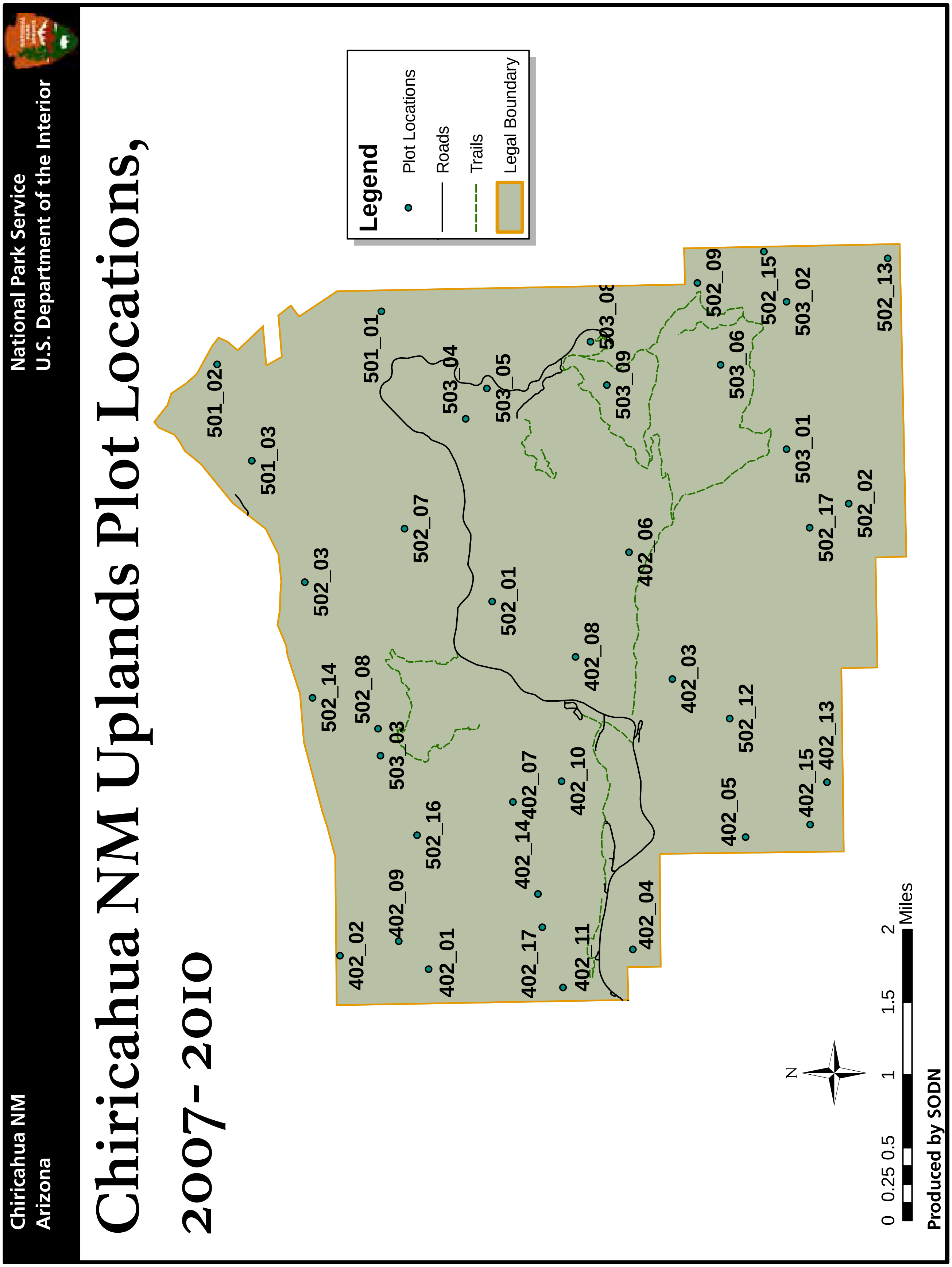

Figure B.20. NPS Sonoran Desert Network vegetation and soils monitoring plot locations at Chiricahua NM, sampled 2007-2010 (NPS SODN 2010c).

Table B.13. Soil substrate cover by monitoring plot, Chiricahua NM (NPS NPS SODN 2010d). "n" = number of samples collected per plot.

Plot	Year Sampled	Substrate					
		Bare soil	Gravel	Litter and Duff	Rock and Bedrock	Plant base	Biological Soil Crust
402_V001	2007	5.0%	36.7%	19.6%	34.2%	4.6%	0.0%
402_V002	2007	9.6%	12.5%	22.9%	50.8%	4.2%	0.0%
402_V003	2007	7.1%	8.8%	65.4%	12.9%	5.4%	0.4%
402_V004	2007	9.6%	15.8%	28.8%	37.5%	8.3%	0.0%
402_V005	2007	18.8%	22.1%	24.6%	28.8%	5.8%	0.0%
402_V007	2007	15.0%	29.2%	25.0%	25.0%	5.8%	0.0%
402_V009	2007	8.3%	31.3%	17.1%	35.4%	7.9%	0.0%
402_V011	2007	10.0%	7.1%	24.6%	57.1%	1.3%	0.0%
402_V017	2007	15.8%	32.5%	27.5%	18.8%	3.3%	2.1%
402_VTEST_057	2007	23.3%	12.5%	15.8%	41.7%	6.7%	0.0%
VTEST_001	2007	22.9%	28.8%	22.5%	15.4%	10.4%	0.0%
VTEST_002	2007	8.8%	3.8%	50.0%	28.8%	8.8%	0.0%
VTEST_037	2007	29.6%	5.8%	56.3%	4.6%	3.3%	0.4%
VTEST_052	2007	12.5%	2.9%	34.6%	40.4%	9.6%	0.0%
401_V003	2008	4.2%	9.6%	64.2%	11.3%	10.8%	0.0%
402_V006	2008	0.8%	4.2%	54.2%	38.8%	2.1%	0.0%
402_V010	2008	5.4%	18.8%	44.2%	24.2%	7.5%	0.0%
501_V001	2008	14.6%	22.5%	52.5%	6.3%	4.2%	0.0%
501_V003	2008	12.5%	21.7%	42.9%	20.0%	2.9%	0.0%
503_V001	2008	0.4%	9.6%	41.3%	47.9%	0.4%	0.4%
503_V002	2008	0.4%	2.5%	69.2%	26.7%	0.8%	0.4%
503_V003	2008	0.4%	5.4%	39.6%	49.6%	5.0%	0.0%
503_V004	2008	0.8%	28.8%	67.1%	2.5%	0.8%	0.0%
503_V005	2008	4.2%	24.2%	67.9%	3.3%	0.4%	0.0%
503_V008	2008	3.3%	19.2%	63.8%	13.8%	0.0%	0.0%
503_V009	2008	0.4%	3.8%	59.2%	35.8%	0.8%	0.0%
VTEST_003	2008	13.8%	38.3%	19.2%	24.2%	4.6%	0.0%

Table B.13. Soil substrate cover by monitoring plot, Chiricahua NM (NPS NPS SODN 2010d). "n" = number of samples collected per plot.

Plot	Year Sampled	Substrate					
		Bare soil	Gravel	Litter and Duff	Rock and Bedrock	Plant base	Biological Soil Crust
402_V008	2009	8.8%	17.5%	35.8%	34.2%	3.8%	0.0%
402_V013	2009	7.9%	12.5%	57.5%	15.0%	7.1%	0.0%
501_V002	2009	0.0%	1.7%	74.2%	15.8%	7.9%	0.4%
502_V001	2009	6.3%	7.9%	80.0%	2.9%	2.9%	0.0%
502_V002	2009	3.3%	35.0%	41.7%	15.0%	5.0%	0.0%
502_V003	2009	1.3%	13.8%	60.0%	21.3%	3.8%	0.0%
502_V007	2009	0.8%	15.4%	54.6%	25.4%	3.8%	0.0%
502_V008	2009	1.3%	5.4%	57.5%	34.6%	1.3%	0.0%
502_V009	2009	2.5%	6.3%	67.9%	18.8%	4.6%	0.0%
402_V014	2010	5.8%	15.4%	30.0%	47.9%	0.8%	0.0%
402_V015	2010	8.8%	22.5%	50.4%	10.0%	8.3%	0.0%
502_V012	2010	5.0%	2.9%	75.4%	15.8%	0.8%	0.0%
502_V013	2010	11.7%	10.8%	52.9%	22.1%	2.1%	0.4%
502_V014	2010	0.4%	4.6%	45.8%	46.3%	2.9%	0.0%
502_V015	2010	5.0%	7.9%	79.6%	5.4%	2.1%	0.0%
502_V016	2010	2.5%	26.3%	39.6%	24.2%	4.6%	2.9%
502_V017	2010	6.7%	18.3%	57.1%	12.5%	5.4%	0.0%
503_V006	2010	4.6%	10.4%	59.6%	22.5%	2.5%	0.4%

Table B.14. Soil surface aggregate stability class by monitoring plot, Chiricahua NM (NPS NPS SODN 2010d). "n" = number of samples collected per plot.

Plot	401_ V003	402_ V001	402_ V002	402_ V003	402_ V004	402_ V005	402_ V006	402_ V007	402_ V008	402_ V009	402_ V010	402_ V011
All Samples												
Average Soil Stability	4.46	2.81	3.69	4.70	4.66	4.40	1.93	2.11	4.17	3.27	4.49	2.40
SD	1.92	1.96	2.07	2.06	1.64	1.75	1.71	1.30	1.90	1.89	2.10	2.10
SE	0.25	0.32	0.37	0.65	0.20	0.25	0.44	0.20	0.35	0.27	0.35	0.33
% samples "very stable"	51%	14%	28%	60%	43%	35%	7%	2%	33%	19%	54%	15%
n	59	37	32	10	68	48	15	44	30	48	37	40
Under Vegetation												
Average Soil Stability	4.51	3.04	3.78	4.70	4.86	4.38	2.00	1.96	4.30	3.43	4.58	2.57
SD	1.88	2.06	2.06	2.06	1.65	1.77	1.75	1.26	1.88	1.88	2.11	2.16
SE	0.27	0.43	0.40	0.65	0.23	0.31	0.47	0.24	0.36	0.30	0.37	0.39
% samples "very stable"	51%	17%	30%	60%	50%	34%	7%	0%	37%	20%	58%	17%
n	49	23	27	10	50	32	14	27	27	40	33	30
No Vegetation Cover												
Average Soil Stability	4.20	2.43	3.20	-	4.11	4.44	1.00	2.35	3.00	2.50	3.75	1.90
SD	2.20	1.79	2.28	-	1.53	1.75	-	1.37	2.00	1.85	2.22	1.91
SE	0.70	0.48	1.02	-	0.36	0.44	-	0.33	1.15	0.65	1.11	0.60
% samples "very stable"	50%	7%	20%	-	22%	38%	0%	6%	0%	13%	25%	10%
n	10	14	5	0	18	16	1	17	3	8	4	10

Table B.14. cont. Soil surface aggregate stability class by monitoring plot, Chiricahua NM (NPS NPS SODN 2010d). "n" = number of samples collected per plot.

Plot	402_ V013	402_ V014	402_ V015	402_ V017	501_ V001	501_ V002	501_ V003	502_ V001	502_ V002	502_ V003	502_ V007	502_ V008
All Samples												
Average Soil Stability	5.29	4.65	4.93	2.14	4.77	4.89	4.34	4.67	1.22	3.80	3.13	5.00
SD	0.91	2.13	1.39	1.55	1.96	2.20	2.24	2.13	0.79	2.41	2.25	1.71
SE	0.16	0.42	0.20	0.23	0.33	0.73	0.38	0.46	0.12	0.44	0.40	0.40
% samples "very stable"	53%	65%	52%	9%	66%	78%	57%	62%	0%	50%	28%	67%
n	34	26	46	44	35	9	35	21	46	30	32	18
Under Vegetation												
Average Soil Stability	5.45	5.25	5.00	2.17	4.97	4.57	4.55	4.79	1.10	4.14	4.19	4.86
SD	0.83	1.62	1.40	1.72	1.79	2.44	2.24	2.08	0.40	2.32	2.14	1.88
SE	0.15	0.36	0.21	0.36	0.32	0.92	0.48	0.56	0.07	0.49	0.53	0.50
% samples "very stable"	62%	75%	56%	13%	69%	71%	64%	64%	0%	55%	44%	64%
n	29	20	43	23	32	7	22	14	31	22	16	14
No Vegetation Cover												
Average Soil Stability	4.40	2.67	4.00	2.10	2.67	6.00	4.00	4.43	1.47	2.88	2.06	5.50
SD	0.89	2.58	1.00	1.37	2.89	0.00	2.27	2.37	1.25	2.59	1.88	1.00
SE	0.40	1.05	0.58	0.30	1.67	0.00	0.63	0.90	0.32	0.91	0.47	0.50
% samples "very stable"	0%	33%	0%	5%	33%	100%	46%	57%	0%	38%	13%	75%
n	5	6	3	21	3	2	13	7	15	8	16	4

Table B.14. cont. Soil surface aggregate stability class by monitoring plot, Chiricahua NM (NPS NPS SODN 2010s). "n" = number of samples collected per plot.

Plot	502_ V009	502_ V012	502_ V013	502_ V014	502_ V015	502_ V016	502_ V017	503_ V001	503_ V002	503_ V003	503_ V004	503_ V005
All Samples												
Average Soil Stability	4.92	5.35	4.03	5.29	5.17	4.14	5.63	3.61	5.00	2.94	4.53	4.18
SD	1.67	1.72	2.11	1.30	1.85	1.67	1.27	1.97	1.66	2.29	1.94	2.02
SE	0.33	0.36	0.36	0.25	0.39	0.28	0.23	0.41	0.31	0.54	0.31	0.43
% samples "very stable"	58%	87%	37%	68%	83%	26%	90%	22%	61%	22%	45%	36%
n	26	23	35	28	23	35	30	23	28	18	38	22
Under Vegetation												
Average Soil Stability	5.48	5.47	4.54	5.38	5.10	4.21	5.59	3.07	5.00	2.80	5.33	3.80
SD	1.17	1.58	1.86	1.28	1.92	1.75	1.34	1.91	1.68	2.31	1.07	2.44
SE	0.25	0.36	0.35	0.28	0.42	0.33	0.26	0.49	0.34	0.60	0.21	0.77
% samples "very stable"	71%	89%	43%	71%	81%	29%	89%	13%	60%	20%	56%	40%
n	21	19	28	21	21	28	27	15	25	15	27	10
No Vegetation Cover												
Average Soil Stability	2.60	4.75	2.00	5.00	6.00	3.86	6.00	4.63	5.00	3.67	2.55	4.50
SD	1.52	2.50	1.91	1.41	0.00	1.35	0.00	1.77	1.73	2.52	2.21	1.62
SE	0.68	1.25	0.72	0.53	0.00	0.51	0.00	0.63	1.00	1.45	0.67	0.47
% samples "very stable"	0%	75%	14%	57%	100%	14%	100%	38%	67%	33%	18%	33%
n	5	4	7	7	2	7	3	8	3	3	11	12

Table B.14. cont. Soil surface aggregate stability class by monitoring plot, Chiricahua NM (NPS NPS SODN 2010d). "n" = number of samples collected per plot.

Plot	503_ V006	503_ V008	503_ V009	VTEST_001	VTEST_003	VTEST_052
All Samples						
Average Soil Stability	3.76	5.61	4.60	2.23	3.47	4.30
SD	2.25	0.96	2.13	1.45	2.00	1.95
SE	0.42	0.16	0.55	0.21	0.30	0.29
% samples "very stable"	38%	78%	67%	4%	27%	37%
n	29	36	15	48	45	46
Under Vegetation						
Average Soil Stability	4.56	5.61	4.50	2.42	4.00	4.55
SD	2.06	1.03	2.28	1.64	1.98	1.86
SE	0.52	0.19	0.66	0.33	0.41	0.30
% samples "very stable"	56%	79%	67%	8%	39%	42%
n	16	28	12	24	23	38
No Vegetation Cover						
Average Soil Stability	2.77	5.63	5.00	2.04	2.91	3.13
SD	2.13	0.74	1.73	1.23	1.90	2.10
SE	0.59	0.26	1.00	0.25	0.41	0.74
% samples "very stable"	15%	75%	67%	0%	14%	13%
n	13	8	3	24	22	8

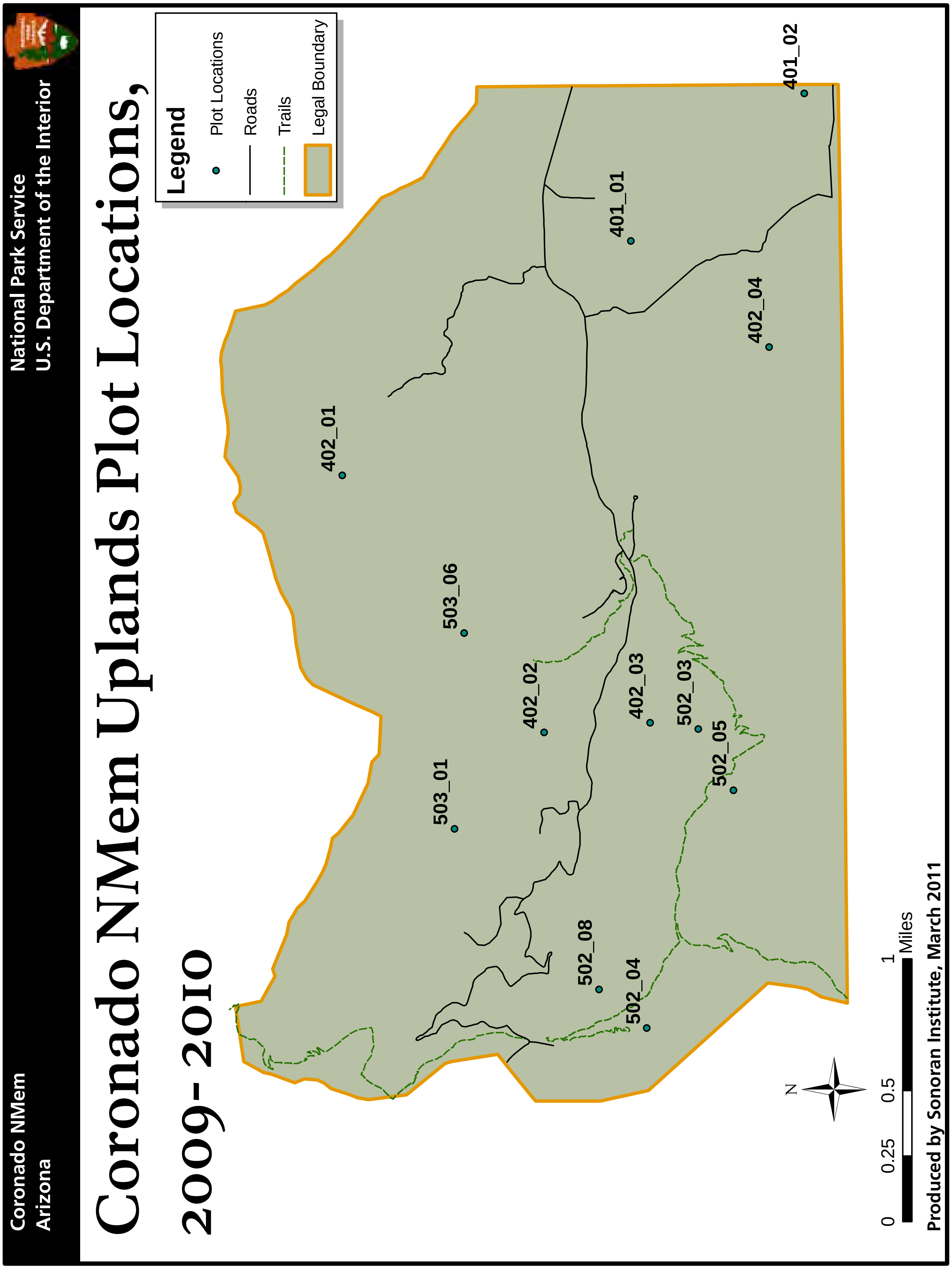

Figure B.21. NPS Sonoran Desert Network vegetation and soils monitoring plot locations at Coronado NMem, sampled 2009-2010 (NPS SODN 2010d).

Table B.15. Soil substrate cover by monitoring plot, Coronado NMem (NPS SODN 2010e). "n" = number of samples collected per plot.

Plot	Year Sampled	Substrate					
		Bare soil	Gravel	Litter and Duff	Rock and Bedrock	Plant base	Biological Soil Crust
401_V001	2009	6.3%	5.4%	70.8%	0.0%	17.5%	0.0%
401_V002	2010	19.6%	0.0%	66.7%	0.0%	10.0%	3.8%
402_V001	2009	0.8%	19.6%	72.1%	0.8%	6.7%	0.0%
402_V002	2009	1.7%	0.8%	82.1%	10.4%	5.0%	0.0%
402_V003	2010	12.9%	3.8%	58.8%	11.7%	12.9%	0.0%
402_V004	2010	27.9%	3.8%	52.9%	0.0%	13.3%	2.1%
502_V003	2009	3.8%	15.8%	36.3%	23.3%	20.8%	0.0%
502_V004	2009	7.5%	44.6%	15.8%	16.7%	15.4%	0.0%
502_V005	2010	5.8%	20.0%	38.3%	25.4%	10.0%	0.4%
502_V008	2010	20.8%	24.6%	27.1%	13.3%	14.2%	0.0%
503_V001	2009	8.3%	21.3%	42.1%	19.6%	8.8%	0.0%
503_V006	2010	7.5%	5.4%	52.1%	27.5%	7.5%	0.0%

Table B.16. Soil surface aggregate stability class by monitoring plot, Coronado NMem (NPS SODN 2010e). "n" = number of samples collected per plot.

Plot	401_ V001	401_ V002	402_ V001	402_ V002	402_ V003	402_ V004	502_ V003	502_ V004	502_ V005	502_ V008	503_ V001	503_ V006
All Samples												
Average Soil Stability	4.02	5.46	4.68	5.07	3.88	5.05	5.32	3.76	4.86	4.02	3.68	3.78
SD	2.02	0.68	1.76	1.71	2.17	1.20	1.23	1.74	1.41	1.99	2.21	2.10
SE	0.29	0.10	0.32	0.33	0.37	0.19	0.19	0.29	0.21	0.30	0.36	0.35
% samples "very stable"	36%	56%	48%	67%	38%	51%	63%	22%	40%	35%	32%	33%
n	47	48	31	27	34	41	41	37	43	43	37	36
Under Vegetation												
Average Soil Stability	4.09	5.46	4.80	5.08	4.10	5.05	5.53	3.97	5.06	4.60	3.69	3.85
SD	1.99	0.68	1.65	1.74	2.14	1.20	0.99	1.70	1.30	1.68	2.22	2.09
SE	0.29	0.10	0.30	0.34	0.39	0.19	0.17	0.31	0.22	0.28	0.39	0.40
% samples "very stable"	37%	56%	50%	69%	43%	51%	71%	26%	46%	43%	34%	33%
n	46	48	30	26	30	41	34	31	35	35	32	27
No Vegetation Cover												
Average Soil Stability	1.00	-	1.00	5.00	2.25	-	4.29	2.67	4.00	1.50	3.60	3.56
SD	-	-	-	-	1.89	-	1.80	1.63	1.60	1.07	2.41	2.24
SE	-	-	-	-	0.95	-	0.68	0.67	0.57	0.38	1.08	0.75
% samples "very stable"	0%	-	0%	0%	0%	-	29%	0%	13%	0%	20%	33%
n	1	0	1	1	4	0	7	6	8	8	5	9

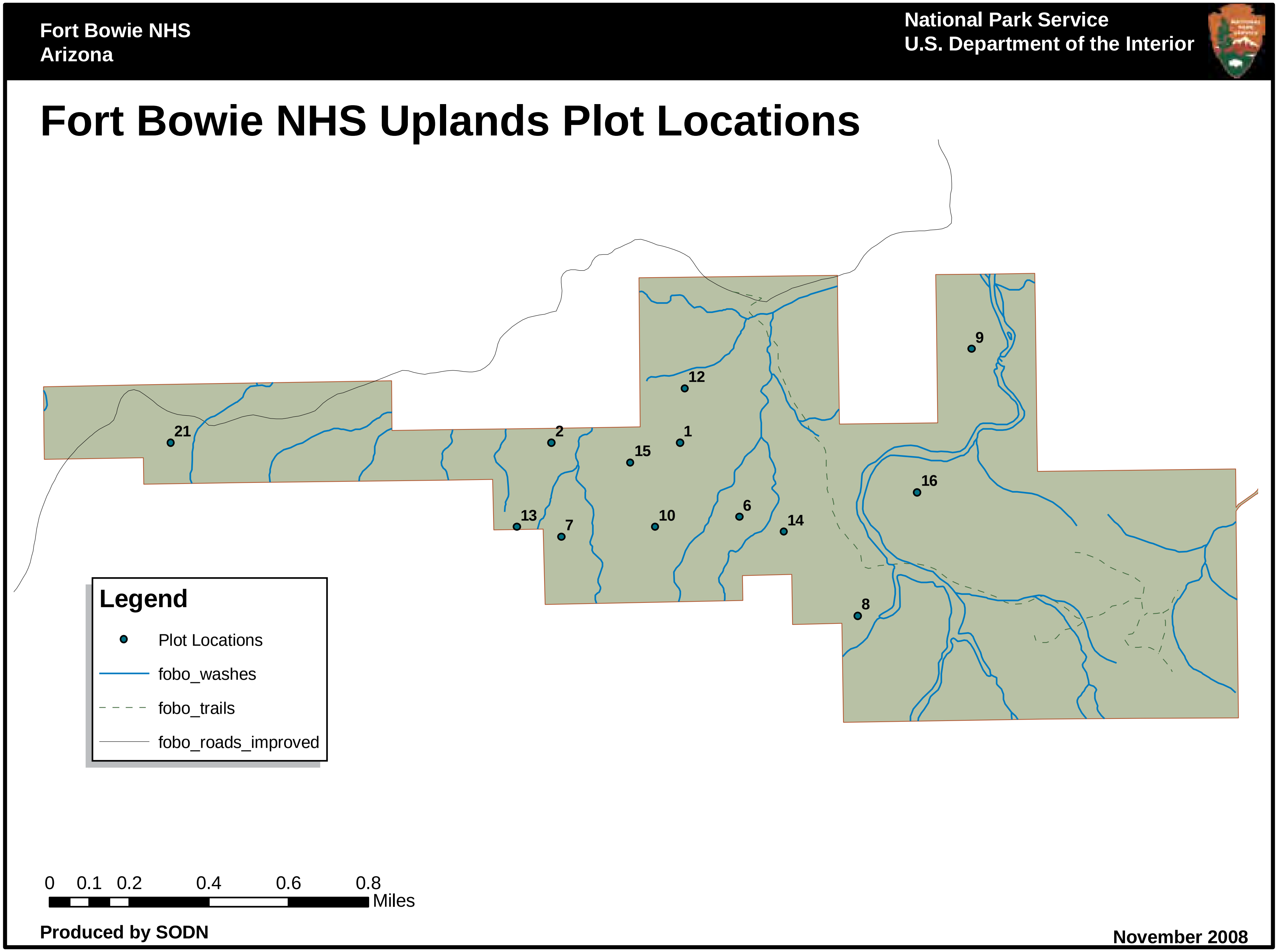

Figure B.22. NPS Sonoran Desert Network vegetation and soils monitoring plot locations at Fort Bowie NHS, sampled 2008 (Hubbard et al. 2010). Figure courtesy of NPS Sonoran Desert Network.

Table B.17. Soil substrate cover by monitoring plot, Fort Bowie NHS (Hubbard et al. 2010). "n" = number of samples collected per plot.

Plot	Year Sampled	Substrate					
		Bare soil	Gravel	Litter and Duff	Rock and Bedrock	Plant base	Biological Soil Crust
V001	2008	4%	36%	37%	18%	5%	0.0%
V002	2008	3%	65%	23%	6%	4%	0.0%
V006	2008	6%	41%	39%	7%	7%	0.0%
V007	2008	5%	54%	35%	3%	3%	0.0%
V008	2008	12%	45%	33%	1%	8%	0.0%
V009	2008	5%	43%	28%	23%	2%	0.0%
V010	2008	5%	60%	28%	3%	4%	0.0%
V012	2008	7%	51%	29%	10%	3%	0.4%
V013	2008	2%	65%	21%	6%	6%	0.0%
V014	2008	2%	53%	37%	3%	5%	0.0%
V015	2008	4%	62%	21%	4%	9%	0.0%
V016	2008	3%	29%	39%	23%	6%	0.0%
V021	2008	0%	33%	44%	13%	10%	0.4%

Table B.18. Soil surface aggregate stability class by monitoring plot, Fort Bowie NHS (Hubbard et al. 2010). "n" = number of samples collected per plot.

Plot	V001	V002	V006	V007	V008	V009	V010	V012	V013	V014	V015	V016	V021
All Samples													
Average Soil Stability	3.39	3.08	3.64	3.36	4.92	3.96	3.00	3.52	4.02	4.04	3.28	4.35	4.87
SD	2.29	2.19	2.27	1.99	1.94	2.12	2.01	2.19	2.14	2.01	2.24	2.05	1.82
SE	0.34	0.32	0.36	0.30	0.28	0.31	0.29	0.33	0.31	0.29	0.33	0.32	0.27
% samples "very stable"	33%	23%	33%	18%	69%	34%	17%	30%	40%	38%	28%	48%	60%
n	46	48	39	45	48	47	47	44	48	47	47	40	45
Under Vegetation													
Average Soil Stability	3.42	3.35	3.94	3.40	5.13	3.98	3.23	3.70	4.14	4.34	3.30	4.39	4.95
SD	2.30	2.19	2.20	1.95	1.79	2.13	2.06	2.19	2.11	1.86	2.25	2.01	1.74
SE	0.35	0.35	0.37	0.30	0.28	0.34	0.33	0.35	0.32	0.30	0.34	0.33	0.26
% samples "very stable"	33%	25%	37%	17%	73%	35%	21%	33%	41%	42%	28%	47%	61%
n	43	40	35	42	40	40	39	40	44	38	43	38	44
No Vegetation Cover													
Average Soil Stability	3.00	1.75	1.00	2.67	3.88	3.86	1.88	1.75	2.75	2.78	3.00	3.50	1.00
SD	2.65	1.75	0.00	2.89	2.47	2.19	1.36	1.50	2.36	2.22	2.45	3.54	-
SE	1.53	0.62	0.00	1.67	0.88	0.83	0.48	0.75	1.18	0.74	1.22	2.50	-
% samples "very stable"	33%	13%	0%	33%	50%	29%	0%	0%	25%	22%	25%	50%	0%
n	3	8	4	3	8	7	8	4	4	9	4	2	1

Table B.19. Soil erosion features mapped by Nauman (2010) within the Apache Spring watershed, Fort Bowie NHS.

	Sheet Erosion	Rill	Gully	All
Number of features mapped	163	212	176	551
Mean depth lost (m)	0.06	0.17	1.45	1.08
Mean cross-section area (m^2)	0.77	0.92	23.15	17.05
Total Volume (m^3)	549	1080	57031	58660
Total Area Affected (m^2)	8448	6329	39301	54078

Appendix C: Supplementary Information on Biological Resources

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Chihuahuan Desertscrub	Chihuahuan Creosotebush Desert Scrub, CES302.731 (6 Associations)	This ecological system is the common lower elevation desert scrub that occurs throughout much of the Chihuahuan Desert and has recently expanded into former desert grasslands in the northern portion of its range. Stands typically occur in flat to gently sloping desert basins and on alluvial plains, extending up into lower to mid positions of piedmont slopes (bajada). Substrates range from coarse-textured loams on gravelly plains to finer-textured silty and clayey soils in basins. Soils are alluvial, typically loamy and non-saline, and frequently calcareous as they are often derived from limestone, and to a lesser degree igneous rocks. The vegetation is characterized by a moderate to sparse shrub layer (<10% cover on extremely xeric sites) that is typically strongly dominated by *Larrea tridentata* with *Flourensia cernua* often present to codominant. A few scattered shrubs or succulents may also be present, such as *Agave lechuguilla*, *Parthenium incanum*, *Jatropha dioica*, *Koeberlinia spinosa*, *Lycium* spp., and *Yucca* spp. Additionally, *Flourensia cernua* will often strongly dominate in silty basins that are included in this ecological system. In general, shrub diversity is low as this ecological system lacks codominant thornscrub and other mixed desert scrub species that are common on the gravelly mid to upper piedmont slopes. However, shrub diversity and cover may increase locally where soils are deeper and along minor drainages with occasional *Atriplex canescens*, *Gutierrezia sarothrae*, or *Prosopis glandulosa*. Herbaceous cover is usually low and composed of grasses. Common species may include *Bouteloua eriopoda*, *Dasyochloa pulchella* (= *Erioneuron pulchellum*), *Muhlenbergia porteri*, *Pleuraphis mutica*, *Scleropogon brevifolius*, and *Sporobolus airoides*. Included in this ecological system are *Larrea tridentata*-dominated shrublands with a sparse understory that occur on gravelly to silty, upper basin floors and alluvial plains. A pebbly desert pavement may be present on the soil surface.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Chihuahuan Desertscrub	Chihuahuan Mixed Desert and Thornscrub, CES302.734 (22 Associations)	This ecological system is the widespread desert scrub that occurs on gravelly mid to upper bajadas, foothills and dissected gravelly alluvial fans in the Chihuahuan Desert and has recently expanded into former desert grasslands in the northern portion of its range. It generally occurs on mid to upper piedmonts above the desert plains Chihuahuan Creosotebush Desert Scrub (CES302.731) and extends up to the chaparral zone. Soils are typically well-drained, non-saline, gravelly loams often with a petrocalic layer. Substrates are frequently derived from limestone although igneous rocks are common in some areas. Vegetation is characterized by the presence of *Larrea tridentata*, typically mixed with thornscrub or other desert scrub such as *Agave lechuguilla*, *Aloysia wrightii*, *Baccharis pteronioides*, *Dasylirion leiophyllum*, *Flourensia cernua* (not bottomland), *Fouquieria splendens*, *Koeberlinia spinosa*, *Krameria erecta*, *Leucophyllum minus*, *Mimosa aculeaticarpa* var. *biuncifera*, *Mortonia scabrella* (= *Mortonia sempervirens* ssp. *scabrella*), *Opuntia engelmannii*, *Parthenium incanum*, *Prosopis glandulosa*, and *Rhus microphylla* (in drainages). Stands of *Acacia constricta*-, *Acacia neovernicosa*- or *Acacia greggii*-dominated thornscrub are included in this system, and limestone substrates appear important for at least these species. If present, *Prosopis glandulosa* has relatively low cover and does not dominate the shrub layer. This system also includes upper piedmont stands of desert scrub that are strongly dominated by *Larrea tridentata*. Grasses are common but generally have lower cover than shrubs. Common species may include *Bouteloua curtipendula*, *Bouteloua eriopoda*, *Bouteloua gracilis*, *Bouteloua hirsuta*, *Bouteloua ramosa*, *Dasyochloa pulchella*, and *Muhlenbergia porteri*. Also included in this ecological system are shrublands with a sparse understory of *Larrea tridentata* that occur on gravelly piedmont slopes that may extend down gravelly upper basins. A pebbly desert pavement may be present on the soil surface. This may indicate remnant erosional surfaces from the early Holocene that are thought to be some of the historic distribution of Larrea tridentata desert scrub in the Chihuahuan Desert. Historically, much of this desert scrub was thought to be a steppe characterized by perennial desert grasses (typically *Bouteloua eriopoda*) with an open creosotebush - mixed desert shrub layer.
Chihuahuan Desertscrub	Chihuahuan Mixed Salt Desert Scrub, CES302.017 (10 Associations)	This ecological system includes extensive open-canopied shrublands of typically saline basins in the Chihuahuan Desert. Stands often occur on alluvial flats and around playas, as well as in floodplains along the Rio Grande and Pecos rivers, possibly also extending into the San Simon of Southeastern Arizona. Substrates are generally fine-textured, saline soils. Vegetation is typically composed of one or more *Atriplex* species such as *Atriplex canescens*, *Atriplex obovata*, or *Atriplex polycarpa* along with species of *Allenrolfea*, *Flourensia*, *Salicornia*, *Suaeda*, or other halophytic plants. Graminoid species may include *Sporobolus airoides*, *Pleuraphis mutica*, or *Distichlis spicata* at varying densities.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Chihuahuan Desertscrub	Chihuahuan Succulent Desert Scrub, CES302.738 (4 Associations)	This ecological system is found in the Chihuahuan Desert on colluvial slopes, upper bajadas, sideslopes, ridges, canyons, hills and mesas. Sites are hot and dry, typically with southerly aspects. Gravel and rock are often abundant on the ground surface. The vegetation is characterized by the relatively high cover of succulent species such as *Agave lechuguilla*, *Euphorbia antisyphilitica*, *Fouquieria splendens*, *Ferocactus* spp., *Opuntia engelmannii*, *Opuntia imbricata*, *Opuntia spinosior*, *Yucca baccata*, and many others. Perennial grass cover is generally low. The abundance of succulents is diagnostic of this desert scrub system, but desert shrubs are usually present. Stands in rolling topography may form a mosaic with more mesic desert scrub or desert grassland ecological systems that would occur on less xeric northerly slopes. *Agave lechuguilla* is more abundant in stands in the southern part of the mapzone. This system does not include loamy plains desert grasslands or shrub-steppe with a strong cacti component such as cholla grasslands.
Desert Grassland	Apacherian-Chihuahuan Mesquite Upland Scrub, CES302.733 (15 Associations)	This ecological system often occurs as invasive upland shrublands that are concentrated in the extensive desert grassland in foothills and piedmonts of the Chihuahuan Desert, extending into the Sky Island region to the west. Substrates are typically derived from alluvium, often gravelly without a well-developed argillic or calcic soil horizon that would limit infiltration and storage of winter precipitation in deeper soil layers. *Prosopis* spp. and other deep-rooted shrubs exploit this deep-soil moisture that is unavailable to grasses and cacti. Vegetation is typically dominated by *Prosopis glandulosa* or *Prosopis velutina* and succulents. Other desert scrub species that may codominate include *Acacia neovernicosa, Acacia constricta*, *Juniperus monosperma*, or *Juniperus coahuilensis*. *Larrea tridentata* is typically absent or has low cover. Grass cover is typically low and composed of desert grasses such as *Dasyochloa pulchella* (= *Erioneuron pulchellum*), M*uhlenbergia porteri*, *Muhlenbergia setifolia*, and *Pleuraphis mutica*. During the last century, the area occupied by this system has increased through conversion of desert grasslands as a result of drought, overgrazing by livestock, and/or decreases in fire frequency. It is similar to Chihuahuan Mixed Desert and Thornscrub (CES302.734) but is generally found at higher elevations where *Larrea tridentata* and other desert scrub are not codominant. It is also similar to Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub (CES302.737) but does not occur on eolian-deposited substrates (sandsheets), although some stands may have evidence of wind erosion and deposition. **Classification Comments**: This system is similar to Chihuahuan Mixed Desert and Thornscrub (CES302.734) but is generally found at higher elevations where Larrea tridentata and other desert scrub are not codominant. It is also similar to Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub (CES302.737) but does not occur on eolian-deposited substrates. This system includes mesquite-dominated types resulting from conversion of desert grasslands to shrublands. Landfire mapzone 25 modeling workshops limited BpS to naturally occurring mesquite shrublands found on rocky outcrop and foothills. During the last century, the area occupied by the uncharacteristic portion of this system has increased through conversion of desert grasslands as a result of drought, overgrazing and seed dispersion by livestock, and/or decreases in fire frequency. The boundary between Apacherian-Chihuahuan Mesquite Upland Scrub (CES302.733) and Tamaulipan Mesquite Upland Scrub (CES301.984) needs to be defined.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Desert Grassland	Apacherian-Chihuahuan Semi-Desert Grassland and Steppe, CES302.735 (scores of Associations)	This ecological system is a broadly defined desert grassland, mixed shrub-succulent or xeromorphic oak savanna that is typical of the Borderlands of Arizona, New Mexico and northern Mexico (Apacherian region) but extends west to the Sonoran Desert, north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is found on gently sloping bajadas that support frequent fire throughout the Sky Islands and on mesas and steeper piedmont, foothill and desert mountain slopes up to 1670 m elevation in the Chihuahuan Desert. It is characterized by typically diverse perennial grasses. Common species include grasses *Bouteloua eriopoda, Bouteloua hirsuta, Bouteloua ramosa, Bouteloua rothrockii, Bouteloua curtipendula, Bouteloua gracilis, Eragrostis intermedia, Muhlenbergia emersleyi, Muhlenbergia porteri, Muhlenbergia setifolia,* and *Pleuraphis jamesii*, succulent species of *Agave, Dasylirion*, and *Yucca*, short-shrub species of *Calliandra, Mimosa*, and *Parthenium*, and tall-shrub/short-tree species of *Acacia, Prosopis*, and various oaks (e.g., *Quercus grisea, Quercus emoryi, Quercus arizonica, Quercus oblongifolia*). *Pleuraphis mutica*-dominated semi-desert grasslands often with *Bouteloua eriopoda* or *Bouteloua gracilis* occurring on lowlands and loamy plains in the Chihuahuan Desert are classified as Chihuahuan Loamy Plains Desert Grassland (CES302.061). Many of the historical desert grassland and savanna areas have been converted through intensive grazing and other land uses, some to Apacherian-Chihuahuan Mesquite Upland Scrub (CES302.733) (*Prosopis* spp.-dominated). **Classification Comments:** *Dasylirion leiophyllum, Dasylirion wheeleri,* and *Fouquieria splendens* foothill shrublands and oak savannas/open woodlands are included in the concept of the this grassland and steppe ecological system. Chihuahuan grassland types that are currently included in this system are: (1) Chino grasslands of mountain slopes on acidic igneous, limestone, or deeper gravelly soils at elevations less than 1070 m (3500 feet). These sites are dominated by *Bouteloua ramosa* with *Euphorbia antisyphilitica, Hechtia texensis* (= *Hechtia scariosa*), *Fouquieria splendens, Jatropha dioica,* and *Agave lechuguilla*. (2) Desert mountain grasslands on mountain slopes between 1070 and 1370 m (3500-4500 feet) elevation on acidic igneous substrates, but also sometimes on limestone. *Bouteloua eriopoda* and *Bouteloua curtipendula* are constituents of this system. (3) Gravelly piedmont slope grasslands between 1370 and 1670 m (4500-5500 feet) elevation on Perdiz conglomerate or Tascotal tuff. These grasslands have B*outeloua eriopoda, Bouteloua gracilis,* and *Dasylirion* as common components. Input from fire ecologist at a Landfire modeling workshop in 2006 suggests a fire-return interval that is generally long (about 10 years), with pluvial periods providing conditions leading to more rapid fuel development.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Desert Grassland	Chihuahuan Loamy Plains Desert Grassland, CES302.061	This ecological system occurs in the northern Chihuahuan Desert and extends into limited areas of the southern Great Plains on alluvial flats, loamy plains, and basins sometimes extending up into lower piedmont slopes. Sites are typically flat or gently sloping so precipitation does not run off and may be somewhat mesic if they receive runoff from adjacent areas, but these are not wetlands. Soils are non-saline, finer textured loams or clay loam. Vegetation is characterized by perennial grasses and is typically dominated by P*leuraphis mutica* (tobosa) or with *Bouteloua eriopoda* codominant (more historically) or *Bouteloua gracilis*. In degraded stands, S*cleropogon brevifolius, Dasyochloa pulchella* (= *Erioneuron pulchellum*), or *Aristida* spp. may codominate. *Pleuraphis jamesii* may become important in northern stands and *Bouteloua gracilis* in the Great Plains and on degraded stands. If present, mesic graminoids such as *Pascopyrum smithii, Panicum obtusum, Sporobolus airoides,* and *Sporobolus wrightii* typically have low cover and are restricted to drainages and moist depressions (inclusions). Scattered shrubs such as E*phedra torreyana, Flourensia cernua, Gutierrezia sarothrae, Larrea tridentata, Opuntia imbricata, Prosopis glandulosa,* and *Yucca* spp. may be present, especially on degraded sites. **Classification Comments:** This upland grassland is similar to the bottomland/depressional wetland system Chihuahuan-Sonoran Desert Bottomland and Swale Grassland (CES302.746) and grades into Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (CES302.735) in the foothills and piedmont desert grasslands. In similar loamy plains land positions in the Great Plains, *Bouteloua gracilis, Buchloe dactyloides,* or *Pleuraphis jamesii* are dominant grasses in Western Great Plains Shortgrass Prairie (CES303.672).
Desert Grassland	Chihuahuan Sandy Plains Semi-Desert Grassland, CES302.736 (5 Associations)	This ecological system occurs across the Chihuahuan Desert and extends into the southern Great Plains where soils have a high sand content. These dry grasslands or steppe are found on sandy plains and sandstone mesas. The graminoid layer is typically dominated or codominated by Bouteloua eriopoda and Sporobolus flexuosus with characteristic Chihuahuan species. Other common species are Achnatherum hymenoides, Aristida purpurea, Bouteloua gracilis, Hesperostipa neomexicana (minor), Muhlenbergia arenicola, Pleuraphis jamesii, Sporobolus airoides, Sporobolus contractus, and Sporobolus cryptandrus. Typically, there are scattered desert shrubs and stem succulents present, such as Ephedra torreyana, Ephedra trifurca, Opuntia imbricata, Yucca baccata, Yucca elata, and Yucca torreyi, that are characteristic of the Chihuahuan Desert. The widespread shrub Artemisia filifolia is also frequently present, especially in the northern extent.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Desert Grassland	Chihuahuan-Sonoran Desert Bottomland and Swale Grassland, CES302.746 (12 Associations)	This ecological system occurs in relatively small depressions or swales and along drainages throughout the northern and central Chihuahuan Desert and adjacent Sky Islands and Sonoran Desert, as well as limited areas of the southern Great Plains on broad mesas, plains and valley bottoms that receive runoff from adjacent areas. Occupying low topographic positions, these sites generally have deep, fine-textured soils that are neutral to slightly or moderately saline/alkaline. During summer rainfall events, ponding is common. Vegetation is typically dominated by *Sporobolus airoides, Sporobolus wrightii, Pleuraphis mutica* (tobosa swales), or other mesic graminoids such as *Pascopyrum smithii* or *Panicum obtusum*. With tobosa swales, sand-adapted species such as *Yucca elata* may grow at the swale's edge in the deep sandy alluvium that is deposited there from upland slopes. *Sporobolus airoides* and *Sporobolus wrightii* are more common in alkaline soils and along drainages. Other grass species may be present, but these mesic species are diagnostic. Scattered shrubs such as *Atriplex canescens, Prosopis glandulosa, Ericameria nauseosa, Fallugia paradoxa, Krascheninnikovia lanata,* or *Rhus microphylla* may be present. **Classification Comments:** When degraded, this grassland will convert to open to dense shrublands frequently dominated by P*rosopis glandulosa* or *Artemisia filifolia* (in its northern extent where it is too cold for Prosopis glandulosa to be abundant) (S. Yanoff pers. comm. 2006). This degraded type is classified as Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub (CES302.737).
Desert Grassland	Inter-Mountain Basins Semi-Desert Grassland, CES304.787 (dozens of Associations)	This widespread ecological system includes the driest grasslands throughout the intermountain western U.S. It occurs on xeric sites over an elevation range of approximately 1450 to 2320 m (4750-7610 feet) on a variety of landforms, including swales, playas, mesas, alluvial flats, and plains. This system may constitute the matrix over large areas of intermountain basins, and also may occur as large patches in mosaics with shrubland systems dominated by *Artemisia tridentata* ssp. *tridentata, Artemisia tridentata* ssp. *wyomingensis*, *Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Gutierrezia sarothrae,* or *Krascheninnikovia lanata*. Grasslands in areas of higher precipitation, at higher elevation, typically belong to other systems. Substrates are often well-drained sandy or loam soils derived from sedimentary parent materials but are quite variable and may include fine-textured soils derived from igneous and metamorphic rocks. The dominant perennial bunch grasses and shrubs within this system are all drought-resistant plants. Dominant or codominant species are *Achnatherum hymenoides, Aristida spp., Bouteloua gracilis, Hesperostipa comata, Muhlenbergia spp.,* or *Pleuraphis jamesii*. Scattered shrubs and dwarf-shrubs often are present, especially *Artemisia tridentata* ssp. t*ridentata, Artemisia tridentata* ssp. *wyomingensis, Atriplex* spp., *Coleogyne* spp., *Ephedra* spp., *Gutierrezia sarothrae*, and *Krascheninnikovia lanata*. Grasslands in the basins of south-central and southwestern Wyoming, dominated by *Pseudoroegneria spicata* and *Poa secunda* and containing cushion-form forbs and other species typical of dry basins, are included in this system.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Desert Grassland	Madrean Juniper Savanna, CES301.730	This Madrean ecological system occurs in lower foothills and plains of southeastern Arizona, southern New Mexico extending into west Texas and Mexico. These savannas have widely spaced mature juniper trees and moderate to high cover of graminoids (>25% cover). The presence of Madrean *Juniperus* spp. such as *Juniperus coahuilensis, Juniperus pinchotii,* and/or *Juniperus deppeana* is diagnostic. J*uniperus monosperma* may be present in some stands; *Juniperus deppeana* has a broader range than this Madrean system and extends north into southern stands of Southern Rocky Mountain Juniper Woodland and Savanna (CES306.834). Stands of *Juniperus pinchotii* may be short and resemble a shrubland. Graminoid species are a mix of those found in Western Great Plains Shortgrass Prairie (CES303.672) and Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (CES302.735), with *Bouteloua gracilis* and *Pleuraphis jamesii* being most common. In addition, these areas include succulents such as species of *Yucca, Opuntia,* and *Agave*. Juniper savanna expansion into grasslands has been documented in the last century.
Madrean Evergreen Woodland	Madrean Encinal, CES305.795	Madrean Encinal occurs on foothills, canyons, bajadas and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, extending north into Trans-Pecos Texas, southern New Mexico and sub-Mogollon Arizona. These woodlands are dominated by Madrean evergreen oaks along a low-slope transition below Madrean Lower Montane Pine-Oak Forest and Woodland (CES305.796) and Madrean Pinyon-Juniper Woodland (CES305.797). Lower elevation stands are typically open woodlands or savannas where they transition into desert grasslands, chaparral or in some cases desertscrub. Common evergreen oak species include *Quercus arizonica, Quercus emoryi, Quercus intricata, Quercus grisea, Quercus oblongifolia, Quercus toumeyi*, and in Mexico *Quercus chihuahuensis* and *Quercus albocincta*. Madrean pine, Arizona cypress, pinyon and juniper trees may be present but do not codominate. Chaparral species such as *Arctostaphylos pungens, Cercocarpus montanus, Purshia spp., Garrya wrightii, Quercus turbinella, Frangula betulifolia* (= *Rhamnus betulifolia*), or *Rhus* spp. may be present but do not dominate. The graminoid layer is usually prominent between trees in grassland or steppe that is dominated by warm-season grasses such as *Aristida* spp., *Bouteloua gracilis, Bouteloua curtipendula, Bouteloua rothrockii, Digitaria californica, Eragrostis intermedia, Hilaria belangeri, Leptochloa dubia, Muhlenbergia* spp., P*leuraphis jamesii*, or *Schizachyrium cirratum*, species typical of Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (CES302.735). This system includes seral stands dominated by shrubby Madrean oaks typically with a strong graminoid layer. In transition areas with drier chaparral systems, stands of chaparral are not dominated by Madrean oaks; however, Madrean Encinal may extend down along drainages. -Considered to be woodland in Mexico.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Madrean Evergreen Woodland	Madrean Lower Montane Pine-Oak Forest and Woodland, CES305.796 (contains 23 Associations)	This system occurs on mountains and plateaus in the Sierra Madre Occidentale and Sierra Madre Orientale in Mexico, Trans-Pecos Texas, southern New Mexico and Arizona, generally south of the Mogollon Rim. These forests and woodlands are composed of Madrean pines (*Pinus arizonica, Pinus engelmannii, Pinus leiophylla,* or *Pinus strobiformis*) and evergreen oaks (*Quercus arizonica, Quercus emoryi,* or *Quercus grisea*) intermingled with patchy shrublands on most mid-elevation slopes (1500-2300 m elevation). Other tree species include *Cupressus arizonica, Juniperus deppeana, Pinus cembroides, Pinus discolor, Pinus ponderosa* (with Madrean pines or oaks), and *Pseudotsuga menziesii*. Subcanopy and shrub layers may include typical encinal and chaparral species such as *Agave* spp., *Arbutus arizonica, Arctostaphylos pringlei, Arctostaphylos pungens, Garrya wrightii, Nolina spp., Quercus hypoleucoides, Quercus rugosa,* and *Quercus turbinella*. Some stands have moderate cover of perennial graminoids such as *Muhlenbergia emersleyi, Muhlenbergia longiligula, Muhlenbergia virescens,* and *Schizachyrium cirratum.* Fires are frequent with perhaps more crown fires than ponderosa pine woodlands, which tend to have more frequent ground fires on gentle slopes.
Madrean Evergreen Woodland	Madrean Upper Montane Conifer-Oak Forest and Woodland, CES305.798 (contains 3 Associations)	This ecological system occurs at the upper elevations in the Sierra Madre Occidentale and Sierra Madre Orientale of Mexico. In the U.S., it is restricted to north and east aspects at high elevations (1980-2440 m) in the Sky Islands (Chiricahua, Huachuca, Pinaleno, Santa Catalina, and Santa Rita mountains) and along the Nantanes Rim. It is more common in Mexico and does not occur north of the Mogollon Rim. The vegetation is characterized by large- and small-patch forests and woodlands dominated by *Pseudotsuga menziesii, Abies coahuilensis,* or *Abies concolor* and Madrean oaks such as *Quercus arizonica, Quercus emoryi, Quercus grisea, Quercus hypoleucoides, Quercus rugosa,* and *Quercus toumeyi*. If *Quercus gambelii* is prominent in the shrub layer, then other Madrean elements are present. This system may include stands of *Quercus gravesii* woodlands. It is similar to Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (CES306.823) which typically lacks Madrean elements.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Petran Conifer Forest	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland, CES306.830	This is a high-elevation system of the Rocky Mountains, dry eastern Cascades and eastern Olympic Mountains dominated by *Picea engelmannii* and *Abies lasiocarpa*. It extends westward into the northeastern Olympic Mountains and the northeastern side of Mount Rainier in Washington, and as far east as mountain "islands" of north-central Montana. It also occurs northward into the Upper Foothills subregion of western Alberta. *Picea engelmannii* is generally more important in southern forests than those in the Pacific Northwest. Occurrences are typically found in locations with cold-air drainage or ponding, or where snowpacks linger late into the summer, such as north-facing slopes and high-elevation ravines. They can extend down in elevation below the subalpine zone in places where cold-air ponding occurs (as low as 970 m [3180 feet] in the Canadian Rockies); northerly and easterly aspects predominate. These forests are found on gentle to very steep mountain slopes, high-elevation ridgetops and upper slopes, plateau-like surfaces, basins, alluvial terraces, well-drained benches, and inactive stream terraces. In the northern Rocky Mountains of northern Idaho and Montana, *Tsuga mertensiana* occurs as small to large patches within the matrix of this mesic spruce-fir system and only in the most maritime of environments (the coldest and wettest of the more Continental subalpine fir forests). In the Olympics and northern Cascades, the climate is more maritime than typical for this system, but due to the lower snowfall in these rainshadow areas, summer drought may be more significant than snowpack in limiting tree regeneration in burned areas. Picea engelmannii is rare in these areas. Mesic understory shrubs include *Menziesia ferruginea, Vaccinium membranaceum, Rhododendron albiflorum, Amelanchier alnifolia, Rubus parviflorus, Ledum glandulosum, Phyllodoce empetriformis,* and *Salix* spp. Herbaceous species include *Actaea rubra, Maianthemum stellatum, Cornus canadensis, Erigeron eximius, Gymnocarpium dryopteris, Rubus pedatus, Saxifraga bronchialis, Tiarella* spp., *Lupinus arcticus* ssp. *subalpinus, Valeriana sitchensis*, and graminoids *Luzula glabrata* var. *hitchcockii* or *Calamagrostis canadensis*. In Alberta, species composition indicates the transition to more boreal floristics, including such species as *Ledum groenlandicum* and *Leymus innovatus*, and more abundant mosses such as *Hylocomium splendens* and *Pleurozium schreberi*. Disturbances include occasional blowdown, insect outbreaks (30-50 years), mixed-severity fire, and stand-replacing fire (every 150-500 years). The more summer-dry climatic areas also have occasional high-severity fires.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Petran Conifer Forest	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland, CES306.823 (contains dozens of Associations)	This is a highly variable ecological system of the montane zone of the Rocky Mountains. It occurs throughout the southern Rockies, north and west into Utah, Nevada, Wyoming and Idaho. These are mixed-conifer forests occurring on all aspects at elevations ranging from 1200 to 3300 m. Rainfall averages less than 75 cm per year (40-60 cm), with summer "monsoons" during the growing season contributing substantial moisture. The composition and structure of the overstory are dependent upon the temperature and moisture relationships of the site and the successional status of the occurrence. *Pseudotsuga menziesii* and *Abies concolor* are most frequent, but *Pinus ponderosa* may be present to codominant. *Pinus flexilis* is common in Nevada. *Pseudotsuga menziesii* forests occupy drier sites, and *Pinus ponderosa* is a common codominant. *Abies concolor*-dominated forests occupy cooler sites, such as upper slopes at higher elevations, canyon sideslopes, ridgetops, and north- and east-facing slopes which burn somewhat infrequently. *Picea pungens* is most often found in cool, moist locations, often occurring as smaller patches within a matrix of other associations. As many as seven conifers can be found growing in the same occurrence, and there are a number of cold-deciduous shrub and graminoid species common, including *Arctostaphylos uva-ursi, Mahonia repens, Paxistima myrsinites, Symphoricarpos oreophilus, Jamesia americana, Quercus gambelii,* and *Festuca arizonica*. This system was undoubtedly characterized by a mixed-severity fire regime in its "natural condition," characterized by a high degree of variability in lethality and return interval.
Petran Conifer Forest	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland, CES306.825 (contains dozens of Associations)	These are mixed conifer forests of the Rocky Mountains west into the ranges of the Great Basin, occurring predominantly in cool ravines and on north-facing slopes. Elevations range from 1200 to 3300 m. Occurrences of this system are found on cooler and more mesic sites than Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland (CES306.823). Such sites include lower and middle slopes of ravines, along stream terraces, moist, concave topographic positions and north- and east-facing slopes which burn somewhat infrequently. *Pseudotsuga menziesii* and A*bies concolor* are most common canopy dominants, but *Picea engelmannii, Picea pungens,* or *Pinus ponderosa* may be present. This system includes mixed conifer/*Populus tremuloides* stands. A number of cold-deciduous shrub species can occur, including *Acer glabrum, Acer grandidentatum, Alnus incana, Betula occidentalis, Cornus sericea, Jamesia americana, Physocarpus malvaceus, Robinia neomexicana, Vaccinium membranaceum,* and *Vaccinium myrtillus*. Herbaceous species include *Bromus ciliatus, Carex geyeri, Carex rossii, Carex siccata, Muhlenbergia virescens, Pseudoroegneria spicata, Erigeron eximius, Fragaria virginiana, Luzula parviflora, Osmorhiza berteroi, Packera cardamine, Thalictrum occidentale,* and *Thalictrum fendleri*. Naturally occurring fires are of variable return intervals and mostly light, erratic, and infrequent due to the cool, moist conditions.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Petran Subalpine Conifer Forest	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland, CES306.828	Engelmann spruce and subalpine fir forests comprise a substantial part of the subalpine forests of the Cascades and Rocky Mountains from southern British Columbia east into Alberta, and south into New Mexico and the Intermountain region. They also occur on mountain "islands" of north-central Montana. They are the matrix forests of the subalpine zone, with elevations ranging from 1275 m in its northern distribution to 3355 m in the south (4100-11,000 feet). They often represent the highest elevation forests in an area. Sites within this system are cold year-round, and precipitation is predominantly in the form of snow, which may persist until late summer. Snowpacks are deep and late-lying, and summers are cool. Frost is possible almost all summer and may be common in restricted topographic basins and benches. Despite their wide distribution, the tree canopy characteristics are remarkably similar, with *Picea engelmannii* and *Abies lasiocarpa* dominating either mixed or alone. *Pseudotsuga menziesii* may persist in occurrences of this system for long periods without regeneration. *Pinus contorta* is common in many occurrences, and patches of pure *Pinus contorta* are not uncommon, as well as mixed conifer/*Populus tremuloides* stands. In some areas, such as Wyoming, *Picea engelmannii*-dominated forests are on limestone or dolomite, while nearby codominated spruce-fir forests are on granitic or volcanic rocks. Upper elevation examples may have more woodland physiognomy, and Pinus albicaulis can be a seral component. What have been called "ribbon forests" or "tree islands" by some authors are included here; they can be found at upper treeline in many areas of the Rockies, including the central and northern ranges in Colorado and the Medicine Bow and Bighorn ranges of Wyoming. These are more typically islands or ribbons of trees, sometimes with a krummholz form, with open-meadow areas in a mosaic. These patterns are controlled by snow deposition and wind-blown ice. Xeric species may include *Juniperus communis, Linnaea borealis, Mahonia repens,* or *Vaccinium scoparium*. In the Bighorn Mountains, *Artemisia tridentata* is a common shrub. More northern occurrences often have taller, more mesic shrub and herbaceous species, such as *Empetrum nigrum, Rhododendron albiflorum,* and *Vaccinium membranaceum*. Disturbance includes occasional blowdown, insect outbreaks and stand-replacing fire. Mean return interval for stand-replacing fire is 222 years as estimated in southeastern British Columbia.
Riparian	North American Warm Desert Lower Montane Riparian Woodland and Shrubland, CES302.748	This ecological system occurs in foothill and mountain canyons and valleys of the warm desert regions of the southwestern U.S. and adjacent Mexico, and consists of mid-to low-elevation (1100-1800 m) riparian corridors along perennial and seasonally intermittent streams. Rivers include upper portions of the Gila, Santa Cruz, Salt, San Pedro, and tributaries of the lower Colorado River (below the Grand Canyon), the lower Rio Grande and Pecos (up to its confluence with Rio Hondo) that occur in the desert portions of their range. The vegetation is a mix of riparian woodlands and shrublands. Dominant trees include *Populus angustifolia, Populus deltoides* ssp. *wislizeni, Populus fremontii, Platanus wrightii, Juglans major, Fraxinus velutina,* and *Sapindus saponaria*. Shrub dominants include *Salix exigua, Prunus* spp., *Alnus oblongifolia*, and *Baccharis salicifolia*. Vegetation is dependent upon annual or periodic flooding and associated sediment scour and/or annual rise in the water table for growth and reproduction.

Table C.1. Conversion of major vegetation types between Brown-Lowe-Pase and the National Vegetation Classification Standard. Data selected from NatureServe.org.

Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Riparian	North American Warm Desert Riparian Mesquite Bosque, CES302.752 (28 Associations, many of which are shrublands not traditionally considered to be riparian)	This ecological system consists of low-elevation (<1100 m) riparian corridors along perennial and intermittent streams in valleys of the warm desert regions of the southwestern U.S. and adjacent Mexico. Rivers include the lower Colorado (within and downstream of the Grand Canyon), Gila, Santa Cruz, Salt, lower Rio Grande, Pecos (up to near its confluence with Rio Hondo), and their tributaries that occur in the desert portions of their range. Dominant trees include *Prosopis glandulosa* and *Prosopis velutina*. Shrub dominants include *Baccharis salicifolia, Pluchea sericea,* and *Salix exigua*. Woody vegetation is relatively dense, especially when compared to drier washes. Vegetation, especially the mesquites, tap groundwater below the streambed when surface flows stop. Vegetation is dependent upon annual rise in the water table for growth and reproduction.
Riparian	North American Warm Desert Riparian Woodland and Shrubland, CES302.753 (dozens of Associations)	This ecological system consists of low-elevation (<1200 m) riparian corridors along medium to large perennial streams throughout canyons and desert valleys of the southwestern United States and adjacent Mexico. Rivers include the lower Colorado (into the Grand Canyon), Gila, Santa Cruz, Salt, lower Rio Grande (below Elephant Butte Reservoir in New Mexico to the Coastal Plain of Texas), and the lower Pecos (up to near its confluence with Rio Hondo in southeastern New Mexico). The vegetation is a mix of riparian woodlands and shrublands. Dominant trees include *Acer negundo, Fraxinus velutina, Populus fremontii, Salix gooddingii, Salix lasiolepis, Celtis laevigata var. reticulata, Platanus racemosa,* and *Juglans major*. Shrub dominants include *Salix geyeriana, Shepherdia argentea*, and *Salix exigua*. Vegetation is dependent upon annual or periodic flooding and associated sediment scour and/or annual rise in the water table for growth and reproduction.
Riparian	Rocky Mountain Subalpine-Montane Riparian Shrubland, CES306.832 (scores of Associations)	This system is found throughout the Rocky Mountain cordillera from New Mexico north into Montana and northwestern Alberta, and also occurs in mountainous areas of the Intermountain West region and Colorado Plateau. These are montane to subalpine riparian shrublands occurring as narrow bands of shrubs lining streambanks and alluvial terraces in narrow to wide, low-gradient valley bottoms and floodplains with sinuous stream channels. Generally, the system is found at higher elevations, but can be found anywhere from 1500-3475 m, and may occur at even lower elevations in the Canadian Rockies. Occurrences can also be found around seeps, fens, and isolated springs on hillslopes away from valley bottoms. Many of the plant associations found within this system are associated with beaver activity. This system often occurs as a mosaic of multiple communities that are shrub- and herb-dominated and includes above-treeline, willow-dominated, snowmelt-fed basins that feed into streams. The dominant shrubs reflect the large elevational gradient and include *Alnus incana, Betula glandulosa, Betula occidentalis, Cornus sericea, Salix bebbiana, Salix boothii, Salix brachycarpa, Salix drummondiana, Salix eriocephala, Salix geyeriana, Salix monticola, Salix planifolia,* and *Salix wolfii*. Generally the upland vegetation surrounding these riparian systems are of either conifer or aspen forests.

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Brown-Lowe-Pase	NatureServe Ecological System, Unique Identifier	Description
Riparian	Rocky Mountain Subalpine-Montane Riparian Woodland, CES306.833 (dozens of Associations)	This riparian woodland system is comprised of seasonally flooded forests and woodlands found at montane to subalpine elevations of the Rocky Mountain cordillera, from southern New Mexico north into Montana, and west into the Intermountain region and the Colorado Plateau. It occurs throughout the interior of British Columbia and the eastern slopes of the Cascade Mountains. This system contains the conifer and aspen woodlands that line montane streams. These are communities tolerant of periodic flooding and high water tables. Snowmelt moisture in this system may create shallow water tables or seeps for a portion of the growing season. Stands typically occur at elevations between 1500 and 3300 m (4920-10,830 feet), farther north elevation ranges between 900 and 2000 m. This is confined to specific riparian environments occurring on floodplains or terraces of rivers and streams, in V-shaped, narrow valleys and canyons (where there is cold-air drainage). Less frequently, occurrences are found in moderate-wide valley bottoms on large floodplains along broad, meandering rivers, and on pond or lake margins. Dominant tree species vary across the latitudinal range, although it usually includes *Abies lasiocarpa* and/or *Picea engelmannii*; other important species include *Pseudotsuga menziesii, Picea pungens, Picea engelmannii X glauca, Populus tremuloides,* and *Juniperus scopulorum*. Other trees possibly present but not usually dominant include *Alnus incana, Abies concolor, Abies grandis, Pinus contorta, Populus angustifolia, Populus balsamifera ssp. trichocarpa,* and *Juniperus osteosperma*.
Sonoran Desertscrub	-Sonoran Brittlebush-Ironwood Desert Scrub CES302.758; -Sonoran Granite Outcrop Desert Scrub CES302.760; -Sonoran Mid-Elevation Desert Scrub CES302.035; -Sonoran Palo Verde-Mixed Cacti Desert Scrub CES302.761	(These ecological systems do not occur in or near the parks.)

Table C.2. Provisional Checklist of Flora of Chiricahua NM. Under development by Steve Buckley, NPS Sonoran Desert Network. Key to presence: X = voucher in herbarium, O = observation by qualified botanist, U = unverified.

Family	Scientific Name	Voucher
Acanthaceae	*Anisacanthus thurberi*	X
	Dyschoriste decumbens	X
Aizoaceae	*Trianthema portulacastrum*	X
Amaranthaceae	*Alternanthera caracasana*	X
	Alternanthera pungens	X
	Amaranthus albus	X
	Amaranthus blitoides	X
	Amaranthus palmeri	X
	Amaranthus powellii	X
	Amaranthus torreyi	X
	Chenopodium album	X
	Chenopodium berlandieri	U
	Chenopodium fremontii	X
	Chenopodium graveolens	X
	Chenopodium leptophyllum	X
	Chenopodium neomexicanum	X
	Chenopodium watsonii	U
	Froelichia arizonica	X
	Froelichia gracilis	X
	Gomphrena caespitosa	X
	Gomphrena nitida	X
	Gomphrena sonorae	X
	Guilleminea densa	X
	Monolepis nuttalliana	U
	Salsola kali	X
	Allium cernuum	X
	Allium cernuum	U
	Zephyranthes longifolia	X
	Rhus aromatica	X
	Rhus glabra	X
	Rhus microphylla	X
	Rhus virens var. *choriophylla*	X
	Toxicodendron radicans ssp. *divaricatum*	X
	Toxicodendron rydbergii	X
Apiaceae	*Cymopterus multinervatus*	U
	Lomatium nevadense	X
	Pseudocymopterus montanus	X
	Yabea microcarpa	U
Apocynaceae	*Apocynum androsaemifolium*	U
	Apocynum cannabinum	X
	Asclepias asperula	X
	Asclepias glaucescens	X

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Family	Scientific Name	Voucher
Apocynaceaa	*Asclepias latifolia*	U
	Asclepias lemmonii	X
	Asclepias linaria	X
	Asclepias nummularia	X
	Asclepias nyctaginifolia	X
	Asclepias quinquedentata	X
	Asclepias speciosa	X
	Asclepias subverticillata	X
	Asclepias tuberosa	X
	Macrosiphonia brachysiphon	X
	Sarcostemma crispum	X
	Sarcostemma cynanchoides	U
Aristolochiaceae	*Aristolochia watsonii*	X
Asparagaceae	*Agave palmeri*	X
	Agave parryi	X
	Asparagus officinalis	X
	Dasylirion wheeleri	X
	Dichelostemma capitatum ssp. *capitatum*	X
	Echeandia flavescens	X
	Maianthemum racemosum	X
	Maianthemum stellatum	X
	Milla biflora	X
	Nolina microcarpa	X
	Yucca baccata	X
	Yucca elata	X
	Yucca madrensis	X
	Asplenium resiliens	X
	Asplenium trichomanes	X
Asteraceae	*Acourtia nana*	X
	Acourtia thurberi	X
	Ageratina herbacea	X
	Ageratina paupercula	X
	Amauriopsis dissecta	X
	Ambrosia psilostachya	X
	Antennaria marginata	X
	Arida parviflora	U
	Artemisia carruthii	X
	Artemisia dracunculus	X
	Artemisia ludoviciana ssp. *mexicana*	X
	Baccharis pteronioides	X
	Baccharis salicifolia	X
	Baccharis sarothroides	X

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Family	Scientific Name	Voucher
Asteraceae	*Baccharis thesioides*	X
	Baileya multiradiata	X
	Berlandiera lyrata	X
	Bidens bigelovii	X
	Bidens heterosperma	X
	Bidens lemmonii	X
	Bidens leptocephala	X
	Brickellia betonicifolia	X
	Brickellia californica	X
	Brickellia eupatorioides var. *chlorolepis*	X
	Brickellia floribunda	X
	Brickellia grandiflora	X
	Brickellia lemmonii	X
	Brickellia pringlei	X
	Brickellia simplex	X
	Brickellia venosa	X
	Brickelliastrum fendleri	X
	Carminatia tenuiflora	X
	Carphochaete bigelovii	X
	Centaurea melitensis	X
	Centaurea rothrockii	U
	Chaetopappa ericoides	X
	Cirsium arizonicum	X
	Cirsium neomexicanum	X
	Cirsium ochrocentrum	X
	Cirsium rothrockii	X
	Conyza canadensis	X
	Cosmos parviflorus	X
	Dieteria asteroides	X
	Dieteria asteroides	X
	Dieteria canescens	X
	Ericameria laricifolia	X
	Ericameria nauseosa var. *latisquamea*	X
	Erigeron concinnus	X
	Erigeron divergens	X
	Erigeron eximius	X
	Erigeron flagellaris	X
	Erigeron neomexicanus	X
	Erigeron oreophilus	X
	Erigeron speciosus	X
	Erigeron vreelandii	X
	Gaillardia pinnatifida	X

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Family	Scientific Name	Voucher
Asteraceae	*Gaillardia pulchella*	X
	Gamochaeta falcata	X
	Gutierrezia sarothrae	X
	Gymnosperma glutinosum	X
	Helianthus ciliaris	X
	Helianthus petiolaris	X
	Heliomeris longifolia var. *annua*	X
	Heliomeris longifolia var. *longifolia*	X
	Heliomeris multiflora var. *brevifolia*	X
	Heliomeris multiflora var. *multiflora*	X
	Heliopsis parvifolia	U
	Heterosperma pinnatum	X
	Heterotheca subaxillaris	X
	Heterotheca villosa var. *minor*	X
	Heterotheca viscida	X
	Hieracium carneum	X
	Hieracium fendleri var. *fendleri*	X
	Hymenothrix wislizeni	X
	Hymenothrix wrightii	X
	Hymenoxys ambigens var. *floribunda*	X
	Isocoma tenuisecta	X
	Lactuca graminifolia	X
	Lactuca serriola	X
	Lactuca tatarica var. *pulchella*	X
	Laennecia coulteri	X
	Laennecia schiedeana	X
	Laennecia sophiifolia	X
	Lasianthaea podocephala	X
	Machaeranthera tagetina	X
	Machaeranthera tanacetifolia	X
	Malacothrix fendleri	X
	Melampodium longicorne	X
	Melampodium strigosum	X
	Packera neomexicana	X
	Parthenium incanum	X
	Pectis filipes var. *subnuda*	X
	Pectis prostrata	X
	Pericome caudata	U
	Perityle cochisensis	X
	Perityle lemmonii	U
	Psacalium decompositum	X
	Pseudognaphalium canescens	X

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Family	Scientific Name	Voucher
Asteraceae	*Pseudognaphalium macounii*	X
	Pseudognaphalium pringlei	X
	Pseudognaphalium stramineum	X
	Psilostrophe cooperi	U
	Sanvitalia abertii	X
	Schkuhria anthemoidea var. *wrightii*	X
	Schkuhria pinnata	X
	Senecio eremophilus var. *macdougalii*	X
	Senecio flaccidus var. *flaccidus*	X
	Senecio flaccidus var. *monoensis*	X
	Senecio parryi	X
	Senecio wootonii	X
	Solidago canadensis var. *scabra*	X
	Solidago missouriensis	X
	Solidago missouriensis var. *missouriensis*	X
	Solidago velutina	X
	Solidago wrightii var. *adenophora*	X
	Sonchus asper	X
	Sonchus oleraceus	X
	Stephanomeria pauciflora	X
	Stephanomeria tenuifolia	X
	Stephanomeria thurberi	X
	Stephanomeria wrightii	X
	Stevia serrata	X
	Symphyotrichum falcatum	X
	Symphyotrichum falcatum var. *commutatum*	X
	Tagetes micrantha	X
	Taraxacum officinale	X
	Thelesperma longipes	U
	Thelesperma megapotamicum	X
	Trixis californica	X
	Uropappus lindleyi	X
	Verbesina encelioides ssp. *exauriculata*	X
	Verbesina longifolia	X
	Viguiera cordifolia	X
	Viguiera dentata	X
	Xanthisma gracile	X
	Xanthisma spinulosum	X
	Xanthium strumarium	X
	Zaluzania grayana	U
	Zinnia grandiflora	X
Berberidaceae	*Mahonia wilcoxii*	X

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Family	Scientific Name	Voucher
Bignoniaceae	*Chilopsis linearis*	X
	Cryptantha cinerea var. *cinerea*	X
	Cryptantha cinerea var. *jamesii*	X
	Cryptantha crassisepala	X
	Heliotropium fruticosum	X
	Lappula occidentalis var. *cupulata*	X
	Lithospermum cobrense	X
	Lithospermum confine	X
	Lithospermum incisum	X
	Lithospermum multiflorum	X
	Plagiobothrys arizonicus	X
Brassicaceae	*Boechera perennans*	X
	Brassica rapa	X
	Capsella bursa-pastoris	X
	Descurainia incana ssp. *incana*	X
	Descurainia obtusa	X
	Descurainia pinnata	X
	Descurainia sophia	X
	Draba cuneifolia	X
	Draba helleriana var. *bifurcata*	X
	Dryopetalon runcinatum	X
	Erysimum capitatum	X
	Lepidium lasiocarpum	X
	Lepidium oblongum	U
	Lepidium thurberi	X
	Noccaea montana var. *fendleri*	X
	Pennellia longifolia	X
	Pennellia micrantha	X
	Physaria gordonii	X
	Rorippa nasturtium-aquaticum	X
	Schoenocrambe linearifolia	X
	Sisymbrium irio	X
	Thelypodium wrightii	X
	Thysanocarpus curvipes	U
Cactaceae	*Coryphantha vivipara*	X
	Cylindropuntia leptocaulis	X
	Cylindropuntia spinosior	X
	Cylindropuntia X *tetracantha*	U
	Echinocereus coccineus	X
	Echinocereus fendleri	X
	Echinocereus ledingii	X
	Echinocereus polyacanthus	X

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Family	Scientific Name	Voucher
Cactaceae	*Echinocereus rigidissimus*	X
	Echinocereus triglochidiatus	X
	Echinomastus erectocentrus	X
	Echinomastus intertextus	X
	Opuntia chlorotica	X
	Opuntia engelmannii	X
	Opuntia macrorhiza	X
	Opuntia phaeacantha	X
Campanulaceae	*Lobelia cardinalis*	X
Cannabaceae	*Celtis laevigata* var. *reticulata*	X
	Lonicera albiflora	X
	Lonicera arizonica	X
	Lonicera japonica	X
	Symphoricarpos oreophilus	X
	Symphoricarpos palmeri	X
Caryophyllaceae	*Arenaria fendleri*	X
	Arenaria lanuginosa ssp. *saxosa*	X
	Cerastium texanum	X
	Drymaria glandulosa	X
	Drymaria leptophylla	X
	Drymaria molluginea	X
	Silene laciniata ssp. *greggii*	X
Celastraceae	*Paxistima myrsinites*	X
Cleomaceae	*Polanisia dodecandra*	X
	Wislizenia refracta	X
Commelinaceae	*Commelina dianthifolia*	X
	Tradescantia pinetorum	X
Convolvulaceae	*Convolvulus arvensis*	U
	Convolvulus equitans	X
	Dichondra brachypoda	X
	Evolvulus sericeus	X
	Ipomoea capillacea	X
	Ipomoea coccinea	X
	Ipomoea costellata	X
	Ipomoea cristulata	X
	Ipomoea hederacea	X
	Ipomoea hederifolia	X
	Ipomoea plummerae	X
	Ipomoea purpurea	X
	Ipomoea tenuiloba	X
Crassulaceae	*Sedum cockerellii*	X
	Sedum stelliforme	U

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Family	Scientific Name	Voucher
Crossosomataceae	*Apacheria chiricahuensis*	X
Cucurbitaceae	*Apodanthera undulata*	X
	Cucurbita digitata	X
	Cucurbita foetidissima	X
	Sicyos ampelophyllus	U
Cupressaceae	*Cupressus arizonica*	X
	Juniperus coahuilensis	X
	Juniperus deppeana	X
	Juniperus monosperma	X
Cyperaceae	*Bulbostylis capillaris*	X
	Bulbostylis capillaris ssp. *capillaris*	X
	Carex agrostoides	X
	Carex chihuahuensis	X
	Carex geophila	X
	Carex leucodonta	X
	Carex praegracilis	X
	Carex senta	X
	Carex ultra	X
	Cyperus esculentus	X
	Cyperus fendlerianus	X
	Cyperus retroflexus	X
	Cyperus sphaerolepis	X
	Cyperus squarrosus	X
	Eleocharis montevidensis	X
	Eleocharis parvula	X
	Eleocharis rostellata	X
	Lipocarpha micrantha	X
	Schoenoplectus americanus	X
	Schoenoplectus pungens	X
Dennstaedtiaceae	*Pteridium aquilinum* var. *pubescens*	X
Dryopteridaceae	*Cystopteris reevesiana*	X
	Dryopteris filix-mas	X
	Phanerophlebia auriculata	X
	Woodsia cochisensis	X
	Woodsia neomexicana	X
	Woodsia plummerae	X
Ephedraceae	*Ephedra trifurca*	X
Equisetaceae	*Equisetum hyemale*	X
	Equisetum laevigatum	X
	Equisetum X ferrissii	X
Ericaceae	*Arbutus arizonica*	X
	Arctostaphylos pringlei	X

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Family	Scientific Name	Voucher
Ericaceae	*Arctostaphylos pungens*	X
	Vaccinium myrtillus	U
Euphorbiaceae	*Acalypha neomexicana*	X
	Acalypha phleoides	X
	Chamaesyce albomarginata	X
	Chamaesyce dioica	X
	Chamaesyce glyptosperma	X
	Chamaesyce hyssopifolia	X
	Chamaesyce prostrata	X
	Chamaesyce revoluta	X
	Chamaesyce serpyllifolia	X
	Chamaesyce serrula	X
	Euphorbia bilobata	X
	Euphorbia brachycera	X
	Euphorbia cuphosperma	X
	Euphorbia dentata	X
	Euphorbia exstipulata	X
	Euphorbia heterophylla	X
	Tragia nepetifolia	X
	Tragia ramosa	X
Fabaceae	*Acacia angustissima* var. *suffrutescens*	X
	Amorpha fruticosa	X
	Astragalus allochrous var. *allochrous*	X
	Astragalus cobrensis var. *maguirei*	X
	Astragalus nothoxys	X
	Astragalus nuttallianus var. *austrinus*	X
	Astragalus thurberi	X
	Calliandra humilis var. *humilis*	X
	Calliandra humilis var. *reticulata*	X
	Chamaecrista nictitans	X
	Clitoria mariana	X
	Cologania angustifolia	X
	Cologania lemmonii	X
	Crotalaria pumila	X
	Crotalaria sagittalis	X
	Dalea albiflora	X
	Dalea candida var. *oligophylla*	X
	Dalea filiformis	X
	Dalea grayi	X
	Dalea nana var. *carnescens*	X
	Dalea pogonathera	U
	Dalea versicolor var. *sessilis*	X

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Family	Scientific Name	Voucher
Fabaceae	*Desmanthus cooleyi*	X
	Desmodium arizonicum	X
	Desmodium batocaulon	X
	Desmodium cinerascens	X
	Desmodium grahamii	X
	Desmodium neomexicanum	X
	Desmodium procumbens	X
	Desmodium rosei	X
	Galactia wrightii	X
	Hoffmannseggia glauca	X
	Indigofera sphaerocarpa	X
	Lathyrus graminifolius	X
	Lotus greenei	X
	Lotus humistratus	X
	Lotus plebeius	X
	Lotus wrightii	X
	Lupinus brevicaulis	X
	Lupinus caudatus ssp. *caudatus*	X
	Lupinus concinnus	U
	Lupinus lemmonii	U
	Macroptilium gibbosifolium	X
	Marina calycosa	X
	Medicago sativa	X
	Melilotus officinalis	X
	Mimosa aculeaticarpa var. *biuncifera*	X
	Mimosa dysocarpa	X
	Oxytropis lambertii var. *bigelovii*	X
	Pediomelum pentaphyllum	U
	Phaseolus acutifolius var. *tenuifolius*	X
	Phaseolus grayanus	X
	Phaseolus maculatus	X
	Phaseolus parvulus	U
	Prosopis glandulosa var. *torreyana*	X
	Prosopis velutina	X
	Psoralidium tenuiflorum	X
	Rhynchosia senna var. *texana*	X
	Robinia neomexicana var. *neomexicana*	X
	Senna bauhinioides	U
	Thermopsis divaricarpa	U
	Trifolium repens	X
	Vicia americana	X
	Vicia pulchella	X

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Family	Scientific Name	Voucher
Fagaceae	*Quercus arizonica*	X
	Quercus chrysolepis	X
	Quercus dunnii	X
	Quercus emoryi	X
	Quercus gambelii	X
	Quercus grisea	X
	Quercus hypoleucoides	X
	Quercus oblongifolia	U
	Quercus pungens	X
	Quercus rugosa	X
	Quercus toumeyi	X
	Quercus turbinella	U
Fouquieriaceae	*Fouquieria splendens*	X
Garryaceae	*Garrya flavescens*	U
	Garrya wrightii	X
Gentianaceae	*Centaurium calycosum*	X
	Gentianella microcalyx	X
	Erodium cicutarium	X
	Geranium caespitosum var. *eremophilum*	X
Haloragaceae	*Myriophyllum sibiricum*	U
Hydrangeaceae	*Fendlera rupicola*	X
	Fendlerella utahensis var. *cymosa*	X
	Philadelphus argenteus	X
	Philadelphus madrensis	X
	Philadelphus microphyllus	X
Hydrophyllaceae	*Nama dichotomum*	X
	Nama hispidum	X
	Phacelia arizonica	U
Juglandaceae	*Juglans major*	X
Juncaceae	*Juncus balticus*	X
	Juncus dudleyi	X
	Juncus interior	X
	Juncus longistylis	X
	Juncus saximontanus	X
Krameriaceae	*Krameria lanceolata*	X
Lamiaceae	*Agastache breviflora*	X
	Hedeoma dentata	X
	Hedeoma hyssopifolia	X
	Hedeoma nana	X
	Hedeoma oblongifolia	X
	Marrubium vulgare	X
	Monarda citriodora ssp. *austromontana*	X

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Family	Scientific Name	Voucher
Lamiaceae	*Monarda fistulosa* var. *menthifolia*	X
	Nepeta cataria	X
	Prunella vulgaris	U
	Salvia lemmonii	X
	Salvia subincisa	X
	Stachys coccinea	X
	Trichostema arizonicum	X
Linaceae	*Linum aristatum*	X
	Linum lewisii	U
	Linum neomexicanum	X
	Linum puberulum	U
Loasaceae	*Mentzelia albicaulis*	U
	Mentzelia isolata	X
	Mentzelia multiflora	X
Lythraceae	*Cuphea wrightii*	X
	Lythrum californicum	X
Malpighiaceae	*Aspicarpa hirtella*	X
Malvaceae	*Anoda cristata*	X
	Hibiscus biseptus	X
	Sida abutifolia	X
	Sida neomexicana	X
	Sida spinosa	X
	Sidalcea neomexicana	U
	Sphaeralcea coccinea	U
	Sphaeralcea emoryi	X
	Sphaeralcea fendleri	U
	Sphaeralcea hastulata	X
	Sphaeralcea laxa	X
	Sphaeralcea rusbyi	U
Martyniaceae	*Proboscidea althaeifolia*	U
	Proboscidea parviflora	X
Melanthiaceae	*Veratrum californicum*	U
	Mollugo verticillata	X
Monotropaceae	*Monotropa hypopithys*	U
Moraceae	*Morus microphylla*	U
Nyctaginaceae	*Allionia incarnata*	U
	Boerhavia coccinea	X
	Boerhavia coulteri	X
	Boerhavia erecta	X
	Boerhavia purpurascens	X
	Mirabilis albida	X
	Mirabilis coccinea	X

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Family	Scientific Name	Voucher
Nyctaginaceae	*Mirabilis comata*	U
	Mirabilis linearis var. *decipiens*	X
	Mirabilis longiflora var. *wrightiana*	X
Oleaceae	*Fraxinus velutina*	X
Onagraceae	*Calylophus hartwegii*	U
	Calylophus toumeyi	X
	Epilobium canum ssp. *latifolium*	X
	Epilobium ciliatum ssp. *ciliatum*	X
	Gaura coccinea	U
	Gaura hexandra ssp. *gracilis*	X
	Gaura mollis	U
	Oenothera albicaulis	U
	Oenothera elata ssp. *hirsutissima*	X
	Oenothera laciniata	U
	Oenothera primiveris	X
Orchidaceae	*Hexalectris spicata*	X
	Hexalectris warnockii	X
	Malaxis soulei	X
	Platanthera limosa	U
	Spiranthes parasitica	U
Orobanchaceae	*Brachystigma wrightii*	X
	Castilleja austromontana	X
	Castilleja integra	X
	Castilleja lanata	X
	Castilleja patriotica	U
	Castilleja tenuiflora	X
	Conopholis alpina var. *mexicana*	X
	Cordylanthus wrightii	X
	Orobanche fasciculata	U
Oxalidaceae	*Oxalis albicans* ssp. *pilosa*	X
	Oxalis alpina	X
	Oxalis decaphylla	X
	Oxalis stricta	X
Papaveraceae	*Argemone pleiacantha*	X
	Corydalis aurea	X
	Eschscholzia californica ssp. *mexicana*	U
Phrymaceae	*Mimulus guttatus*	X
	Mimulus rubellus	X
Phytolaccaceae	*Phytolacca americana*	X
	Phytolacca icosandra	X
Pinaceae	*Pinus arizonica*	X
	Pinus ponderosa var. *arizonica*	X

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Family	Scientific Name	Voucher
Pinaceae	*Pinus discolor*	X
	Pinus edulis	X
	Pinus engelmannii	X
	Pinus leiophylla var. *chihuahuana*	X
	Pseudotsuga menziesii var. *glauca*	X
Plantaginaceae	*Maurandella antirrhiniflora*	X
	Nuttallanthus texanus	U
	Penstemon barbatus	X
	Penstemon linarioides	X
	Penstemon pinifolius	X
	Penstemon pseudospectabilis ssp. *connatifolius*	X
	Penstemon racemosus	U
	Plantago major	X
	Plantago patagonica	X
	Schistophragma intermedia	X
Platanaceae	*Platanus wrightii*	X
Poaceae	*Agrostis scabra*	X
	Aristida adscensionis	X
	Aristida divaricata	X
	Aristida havardii	U
	Aristida purpurea var. *fendleriana*	X
	Aristida purpurea var. *longiseta*	X
	Aristida schiedeana var. *orcuttiana*	X
	Aristida ternipes var. *gentilis*	X
	Blepharoneuron tricholepis	X
	Bothriochloa barbinodis	X
	Bothriochloa springfieldii	X
	Bouteloua barbata	U
	Bouteloua curtipendula var. *caespitosa*	X
	Bouteloua eriopoda	X
	Bouteloua gracilis	X
	Bouteloua hirsuta	X
	Bouteloua radicosa	X
	Bouteloua rothrockii	U
	Bromus anomalus	X
	Bromus carinatus	X
	Bromus catharticus	X
	Bromus ciliatus var. *richardsonii*	X
	Bromus hordeaceus	X
	Bromus porteri	X
	Cenchrus spinifex	X
	Chloris virgata	X

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Family	Scientific Name	Voucher
Poaceae	*Cynodon dactylon*	X
	Dasyochloa pulchella	X
	Dichanthelium oligosanthes var. *scribnerianum*	X
	Digitaria sanguinalis	X
	Echinochloa colona	X
	Echinochloa crus-galli	X
	Elionurus barbiculmis	X
	Elymus arizonicus	X
	Elymus elymoides	X
	Eragrostis cilianensis	X
	Eragrostis curvula	X
	Eragrostis intermedia	X
	Eragrostis lehmanniana	X
	Eragrostis lugens	X
	Eragrostis mexicana	X
	Eragrostis pectinacea var. *miserrima*	X
	Eriochloa acuminata var. *acuminata*	X
	Eriochloa acuminata var. *minor*	X
	Hackelochloa granularis	X
	Heteropogon contortus	X
	Hilaria belangeri	X
	Hordeum murinum	X
	Hordeum murinum ssp. *glaucum*	X
	Koeleria macrantha	X
	Leptochloa dubia	X
	Lycurus setosus	X
	Muhlenbergia arenacea	U
	Muhlenbergia arizonica	X
	Muhlenbergia asperifolia	X
	Muhlenbergia emersleyi	X
	Muhlenbergia fragilis	X
	Muhlenbergia glauca	X
	Muhlenbergia longiligula	X
	Muhlenbergia minutissima	X
	Muhlenbergia montana	u
	Muhlenbergia pauciflora	X
	Muhlenbergia polycaulis	X
	Muhlenbergia repens	X
	Muhlenbergia rigens	X
	Muhlenbergia rigida	X
	Muhlenbergia sinuosa	X
	Muhlenbergia straminea	X

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Family	Scientific Name	Voucher
Poaceae	*Muhlenbergia tenuifolia*	X
	Muhlenbergia texana	X
	Muhlenbergia wrightii	X
	Panicum capillare	U
	Panicum hallii	X
	Panicum hirticaule	X
	Panicum miliaceum	X
	Panicum obtusum	X
	Paspalum distichum	X
	Piptochaetium fimbriatum	X
	Piptochaetium pringlei	X
	Poa fendleriana ssp. *albescens*	X
	Poa fendleriana ssp. *fendleriana*	X
	Polypogon monspeliensis	X
	Polypogon viridis	X
	Schedonorus phoenix	X
	Schizachyrium cirratum	X
	Schizachyrium sanguineum	X
	Setaria grisebachii	X
	Setaria leucopila	X
	Setaria viridis	X
	Sorghastrum nutans	X
	Sorghum halepense	X
	Sphenopholis obtusata	X
	Sporobolus airoides	X
	Sporobolus contractus	X
	Sporobolus cryptandrus	U
	Trachypogon spicatus	X
	Tragus berteronianus	U
	Urochloa arizonica	X
	Vulpia octoflora	X
	Zuloagaea bulbosum	X
Polemoniaceae	*Gilia mexicana*	X
	Gilia sinuata	U
	Ipomopsis macombii	X
	Ipomopsis multiflora	X
	Microsteris gracilis	X
	Polemonium pauciflorum	U
Polygalaceae	*Monnina wrightii*	X
	Polygala alba	X
	Polygala barbeyana	X
	Polygala hemipterocarpa	X

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Family	Scientific Name	Voucher
Polygalaceae	*Polygala obscura*	X
Polygonaceae	*Eriogonum abertianum*	X
	Eriogonum alatum	X
	Eriogonum jamesii var. *undulatum*	X
	Eriogonum polycladon	X
	Eriogonum wrightii	X
	Polygonum aviculare	X
	Polygonum douglasii ssp. *johnstonii*	X
	Rumex crispus	X
	Rumex hymenosepalus	U
Polypodiaceae	*Woodsia mexicana*	U
Portulacaceae	*Calandrinia ciliata*	U
	Phemeranthus aurantiacus	X
	Phemeranthus parviflorus	X
	Portulaca halimoides	X
	Portulaca oleracea	X
	Portulaca suffrutescens	X
	Portulaca umbraticola	X
	Talinum paniculatum	X
Primulaceae	*Anagallis arvensis*	X
	Androsace occidentalis	X
	Samolus vagans	U
Pteridaceae	*Adiantum capillus-veneris*	X
	Argyrochosma limitanea	X
	Astrolepis cochisensis ssp. *cochisensis*	X
	Astrolepis sinuata ssp. *sinuata*	X
	Bommeria hispida	X
	Cheilanthes bonariensis	X
	Cheilanthes eatonii	X
	Cheilanthes feei	X
	Cheilanthes fendleri	X
	Cheilanthes lendigera	X
	Cheilanthes lindheimeri	X
	Cheilanthes wootonii	X
	Cheilanthes wrightii	X
	Notholaena grayi	X
	Notholaena standleyi	X
	Pellaea atropurpurea	X
	Pellaea intermedia	X
	Pellaea truncata	X
	Pellaea wrightiana	X

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Family	Scientific Name	Voucher
Ranunculaceae	*Aquilegia triternata*	X
	Clematis ligusticifolia	X
	Delphinium wootonii	X
	Myosurus cupulatus	X
	Thalictrum fendleri	X
Rhamnaceae	*Ceanothus fendleri*	X
	Ceanothus greggii	X
	Ceanothus integerrimus	U
	Frangula betulifolia	X
	Frangula californica	X
	Rhamnus serrata	X
Rosaceae	*Cercocarpus montanus* var. *paucidentatus*	X
	Fallugia paradoxa	X
	Holodiscus discolor	X
	Holodiscus dumosus	X
	Physocarpus monogynus	U
	Potentilla thurberi	X
	Prunus serotina var. *virens*	X
	Rosa woodsii	X
	Rubus neomexicanus	X
	Rubus parviflorus var. *parviflorus*	U
Rubiaceae	*Bouvardia ternifolia*	X
	Crusea diversifolia	X
	Diodia teres	X
	Galium aparine	U
	Galium fendleri	X
	Galium mexicanum ssp. *asperrimum*	X
	Galium microphyllum	X
	Galium wrightii	X
	Hedyotis greenei	X
	Houstonia wrightii	X
Rutaceae	*Ptelea trifoliata* ssp. *angustifolia*	X
	Thamnosma texana	U
Salicaceae	*Populus fremontii*	X
	Salix bonplandiana	X
	Salix exigua	U
	Salix gooddingii	X
	Salix irrorata	U
	Salix lasiolepis	X
	Salix taxifolia	X
Santalaceae	*Arceuthobium gillii*	X
	Comandra umbellata ssp. *pallida*	X

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Family	Scientific Name	Voucher
Santalaceae	*Phoradendron capitellatum*	X
	Phoradendron coryae	X
	Phoradendron juniperinum	X
	Phoradendron leucarpum	U
	Phoradendron serotinum ssp. *macrophyllum*	U
	Phoradendron tomentosum	X
	Phoradendron villosum	X
Sapindaceae	*Acer grandidentatum*	X
	Sapindus saponaria	X
Saxifragaceae	*Heuchera glomerulata*	X
	Heuchera sanguinea	X
Scrophulariaceae	*Scrophularia parviflora*	X
	Verbascum blattaria	U
	Verbascum thapsus	X
	Verbascum virgatum	X
Sellaginellaceae	*Selaginella underwoodii*	U
Solanaceae	*Chamaesaracha coronopus*	X
	Datura wrightii	X
	Lycium pallidum var. *pallidum*	X
	Margaranthus solanaceus	X
	Nicotiana attenuata	U
	Nicotiana obtusifolia	U
	Physalis hederifolia	X
	Physalis pubescens	X
	Solanum americanum	U
	Solanum douglasii	X
	Solanum elaeagnifolium	X
	Solanum fendleri	X
	Solanum heterodoxum	X
	Solanum jamesii	X
	Solanum rostratum	X
Verbenaceae	*Aloysia wrightii*	X
	Glandularia bipinnatifida var. *bipinnatifida*	X
	Tetraclea coulteri	U
	Verbena carolina	X
	Verbena bracteata	X
	Verbena gracilis	X
	Verbena neomexicana	X
Violaceae	*Hybanthus verticillatus*	X
	Viola canadensis	X
Vitaceae	*Parthenocissus quinquefolia*	X
	Vitis arizonica	X

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Family	Scientific Name	Voucher
Zygophyllaceae	*Kallstroemia californica*	U
	Kallstroemia grandiflora	U
	Kallstroemia parviflora	X
	Tribulus terrestris	X
TOTAL	**803 TAXA**	

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Family	Scientific Name	Voucher
Acanthaceae	*Dyschoriste decumbens*	X
	Anisacanthus thurberi	X
Hydrangeaceae	*Fendlerella utahensis*	O
Adoxaceae	*Sambucus nigra*	X
Amaranthaceae	*Amaranthus albus*	X
	Amaranthus arenicola	O
	Amaranthus hybridus	X
	Amaranthus palmeri	X
	Amaranthus powellii	X
	Amaranthus torreyi	X
	Atriplex elegans	X
	Chenopodium fremontii	X
	Chenopodium graveolens	X
	Chenopodium neomexicanum	X
	Froelichia arizonica	X
	Gomphrena caespitosa	X
	Gomphrena nitida	X
	Gomphrena sonorae	X
	Guilleminea densa	X
	Iresine heterophylla	O
	Salsola kali	O
	Salsola tragus	X
Amaryllidaceae	*Allium macropetalum*	O
	Rhus aromatica var. *trilobata*	X
	Rhus glabra	O
	Rhus virens var. *choriophylla*	X
	Toxicodendron radicans	X
Apiaceae	*Eryngium heterophyllum*	O
	Spermolepis echinata	X
	Yabea microcarpa	U
Apocynaceae	*Asclepias asperula*	X
	Asclepias engelmanniana	O
	Asclepias glaucescens	X
	Asclepias linaria	X
	Asclepias macrotis	X
	Asclepias nummularia	X
	Asclepias nyctaginifolia	X
	Macrosiphonia brachysiphon	X
	Sarcostemma crispum	X
	Sarcostemma cynanchoides ssp. *heterophyllum*	X
Araliaceae	*Aralia humilis*	X

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Family	Scientific Name	Voucher
Asparagaceae	*Agave palmeri*	X
	Agave parryi	O
	Asparagus officinalis	X
	Dasylirion wheeleri	X
	Dichelostemma capitatum ssp. *pauciflorum*	X
	Echeandia flavescens	X
	Milla biflora	X
	Nolina microcarpa	X
	Yucca madrensis	X
Asteraceae	*Acourtia thurberi*	X
	Ageratina herbacea	X
	Ageratina paupercula	X
	Ambrosia confertiflora	X
	Ambrosia psilostachya	X
	Arida parviflora	O
	Artemisia ludoviciana ssp. *mexicana*	X
	Baccharis bigelovii	X
	Baccharis neglecta	O
	Baccharis pteronioides	X
	Baccharis salicifolia	O
	Baccharis sarothroides	X
	Baccharis thesioides	X
	Bahia absinthifolia	X
	Bahia dissecta	X
	Baileya multiradiata	O
	Bidens aurea	X
	Bidens bigelovii	X
	Bidens leptocephala	X
	Brickellia baccharidea	O
	Brickellia betonicifolia	X
	Brickellia californica	X
	Brickellia eupatorioides var. *chlorolepis*	X
	Brickellia floribunda	O
	Brickellia grandiflora	O
	Brickellia lemmonii	O
	Brickellia simplex	X
	Brickellia venosa	X
	Carminatia tenuiflora	X
	Carphochaete bigelovii	X
	Chaetopappa ericoides	X
	Cirsium arizonicum	X

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Family	Scientific Name	Voucher
Asteraceae	*Cirsium neomexicanum*	X
	Cirsium ochrocentrum	X
	Conyza canadensis	X
	Cosmos parviflorus	X
	Dieteria canescens var. *canescens*	X
	Ericameria laricifolia	X
	Ericameria nauseosa	O
	Erigeron concinnus	O
	Erigeron divergens	X
	Erigeron flagellaris	X
	Erigeron neomexicanus	X
	Erigeron oreophilus	X
	Fleischmannia pycnocephala	X
	Gamochaeta purpurea	X
	Guardiola platyphylla	X
	Gutierrezia microcephala	U
	Gutierrezia sarothrae	X
	Gutierrezia wrightii	X
	Gymnosperma glutinosum	X
	Hedosyne ambrosiifolia	X
	Helianthus annuus	X
	Helianthus petiolaris ssp. *fallax*	U
	Heliomeris longifolia var. *annua*	X
	Heliomeris longifolia var. *longifolia*	X
	Heliomeris multiflora var. *breviflora*	X
	Heliopsis parvifolia	X
	Heterosperma pinnatum	X
	Heterotheca subaxillaris	X
	Heterotheca villosa var. *minor*	X
	Hymenothrix wislizeni	X
	Hymenothrix wrightii	X
	Isocoma tenuisecta	O
	Lactuca serriola	O
	Laennecia coulteri	X
	Laennecia sophiifolia	X
	Lasianthaea podocephala	X
	Logfia californica	X
	Machaeranthera tagetina	X
	Machaeranthera tanacetifolia	O
	Malacothrix fendleri	X
	Melampodium leucanthum	X

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Family	Scientific Name	Voucher
Asteraceae	*Melampodium longicorne*	X
	Melampodium strigosum	X
	Packera neomexicana var. *neomexicana*	O
	Packera neomexicana var. *toumeyi*	X
	Parthenium incanum	X
	Pectis filipes var. *subnuda*	X
	Pectis imberbis	X
	Pectis longipes	X
	Pectis prostrata	X
	Perityle coronopifolia	X
	Porophyllum ruderale ssp. *macrocephalum*	X
	Pseudognaphalium arizonicum	X
	Pseudognaphalium canescens	X
	Pseudognaphalium leucocephalum	X
	Sanvitalia abertii	X
	Schkuhria anthemoidea var. *wrightii*	X
	Schkuhria pinnata	X
	Senecio flaccidus var. *flaccidus*	X
	Solidago canadensis	X
	Solidago velutina	O
	Solidago wrightii	X
	Sonchus asper	X
	Sonchus oleraceus	X
	Stephanomeria exigua	O
	Stephanomeria pauciflora	X
	Stephanomeria thurberi	X
	Stevia serrata	X
	Tagetes lemmonii	X
	Tagetes micrantha	X
	Thelesperma megapotamicum	X
	Thymophylla pentachaeta	X
	Trixis californica	X
	Verbesina encelioides	X
	Verbesina longifolia	X
	Verbesina rothrockii	X
	Viguiera cordifolia	X
	Viguiera dentata var. *dentata*	X
	Xanthisma gracile	X
	Xanthisma spinulosum	X
	Xanthium strumarium	U
	Zinnia acerosa	X

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Family	Scientific Name	Voucher
Asteraceae	*Zinnia grandiflora*	X
	Zinnia peruviana	X
Berberidaceae	*Mahonia wilcoxii*	O
Bignoniaceae	*Chilopsis linearis*	X
	Cryptantha cinerea var. *jamesii*	U
	Cryptantha pusilla	X
	Lithospermum cobrense	X
	Plagiobothrys arizonicus	X
Brassicaceae	*Brassica tournefortii*	X
	Descurainia pinnata	X
	Descurainia sophia	X
	Draba cuneifolia var. *cuneifolia*	X
	Erysimum asperum	X
	Erysimum capitatum var. *capitatum*	O
	Lepidium lasiocarpum	X
	Lepidium oblongum	X
	Lepidium thurberi	O
	Physaria gordonii	O
	Physaria tenella	X
	Schoenocrambe linearifolia	X
	Sisymbrium irio	X
	Thysanocarpus curvipes	X
Cactaceae	*Coryphantha vivipara*	X
	Cylindropuntia arbuscula	O
	Cylindropuntia imbricata X *spinosior*	X
	Cylindropuntia spinosior	X
	Cylindropuntia versicolor	O
	Echinocereus arizonicus	X
	Echinocereus coccineus var. *arizonicus*	X
	Echinocereus fendleri ssp. *rectispinus*	X
	Echinocereus polyacanthus	X
	Echinocereus rigidissimus	O
	Echinocereus triglochidiatus	X
	Echinomastus intertextus	X
	Mammillaria heyderi var. *macdougalii*	O
	Mammillaria wrightii var. *wilcoxii*	X
	Opuntia chlorotica	X
	Opuntia engelmannii var. *engelmannii*	X
	Opuntia macrorhiza var. *macrorhiza*	X
	Opuntia phaeacantha	X
Campanulaceae	*Lobelia cardinalis*	X

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Family	Scientific Name	Voucher
Campanulaceae	*Triodanis perfoliata*	X
Cannabaceae	*Celtis laevigata* var. *reticulata*	O
Caprifoliaceae	*Lonicera albiflora*	X
Caryophyllaceae	*Arenaria lanuginosa* ssp. *saxosa*	O
	Cerastium texanum	X
	Drymaria molluginea	X
	Silene antirrhina	X
	Silene laciniata	X
Commelinaceae	*Commelina dianthifolia*	X
	Tradescantia pinetorum	O
Convolvulaceae	*Calystegia longipes*	O
	Convolvulus equitans	X
	Cuscuta potosina	X
	Evolvulus alsinoides	O
	Evolvulus arizonicus	X
	Evolvulus nuttallianus	X
	Evolvulus sericeus	X
	Ipomoea capillacea	X
	Ipomoea coccinea	O
	Ipomoea costellata	X
	Ipomoea cristulata	X
	Ipomoea hederacea	X
	Ipomoea longifolia	X
	Ipomoea pubescens	U
	Ipomoea purpurea	X
Crassulaceae	*Sedum cockerellii*	O
Cucurbitaceae	*Cucurbita digitata*	X
	Cucurbita foetidissima	X
	Cucurbita palmata	O
	Sicyos ampelophyllus	X
Cupressaceae	*Cupressus arizonica* ssp. *arizonica*	O
	Juniperus coahuilensis	X
	Juniperus deppeana	X
Cyperaceae	*Bulbostylis capillaris*	X
	Bulbostylis funckii	O
	Carex geophila	X
	Cyperus aggregatus	O
	Cyperus dipsaceus	X
	Cyperus fendlerianus	X
	Cyperus mutisii	X
	Cyperus niger	O

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Family	Scientific Name	Voucher
Cyperaceae	*Cyperus pallidicolor*	X
	Cyperus spectabilis	X
	Cyperus sphaerolepis	X
	Cyperus squarrosus	X
	Eleocharis spp.	X
	Lipocarpha micrantha	X
	Schoenoplectus acutus	X
Dryopteridaceae	*Woodsia cochisensis*	X
Equisetaceae	*Equisetum* X *ferrissii*	X
Ericaceae	*Arbutus arizonica*	X
	Arctostaphylos pringlei	O
	Arctostaphylos pungens	X
Euphorbiaceae	*Acalypha neomexicana*	X
	Acalypha ostryifolia	X
	Chamaesyce dioica	X
	Chamaesyce hirta	X
	Chamaesyce hyssopifolia	X
	Chamaesyce prostrata	X
	Chamaesyce revoluta	X
	Chamaesyce serpyllifolia ssp. *serpyllifolia*	O
	Croton pottsii	X
	Croton pottsii var. *pottsii*	O
	Euphorbia bilobata	X
	Euphorbia brachycera	X
	Euphorbia euphosperma	X
	Euphorbia cyathophora	X
	Euphorbia dentata	O
	Euphorbia exstipulata	X
	Euphorbia heterophylla	X
	Euphorbia incisa	O
	Jatropha macrorhiza var. *septemfida*	X
	Tragia nepetifolia	X
	Tragia ramosa	X
Fabaceae	*Acacia angustissima*	X
	Acacia constricta	O
	Acacia greggii	O
	Amorpha fruticosa	O
	Astragalus allochrous var. *playanus*	X
	Astragalus hypoxylus	O
	Astragalus lentiginosus	O
	Astragalus nothoxys	X

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Family	Scientific Name	Voucher
Fabaceae	*Astragalus nuttallianus*	X
	Astragalus thurberi	X
	Caesalpinia gilliesii	U
	Calliandra eriophylla	X
	Calliandra humilis var. *reticulata*	X
	Chamaecrista nictitans	X
	Chamaecrista nictitans var. *leptadenia*	O
	Clitoria mariana	O
	Cologania angustifolia	X
	Cologania pallida	X
	Coursetia caribaea var. *caribaea*	O
	Crotalaria pumila	X
	Crotalaria sagittalis	X
	Dalea albiflora	X
	Dalea brachystachya	X
	Dalea exigua	X
	Dalea filiformis	X
	Dalea grayi	X
	Dalea lachnostachys	X
	Dalea nana var. *carnescens*	X
	Dalea pogonathera	X
	Dalea pulchra	X
	Dalea versicolor var. *sessilis*	X
	Desmanthus cooleyi	X
	Desmodium batocaulon	U
	Desmodium cinerascens	X
	Desmodium neomexicanum	O
	Desmodium retinens	X
	Desmodium rosei	X
	Erythrina flabelliformis	X
	Eysenhardtia orthocarpa	X
	Galactia wrightii var. *mollissima*	X
	Galactia wrightii var. *wrightii*	X
	Hoffmannseggia glauca	O
	Lathyrus graminifolius	X
	Lotus greenei	X
	Lotus humistratus	X
	Lotus mearnsii	X
	Lotus plebeius	X
	Lotus wrightii	X
	Lupinus concinnus	X

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Family	Scientific Name	Voucher
Fabaceae	*Lupinus palmeri*	O
	Macroptilium gibbosifolium	X
	Medicago lupulina	X
	Melilotus indicus	X
	Mimosa aculeaticarpa var. *biuncifera*	O
	Mimosa dysocarpa	X
	Mimosa grahamii	X
	Nissolia wislizeni	X
	Phaseolus acutifolius var. *tenuifolius*	X
	Phaseolus maculatus	X
	Phaseolus ritensis	O
	Prosopis glandulosa	X
	Prosopis velutina	X
	Psoralidium tenuiflorum	X
	Rhynchosia senna var. *texana*	X
	Robinia neomexicana	X
	Senna bauhinioides	O
	Senna hirsuta var. *glaberrima*	X
	Tephrosia thurberi	X
	Tephrosia vicioides	X
	Vicia ludoviciana	X
	Zornia reticulata	O
Fagaceae	*Quercus arizonica*	U
	Quercus chrysolepis	U
	Quercus dunnii	O
	Quercus emoryi	X
	Quercus gambelii	O
	Quercus grisea	X
	Quercus hypoleucoides	X
	Quercus oblongifolia	X
	Quercus pungens	O
	Quercus rugosa	O
	Quercus toumeyi	X
	Quercus turbinella	O
Fouquieriaceae	*Fouquieria splendens*	X
Garryaceae	*Garrya flavescens*	O
	Garrya wrightii	X
Gentianaceae	*Centaurium calycosum*	X
Geraniaceae	*Erodium cicutarium*	X
	Geranium caespitosum var. *parryi*	X
Grossulariaceae	*Ribes spp.*	O

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Family	Scientific Name	Voucher
Hydrangeaceae	*Fendlera rupicola*	X
	Philadelphus microphyllus	X
Hydrophyllaceae	*Nama dichotomum*	X
	Phacelia arizonica	X
	Phacelia caerulea	X
Juglandaceae	*Juglans major*	X
Juncaceae	*Juncus bufonius*	X
	Juncus ensifolius	X
	Juncus saximontanus	X
	Juncus tenuis	X
Krameriaceae	*Krameria erecta*	X
Lamiaceae	*Agastache wrightii*	O
	Hedeoma dentata	X
	Hedeoma nana	X
	Salvia lemmonii	X
	Salvia parryi	X
	Salvia subincisa	X
	Trichostema arizonicum	X
Linaceae	*Linum puberulum*	X
Loasaceae	*Mentzelia albicaulis*	X
	Mentzelia asperula	X
	Mentzelia isolata	X
	Mentzelia montana	X
	Mentzelia multiflora	X
	Mentzelia texana	O
Lythraceae	*Cuphea wrightii*	X
	Lythrum californicum	X
Malpighiaceae	*Aspicarpa hirtella*	X
Malvaceae	*Abutilon parvulum*	X
	Anoda cristata	X
	Malva parviflora	O
	Sida abutifolia	X
	Sida neomexicana	X
	Sida spinosa	X
	Sphaeralcea angustifolia	X
Martyniaceae	*Proboscidea parviflora* ssp. *parviflora*	X
Molluginaceae	*Mollugo verticillata*	X
Moraceae	*Morus microphylla*	O
Nyctaginaceae	*Allionia incarnata*	X
	Boerhavia coccinea	X
	Boerhavia erecta	X

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Family	Scientific Name	Voucher
Nyctaginaceae	*Boerhavia purpurascens*	X
	Mirabilis albida	X
	Mirabilis coccinea	X
	Mirabilis comata	X
	Mirabilis linearis	X
	Mirabilis longiflora	X
Oleaceae	*Fraxinus pennsylvanica*	?
	Fraxinus velutina	X
Onagraceae	*Camissonia chamaenerioides*	X
	Gaura coccinea	X
	Gaura hexandra ssp. *gracilis*	X
	Oenothera albicaulis	X
	Oenothera brachycarpa	X
	Oenothera caespitosa	X
	Oenothera primiveris	X
Orobanchaceae	*Castilleja integra*	X
	Castilleja lanata	O
	Castilleja tenuiflora	X
Oxalidaceae	*Oxalis albicans* ssp. *pilosa*	X
	Oxalis alpina	O
	Oxalis corniculata	X
	Oxalis decaphylla	X
Papaveraceae	*Argemone pleiacantha* ssp. *pleiacantha*	X
	Corydalis aurea	X
	Corydalis curvisiliqua ssp. *occidentalis*	X
Phrymaceae	*Mimulus guttatus*	X
	Mimulus rubellus	X
Phytolaccaceae	*Phytolacca americana*	O
	Phytolacca icosandra	X
Pinaceae	*Pinus discolor*	X
	Pinus pinea	O
	Pseudotsuga menziesii	X
Plantaginaceae	*Brachystigma wrightii*	X
	Maurandella antirrhiniflora	X
	Nuttallanthus texanus	X
	Penstemon barbatus	X
	Penstemon dasyphyllus	O
	Penstemon parryi	X
	Penstemon stenophyllus	X
	Penstemon superbus	X
	Penstemon virgatus	O

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Family	Scientific Name	Voucher
Plantaginaceae	*Plantago patagonica*	X
	Schistophragma intermedia	X
	Veronica peregrina ssp. *xalapensis*	X
Platanaceae	*Platanus wrightii*	X
Poaceae	*Achnatherum eminens*	X
	Agrostis scabra	X
	Aristida adscensionis	X
	Aristida divaricata	X
	Aristida havardii	O
	Aristida pansa	O
	Aristida purpurea var. *nealleyi*	X
	Aristida schiedeana var. *orcuttiana*	X
	Aristida ternipes var. *gentilis*	O
	Aristida ternipes var. *ternipes*	X
	Blepharoneuron tricholepis	O
	Bothriochloa barbinodis	X
	Bouteloua aristidoides	O
	Bouteloua barbata	O
	Bouteloua chondrosioides	X
	Bouteloua curtipendula var. *caespitosa*	O
	Bouteloua eludens	X
	Bouteloua eriopoda	X
	Bouteloua gracilis	X
	Bouteloua hirsuta var. *hirsuta*	O
	Bouteloua radicosa	X
	Bouteloua repens	X
	Bouteloua rothrockii	X
	Bromus anomalus	X
	Bromus catharticus	X
	Bromus ciliatus	X
	Cenchrus spinifex	X
	Chloris virgata	O
	Cynodon dactylon	X
	Dasyochloa pulchella	O
	Digitaria californica	X
	Digitaria cognata	X
	Digitaria sanguinalis	X
	Echinochloa colona	X
	Elionurus barbiculmis	X
	Elymus canadensis	O
	Elymus elymoides ssp. *elymoides*	O

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Family	Scientific Name	Voucher
Poaceae	*Enneapogon desvauxii*	O
	Eragrostis cilianensis	X
	Eragrostis curvula	X
	Eragrostis intermedia	X
	Eragrostis lehmanniana	X
	Eragrostis mexicana ssp. *mexicana*	X
	Eragrostis pectinacea var. *miserrima*	X
	Eragrostis pectinacea var. *pectinacea*	X
	Eragrostis superba	O
	Eriochloa acuminata var. *acuminata*	O
	Eriochloa lemmonii	O
	Erioneuron avenaceum	X
	Hackelochloa granularis	X
	Hesperostipa neomexicana	X
	Heteropogon contortus	X
	Hilaria belangeri	X
	Hordeum murinum ssp. *glaucum*	X
	Koeleria macrantha	O
	Leptochloa dubia	X
	Lolium perenne	X
	Lycurus setosus	X
	Muhlenbergia arizonica	X
	Muhlenbergia emersleyi	X
	Muhlenbergia fragilis	X
	Muhlenbergia glauca	X
	Muhlenbergia longiligula	O
	Muhlenbergia minutissima	O
	Muhlenbergia montana	O
	Muhlenbergia pauciflora	X
	Muhlenbergia porteri	O
	Muhlenbergia repens	O
	Muhlenbergia richardsonis	O
	Muhlenbergia rigens	X
	Muhlenbergia rigida	X
	Muhlenbergia sinuosa	X
	Muhlenbergia tenuifolia	X
	Panicum capillare	O
	Panicum hallii	X
	Panicum hirticaule var. *hirticaule*	X
	Panicum obtusum	X
	Pappophorum spp.	O

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Family	Scientific Name	Voucher
Poaceae	*Paspalum setaceum*	X
	Piptochaetium fimbriatum	X
	Piptochaetium pringlei	X
	Pleuraphis mutica	O
	Poa fendleriana ssp. *fendleriana*	X
	Polypogon monspeliensis	O
	Schizachyrium cirratum	X
	Schizachyrium sanguineum	X
	Setaria grisebachii	X
	Setaria leucopila	X
	Sorghum halepense	X
	Sporobolus wrightii	X
	Trachypogon secundus	X
	Tridens muticus var. *muticus*	X
	Tripsacum lanceolatum	X
	Triticum aestivum	X
	Urochloa arizonica	X
	Vulpia octoflora var. *hirtella*	X
	Vulpia octoflora var. *octoflora*	X
	Zuloagaea bulbosum	X
Polemoniaceae	*Eriastrum diffusum*	X
	Gilia flavocincta ssp. *australis*	X
	Gilia mexicana	X
	Ipomopsis longiflora	X
	Ipomopsis thurberi	X
Polygalaceae	*Polygala hemipterocarpa*	X
	Polygala obscura	X
Polygonaceae	*Eriogonum abertianum*	X
	Eriogonum palmerianum	O
	Eriogonum polycladon	X
	Eriogonum wrightii var. *wrightii*	X
	Polygonum aviculare	O
Portulacaceae	*Calandrinia ciliata*	X
	Cistanthe ambigua	O
	Phemeranthus aurantiacus	X
	Phemeranthus brevicaulis	X
	Phemeranthus parviflorus	X
	Portulaca oleracea	X
	Portulaca pilosa	O
	Portulaca suffrutescens	X
	Portulaca umbraticola	X

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Family	Scientific Name	Voucher
Portulacaceae	*Talinum paniculatum*	X
Pteridaceae	*Adiantum capillus-veneris*	X
	Argyrochosma limitanea	X
	Argyrochosma limitanea ssp. *limitanea*	O
	Astrolepis cochisensis ssp. *cochisensis*	X
	Astrolepis integerrima	X
	Astrolepis sinuata ssp. *sinuata*	O
	Bommeria hispida	X
	Cheilanthes bonariensis	X
	Cheilanthes eatonii	X
	Cheilanthes fendleri	X
	Cheilanthes lendigera	O
	Cheilanthes lindheimeri	X
	Cheilanthes tomentosa	X
	Cheilanthes villosa	X
	Cheilanthes wootonii	X
	Cheilanthes wrightii	X
	Notholaena grayi	X
	Notholaena standleyi	X
	Pellaea atropurpurea	X
Ranunculaceae	*Anemone tuberosa*	X
	Thalictrum fendleri	X
Rhamnaceae	*Ceanothus fendleri*	X
	Ceanothus greggii	O
Rosaceae	*Cercocarpus montanus* var. *glaber*	O
	Cercocarpus montanus var. *paucidentatus*	X
	Prunus armeniaca	X
	Prunus serotina var. *rufula*	X
	Prunus serotina var. *virens*	O
	Purshia stansburiana	X
	Pyracantha koidzumii	X
Rubiaceae	*Bouvardia ternifolia*	X
	Crusea diversifolia	X
	Diodia teres	X
	Galium aparine	O
	Galium mexicanum ssp. *asperrimum*	X
	Galium microphyllum	X
	Galium wrightii	X
	Houstonia wrightii	X
	Mitracarpus breviflorus	X
Rutaceae	*Ptelea trifoliata*	O

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Family	Scientific Name	Voucher
Salicaceae	*Populus fremontii* ssp. *fremontii*	X
	Salix gooddingii	X
Santalaceae	*Comandra umbellata* ssp. *pallida*	X
	Phoradendron capitellatum	O
	Phoradendron coryae	X
	Phoradendron juniperinum	O
	Phoradendron villosum	O
Sapindaceae	*Sapindus saponaria* var. *drummondii*	X
Saxifragaceae	*Heuchera sanguinea*	X
Simaroubaceae	*Ailanthus altissima*	X
Solanaceae	*Datura quercifolia*	X
	Datura stramonium	O
	Datura wrightii	X
	Margaranthus solanaceus	X
	Nicotiana obtusifolia var. *obtusifolia*	X
	Physalis crassifolia	X
	Physalis hederifolia	O
	Physalis longifolia var. *longifolia*	X
	Solanum adscendens	X
	Solanum douglasii	X
	Solanum elaeagnifolium	X
	Solanum jamesii	X
	Solanum rostratum	X
Sterculiaceae	*Ayenia compacta*	O
	Ayenia filiformis	X
Urticaceeae	*Parietaria hespera*	X
Valerianaceae	*Valeriana sorbifolia*	X
Verbenaceae	*Aloysia wrightii*	X
	Bouchea prismatica	X
	Glandularia bipinnatifida var. *bipinnatifida*	X
	Glandularia bipinnatifida var. *ciliata*	O
	Tetraclea coulteri	X
	Verbena bracteata	O
Vitaceae	*Vitis arizonica*	X
Zygophyllaceae	*Kallstroemia parviflora*	X
	Tribulus terrestris	X
TOTAL	**651 taxa**	

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Family	Scientific Name	Voucher
Acanthaceae	*Anisacanthus thurberi*	X
	Carlowrightia arizonica	X
Aizoaceae	*Trianthema portulacastrum*	X
Amaranthaceae	*Amaranthus fimbriatus*	U
	Amaranthus palmeri	X
	Atriplex canescens	X
	Atriplex elegans	X
	Chenopodium desiccatum	O
	Chenopodium fremontii	X
	Chenopodium leptophyllum	O
	Chenopodium murale	O
	Chenopodium pratericola	X
	Chenopodium watsonii	X
	Froelichia arizonica	X
	Gomphrena caespitosa	X
	Guilleminea densa	X
	Krascheninnikovia lanata	X
	Salsola kali	X
	Salsola tragus	O
Amaryllidaceae	*Allium acuminatum*	O
	Allium macropetalum	X
	Zephyranthes longifolia	X
Anacardiaceae	*Rhus aromatica*	X
	Rhus microphylla	X
	Rhus virens var. *choriophylla*	X
	Toxicodendron radicans	X
Apiaceae	*Cymopterus multinervatus*	X
	Daucus pusillus	X
	Lomatium nevadense	X
	Pseudocymopterus montanus	O
	Spermolepis echinata	X
Apocynaceae	*Asclepias asperula* ssp. *capricornu*	X
	Asclepias engelmanniana	O
	Asclepias macrotis	O
	Asclepias nyctaginifolia	X
	Macrosiphonia brachysiphon	X
	Matelea producta	X
	Sarcostemma crispum	X
	Sarcostemma cynanchoides ssp. *cynanchoides*	O
	Sarcostemma cynanchoides ssp. *heterophyllum*	O
Aristolochiaceae	*Aristolochia watsonii*	X
Asparagaceae	*Agave palmeri*	X

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Family	Scientific Name	Voucher
Asparagaceae	*Agave parryi*	X
	Dasylirion wheeleri	X
	Dichelostemma capitatum ssp. *capitatum*	X
	Echeandia flavescens	U
	Nolina microcarpa	X
	Yucca baccata	X
	Yucca elata	X
	Yucca madrensis	U
Asteraceae	*Acourtia nana*	X
	Acourtia wrightii	X
	Ambrosia confertiflora	X
	Artemisia dracunculus	X
	Artemisia ludoviciana	X
	Baccharis bigelovii	X
	Baccharis pteronioides	X
	Baccharis salicifolia	X
	Baccharis sarothroides	X
	Baccharis sergiloides	U
	Baccharis thesioides	O
	Baccharis wrightii	O
	Bahia absinthifolia	X
	Bahiopsis parishii	O
	Baileya multiradiata	X
	Baileya pleniradiata	O
	Berlandiera lyrata	X
	Bidens leptocephala	X
	Brickellia baccharidea	O
	Brickellia californica	X
	Brickellia eupatorioides var. *chlorolepis*	X
	Brickellia venosa	X
	Carminatia tenuiflora	X
	Carphochaete bigelovii	X
	Chaenactis stevioides	O
	Chaetopappa ericoides	X
	Cirsium neomexicanum	X
	Cirsium ochrocentrum	O
	Conyza canadensis	X
	Dieteria canescens	X
	Ericameria laricifolia	X
	Ericameria nauseosa var. *latisquamea*	O
	Ericameria nauseosa var. *nauseosa*	U
	Erigeron colomexicanus	O

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Family	Scientific Name	Voucher
Asteraceae	*Erigeron divergens*	O
	Erigeron oreophilus	X
	Flourensia cernua	O
	Gaillardia pulchella	X
	Gnaphalium spp.	O
	Gutierrezia microcephala	O
	Gutierrezia sarothrae	X
	Gymnosperma glutinosum	X
	Hedosyne ambrosiifolia	X
	Helianthus annuus	X
	Helianthus petiolaris	O
	Heliomeris multiflora var. *multiflora*	U
	Heterosperma pinnatum	X
	Heterotheca subaxillaris	U
	Hymenoclea monogyra	X
	Hymenothrix wislizeni	X
	Hymenoxys ambigens var. *floribunda*	O
	Isocoma tenuisecta	X
	Lactuca serriola	X
	Laennecia coulteri	O
	Lasthenia californica	O
	Leuciva dealbata	X
	Machaeranthera tagetina	X
	Malacothrix fendleri	X
	Packera neomexicana	X
	Packera quercetorum	X
	Parthenium incanum	X
	Pectis filipes	X
	Pectis longipes	X
	Pectis prostrata	X
	Pseudognaphalium canescens ssp. *canescens*	X
	Psilostrophe cooperi	O
	Psilostrophe sparsiflora	X
	Psilostrophe tagetina	X
	Rafinesquia neomexicana	O
	Ratibida columnifera	X
	Sanvitalia abertii	X
	Schkuhria pinnata	X
	Senecio flaccidus var. *douglasii*	X
	Senecio spartioides var. *multicapitatus*	X
	Solidago velutina	X
	Sonchus oleraceus	O

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Family	Scientific Name	Voucher
Asteraceae	*Stephanomeria pauciflora*	X
	Tagetes micrantha	X
	Thelesperma longipes	X
	Thelesperma megapotamicum	X
	Thymophylla acerosa	X
	Thymophylla pentachaeta	X
	Trixis californica	X
	Uropappus lindleyi	O
	Verbesina encelioides	X
	Verbesina rothrockii	X
	Viguiera dentata	X
	Xanthisma gracilis	O
	Xanthisma spinulosum	X
	Zinnia acerosa	X
	Zinnia grandiflora	X
Bignoniaceae	*Chilopsis linearis*	X
Boraginaceae	*Amsinckia menziesii* var. *intermedia*	O
	Cryptantha crassisepala	X
	Cryptantha micrantha	O
	Cryptantha pterocarya	X
	Lappula occidentalis var. *cupulata*	O
	Lappula occidentalis var. *occidentalis*	O
	Lithospermum cobrense	O
	Lithospermum incisum	O
	Pectocarya platycarpa	O
	Pectocarya recurvata	O
	Plagiobothrys arizonicus	X
	Tiquilia canescens	X
Brassicaceae	*Boechera perennans*	X
	Descurainia pinnata	X
	Descurainia sophia	X
	Draba cuneifolia	X
	Draba standleyi	O
	Hesperidanthus linearifolius	X
	Lepidium lasiocarpum var. *lasiocarpum*	X
	Lepidium thurberi	X
	Lepidium virginicum var. *medium*	O
	Pennellia longifolia	X
	Physaria fendleri	X
	Physaria gordonii	X
	Physaria tenella	U
	Sisymbrium irio	X

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Family	Scientific Name	Voucher
Brassicaceae	*Streptanthella longirostris*	O
	Streptanthus carinatus ssp. *arizonicus*	X
	Thelypodium wrightii	X
Cactaceae	*Coryphantha vivipara*	U
	Cylindropuntia leptocaulis	X
	Cylindropuntia spinosior	X
	Echinocereus coccineus	O
	Echinocereus fasciculatus	O
	Echinocereus fendleri ssp. *rectispinus*	U
	Echinocereus ledingii	O
	Echinocereus rigidissimus	X
	Echinocereus triglochidiatus	O
	Echinomastus intertextus var. *intertextus*	U
	Ferocactus wislizeni	X
	Mammillaria grahamii	U
	Mammillaria heyderi	U
	Mammillaria macdougalii	X
	Opuntia chlorotica	X
	Opuntia engelmannii	X
	Opuntia macrocentra var. *macrocentra*	X
	Opuntia phaeacantha	X
	Opuntia santa-rita	O
	Opuntia X *curvospina*	U
	Peniocereus greggii var. *greggii*	O
Campanulaceae	*Nemacladus glanduliferus*	X
	Triodanis perfoliata	O
Cannabaceae	*Celtis ehrenbergiana*	O
	Celtis laevigata var. *reticulata*	O
Caryophyllaceae	*Silene antirrhina*	O
Cleomaceae	*Polanisia dodecandra* ssp. *trachysperma*	X
Commelinaceae	*Commelina dianthifolia*	X
Convolvulaceae	*Convolvulus arvensis*	O
	Convolvulus equitans	X
	Evolvulus nuttallianus	X
	Evolvulus sericeus	X
	Ipomoea barbatisepala	O
	Ipomoea coccinea	X
	Ipomoea hederacea	O
	Ipomoea purpurea	U
Crassulaceae	*Sedum cockerellii*	O
Cucurbitaceae	*Apodanthera undulata*	X
	Cucurbita digitata	X

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Cucurbitaceae	*Cucurbita foetidissima*	X
	Marah gilensis	O
Cupressaceae	*Juniperus coahuilensis*	X
	Juniperus deppeana	X
	Juniperus monosperma	X
Cyperaceae	*Cyperus esculentus*	O
	Cyperus sphaerolepis	U
	Cyperus squarrosus	U
Dryopteridaceae	*Woodsia cochisensis*	U
Ephedraceae	*Ephedra trifurca*	X
Ericaceae	*Arctostaphylos pringlei*	O
	Arctostaphylos pungens	X
Euphorbiaceae	*Acalypha neomexicana*	X
	Chamaesyce albomarginata	X
	Chamaesyce hyssopifolia	X
	Chamaesyce revoluta	X
	Chamaesyce serpyllifolia ssp. *serpyllifolia*	U
	Chamaesyce serrula	X
	Chamaesyce stictospora	O
	Croton pottsii var. *pottsii*	X
	Euphorbia bilobata	X
	Euphorbia dentata	X
	Euphorbia exstipulata	X
	Euphorbia heterophylla	X
	Tragia ramosa	X
Fabaceae	*Acacia angustissima*	X
	Acacia constricta	O
	Acacia greggii	X
	Amorpha fruticosa	X
	Astragalus allochrous	X
	Astragalus arizonicus	X
	Astragalus calycosus	X
	Astragalus nothoxys	X
	Astragalus nuttallianus	X
	Astragalus tephrodes	X
	Astragalus thurberi	X
	Calliandra eriophylla	X
	Calliandra humilis var. *reticulata*	X
	Canavalia ensiformis	U
	Chamaecrista nictitans	X
	Crotalaria pumila	X
	Dalea albiflora	X

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Family	Scientific Name	Voucher
Fabaceae	*Dalea candida* var. *oligophylla*	X
	Dalea formosa	X
	Dalea nana var. *nana*	X
	Dalea pogonathera	X
	Dalea pringlei	X
	Dalea versicolor var. *sessilis*	X
	Dalea wrightii	X
	Desmanthus cooleyi	X
	Desmodium neomexicanum	X
	Desmodium procumbens	X
	Erythrina flabelliformis	O
	Galactia wrightii var. *mollissima*	O
	Hoffmannseggia drepanocarpa	X
	Hoffmannseggia glauca	X
	Lotus greenei	X
	Lotus humistratus	X
	Lotus plebeius	O
	Lotus rigidus	O
	Lotus wrightii	O
	Lupinus brevicaulis	X
	Lupinus concinnus	X
	Lupinus sparsiflorus	O
	Macroptilium gibbosifolium	X
	Marina calycosa	O
	Mimosa aculeaticarpa var. *biuncifera*	X
	Phaseolus acutifolius var. *tenuifolius*	O
	Prosopis glandulosa var. *torreyana*	O
	Prosopis velutina	X
	Rhynchosia senna var. *texana*	X
	Robinia neomexicana	X
	Senna bauhinioides	O
	Senna covesii	O
	Vicia ludoviciana ssp. *ludoviciana*	O
Fagaceae	*Quercus arizonica*	X
	Quercus dunnii	O
	Quercus emoryi	X
	Quercus grisea	X
	Quercus hypoleucoides	X
	Quercus pungens	X
	Quercus rugosa	X
	Quercus toumeyi	X
	Quercus turbinella	X

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Family	Scientific Name	Voucher
Fouquieriaceae	*Fouquieria splendens*	X
Garryaceae	*Garrya flavescens*	O
	Garrya wrightii	X
Geraniaceae	*Erodium cicutarium*	X
	Erodium texanum	X
Hydrangeaceae	*Fendlera rupicola*	X
Hydrophyllaceae	*Nama hispidum*	O
	Phacelia arizonica	X
	Phacelia congesta	O
	Phacelia crenulata	X
	Phacelia rupestris	X
Juglandaceae	*Juglans major*	X
Juncaceae	*Juncus bufonius*	X
	Juncus drummondii	O
	Juncus saximontanus	X
	Juncus tenuis	X
Krameriaceae	*Krameria erecta*	O
	Krameria lanceolata	X
Lamiaceae	*Hedeoma drummondii*	X
	Hedeoma hyssopifolia	O
	Hedeoma nana	X
	Hedeoma oblongifolia	X
	Lamium amplexicaule	X
	Marrubium vulgare	X
	Salvia columbariae	X
	Salvia henryi	X
	Salvia lemmonii	O
	Salvia subincisa	X
	Stachys coccinea	X
	Trichostema arizonicum	X
Liliaceae	*Calochortus ambiguus*	O
Linaceae	*Linum lewisii*	X
	Linum puberulum	X
	Linum usitatissimum	X
Loasaceae	*Cevallia sinuata*	X
	Mentzelia albicaulis	X
	Mentzelia multiflora	O
Malpighiaceae	*Janusia gracilis*	X
Malvaceae	*Abutilon parvulum*	X
	Ayenia filiformis	X
	Gossypium thurberi	O
	Malvella lepidota	X

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Family	Scientific Name	Voucher
Malvaceae	*Rhynchosida physocalyx*	X
	Sida abutifolia	X
	Sphaeralcea hastulata	O
	Sphaeralcea laxa	X
	Sphaeralcea wrightii	O
Martyniaceeae	*Proboscidea parviflora*	U
Moraceae	*Morus microphylla*	X
Nyctaginaceae	*Allionia incarnata*	X
	Boerhavia coccinea	X
	Boerhavia coulteri	O
	Boerhavia erecta	O
	Boerhavia intermedia	O
	Boerhavia purpurascens	X
	Boerhavia spicata	X
	Mirabilis albida	X
	Mirabilis coccinea	X
	Mirabilis comata	X
	Mirabilis laevis var. *villosa*	X
	Mirabilis linearis	X
	Mirabilis longiflora	X
	Mirabilis multiflora	X
Oleaceae	*Fraxinus velutina*	X
	Menodora scabra	X
Onagraceae	*Calylophus hartwegii*	X
	Camissonia californica	O
	Camissonia contorta	X
	Epilobium canum ssp. *latifolium*	X
	Epilobium ciliatum ssp. *ciliatum*	O
	Gaura hexandra ssp. *gracilis*	X
	Oenothera brachycarpa	X
	Oenothera caespitosa	X
	Oenothera elata ssp. *hirsutissima*	O
	Oenothera elata ssp. *hookeri*	O
	Oenothera pallida ssp. *runcinata*	O
	Oenothera primiveris	X
Orobanchaceae	*Castilleja austromontana*	X
	Castilleja integra	X
	Castilleja lanata	X
	Castilleja sessiliflora	X
	Castilleja tenuiflora	O
	Orobanche cooperi	O
	Orobanche ludoviciana	X

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Family	Scientific Name	Voucher
Papaveraceae	*Argemone pleiacantha*	X
	Corydalis aurea	X
	Corydalis curvisiliqua ssp. *occidentalis*	O
	Eschscholzia californica ssp. *mexicana*	X
Phrymaceae	*Mimulus guttatus*	X
	Mimulus rubellus	O
Pinaceae	*Pinus discolor*	U
	Pinus edulis	X
	Pinus monophylla var. *fallax*	U
Plantaginaceae	*Linaria dalmatica*	X
	Maurandella antirrhiniflora	X
	Penstemon barbatus	X
	Penstemon linarioides	X
	Penstemon ramosus	O
	Plantago patagonica	X
	Veronica peregrina	X
Platanaceae	*Platanus wrightii*	O
Poaceae	*Achnatherum eminens*	O
	Aristida adscensionis	X
	Aristida pansa	X
	Aristida purpurea var. *longiseta*	X
	Aristida purpurea var. *nealleyi*	X
	Aristida purpurea var. *purpurea*	O
	Aristida ternipes var. *gentilis*	X
	Aristida ternipes var. *ternipes*	X
	Avena fatua	O
	Bothriochloa barbinodis	X
	Bothriochloa saccharoides	X
	Bouteloua aristidoides	X
	Bouteloua barbata	X
	Bouteloua chondrosioides	X
	Bouteloua curtipendula	X
	Bouteloua eriopoda	X
	Bouteloua gracilis	X
	Bouteloua hirsuta	X
	Bouteloua repens	X
	Bromus carinatus	O
	Bromus rubens	X
	Bromus tectorum	X
	Cenchrus spinifex	X
	Chloris virgata	X
	Cynodon dactylon	X

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Family	Scientific Name	Voucher
Poaceae	*Dasyochloa pulchella*	X
	Digitaria californica	X
	Digitaria cognata var. *cognata*	O
	Digitaria sanguinalis	X
	Echinochloa colona	X
	Echinochloa crus-galli	X
	Elionurus barbiculmis	O
	Elymus elymoides	X
	Enneapogon desvauxii	X
	Eragrostis cilianensis	X
	Eragrostis curvula	X
	Eragrostis intermedia	X
	Eragrostis lehmanniana	X
	Eragrostis pectinacea var. *miserrima*	O
	Eragrostis pectinacea var. *pectinacea*	O
	Eriochloa acuminata	X
	Eriochloa lemmonii	X
	Erioneuron avenaceum	X
	Hesperostipa neomexicana	X
	Heteropogon contortus	X
	Hilaria belangeri	X
	Hordeum murinum ssp. *leporinum*	O
	Koeleria macrantha	X
	Leptochloa dubia	X
	Lycurus phleoides	X
	Lycurus setosus	X
	Muhlenbergia arenacea	X
	Muhlenbergia arenicola	X
	Muhlenbergia emersleyi	X
	Muhlenbergia fragilis	X
	Muhlenbergia porteri	X
	Muhlenbergia repens	X
	Muhlenbergia rigens	X
	Panicum capillare	X
	Panicum hallii	X
	Panicum hirticaule	X
	Panicum obtusum	X
	Pleuraphis mutica	X
	Poa annua	X
	Poa bigelovii	X
	Polypogon viridis	O
	Schizachyrium cirratum	O

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Family	Scientific Name	Voucher
Poaceae	*Scleropogon brevifolius*	X
	Setaria grisebachii	X
	Setaria leucopila	X
	Setaria vulpiseta	O
	Sorghum halepense	O
	Sporobolus airoides	X
	Sporobolus contractus	X
	Sporobolus cryptandrus	X
	Sporobolus wrightii	O
	Trachypogon secundus	O
	Tragus berteronianus	O
	Tridens muticus	X
	Trisetum interruptum	X
	Urochloa arizonica	X
	Vulpia octoflora var. *hirtella*	X
	Vulpia octoflora var. *octoflora*	X
Polemoniaceae	*Eriastrum diffusum*	O
	Gilia mexicana	X
	Gilia ophthalmoides	X
	Gilia sinuata	O
	Ipomopsis longiflora	X
	Ipomopsis multiflora	X
	Leptosiphon aureus ssp. *aureus*	X
	Microsteris gracilis ssp. *gracilis*	O
	Phlox nana	X
	Phlox triovulata	O
Polygalaceae	*Polygala barbeyana*	X
	Polygala macradenia	O
	Eriogonum abertianum	X
	Eriogonum deflexum	X
	Eriogonum polycladon	X
	Eriogonum wrightii	X
	Polygonum convolvulus	O
	Rumex crispus	X
	Rumex hymenosepalus	X
Portulacaceae	*Phemeranthus aurantiacus*	X
	Phemeranthus parviflorus	X
	Portulaca halimoides	O
	Portulaca oleracea	O
	Portulaca suffrutescens	X
	Portulaca umbraticola	X
Primulaceae	*Androsace occidentalis*	O

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Family	Scientific Name	Voucher
Pteridaceae	*Argyrochosma limitanea* ssp. *limitanea*	O
	Astrolepis sinuata ssp. *sinuata*	O
	Bommeria hispida	X
	Cheilanthes eatonii	X
	Cheilanthes lindheimeri	X
	Cheilanthes wootonii	X
	Cheilanthes wrightii	X
	Notholaena standleyi	O
	Pellaea truncata	X
Ranunculaceae	*Anemone tuberosa*	X
	Clematis drummondii	O
	Delphinium wootonii	O
Rhamnaceae	*Ceanothus fendleri*	O
	Ceanothus greggii	X
	Condalia warnockii var. *kearneyana*	X
	Frangula californica ssp. *californica*	O
	Frangula californica ssp. *ursina*	O
	Ziziphus obtusifolia var. *canescens*	X
Rosaceae	*Cercocarpus montanus* var. *argenteus*	O
	Cercocarpus montanus var. *glaber*	O
	Cercocarpus montanus var. *paucidentatus*	X
	Fallugia paradoxa	X
	Purshia mexicana	U
Rubiaceae	*Bouvardia ternifolia*	X
	Diodia teres	X
	Galium proliferum	X
	Galium stellatum	X
	Galium wrightii	X
	Houstonia rubra	X
Rutaceae	*Ptelea trifoliata* ssp. *angustifolia*	X
	Thamnosma texana	X
Salicaceae	*Populus fremontii* ssp. *fremontii*	U
	Salix bonplandiana	O
	Salix exigua	X
	Salix gooddingii	X
Santalaceae	*Comandra umbellata* ssp. *pallida*	O
	Phoradendron californicum	X
	Phoradendron capitellatum	O
	Phoradendron coryae	X
Sapindaceae	*Sapindus saponaria*	X
Sapotaceae	*Sideroxylon lanuginosum*	X
Saxifragaceae	*Heuchera sanguinea*	X

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Family	Scientific Name	Voucher
Scrophulariaceae	*Verbascum virgatum*	X
Solanaceae	*Chamaesaracha coronopus*	O
	Chamaesaracha sordida	X
	Datura wrightii	X
	Lycium fremontii	O
	Lycium pallidum	X
	Margaranthus solanaceus	X
	Nicotiana obtusifolia var. *obtusifolia*	X
	Physalis acutifolia	X
	Physalis hederifolia var. *fendleri*	X
	Physalis longifolia var. *longifolia*	O
	Solanum americanum	X
	Solanum elaeagnifolium	X
Tamaricaceae	*Tamarix spp.*	O
Verbenaceae	*Aloysia wrightii*	X
	Glandularia bipinnatifida var. *bipinnatifida*	O
	Glandularia bipinnatifida var. *ciliata*	X
	Glandularia gooddingii	U
	Tetraclea coulteri	X
	Verbena gracilis	X
Violaceae	*Hybanthus verticillatus*	O
Vitaceae	*Vitis arizonica*	X
Zygophyllaceae	*Kallstroemia grandiflora*	X
	Kallstroemia parviflora	X
	Larrea tridentata	X
	Tribulus terrestris	X
TOTAL	**572 TAXA**	

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Butterflies & Moths (Lepidoptera)					
Arizona giant skipper (Hesperiidae: *Agathymus aryxna*)	FS-S TNC-G3 This species has been proposed for state listing, but too little information exists to make a ruling.	CHIR ? FOBO ? CORO ?	Associated with agaves, especially *Agave palmeri,* in grasslands and rocky canyons, 4585-7642 ft, throughout Coronado National Forest. Larvae bore into agave leaves and stems.	Loss of host (agaves, esp. *A. palmeri*); deterioration of grassland habitat.	Found throughout SE Arizona. Colonies should be identified and monitored where threats to habitat are possible. Although no published records exist within the boundaries of CHIR, FOBO or CORO, there is a high probability that this species occurs at one or more of these sites.
Arizona metalmark (Riodinidae: *Calephelis arizonensis*)	TNC-G2	CHIR ? FOBO ? CORO ?	Riparian canyons along desert foothills. Feeds on riparian vegetation.	Degradation of riparian habitats (e.g., livestock, drought); climate change (e.g., climate drying).	Although no published records exist within the boundaries of CHIR, FOBO or CORO, there is a high probability that this species occurs at one or more of these sites.
Arizona viceroy, obsolete viceroy, Hulst's admiral (Nymphalidae: *Limenitis archippus obsoleta*; = *Basilarchia archippus obsoleta*-the "western viceroy")	FS-S NS-vulnerable	CHIR ? CORO ?	Riparian areas below 5900 ft; larvae rely on willows as food plants (*Salix gooddingii* in the Coronado National Forest).	Degradation or loss of wetlands and riparian areas (e.g., livestock, drought, over-draft, invasive salt cedar); climate change (e.g. climate drying).	Wide ranging in the Southwest and into northwestern Mexico. Although no published records exist within the boundaries of CHIR or CORO, there is a high probability that this species occurs at both sites (e.g., Montezuma, Rhyolite, and Bontia, Canyons).
Biederman's astylis (Notodontidae: *Astylis bierdermani*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	N.A.	Presence in CHIR and CORO unknown.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Chiricahua pine white, Terloot's white, Mexican pine white (Pieridae: *Neophasia terlootii*)	TNC-G3	CHIR ? CORO ?	Colonies have been reported only from pine forests >6233 ft. Larvae are reported to eat leaves of ponderosa pine and Englemann spruce. U.S. records from Pinaleños, Catalinas, Santa Ritas, Huachucas and Chiricahuas.	Threats to host plants (conifers), including pine beetle infestations, fire, and climate warming/ drying.	Very little is known about the biology of this rare, tropical, canopy-dwelling species, which ranges south at least to Jalisco (Mexico). Although no published records exist within the boundaries of CHIR or CORO, there is a probability that this species occurs at one or both sites.
Crescent metalmark, Chiricahua metalmark (Riodinidae: *Apodemia phyciodoides*)	FS-S NS-imperiled	CHIR	Streambeds in steep mountains in lower pine zones and oak woodlands.	Degradation of riparian habitats (e.g., livestock, drought); climate change (e.g. climate drying).	Described from 2 individuals collected near Paradise in the Chiricahua Mtns, ~1915, and not collected in the U.S. since 1924; presumed extirpated in the U.S., although some collectors feel small populations may still exist.
Cyna blue (Lycaenidae*: Zizula cyna*)	FS-S	CORO ?	One or two breeding populations have been reported from Sawmill Canyon (Garden Canyon), Huachucas, 5500 and 7000 ft.	Habitat degradation; loss of "host" plants in the genus *Anisacanthus*.	A very small butterfly about which almost nothing is known. Rare throughout its range (SE Arizona to central Texas; Chihuahua). Although no published records exist within the boundaries of CORO, there is a good possibility that this species occurs there.
Cyneas checkerspot, black checkerspot (Nymphalidae: *Chlosyne* (*Thessalia*) *cyneas*)	FS-S	CHIR ? CORO ?	Oak woodlands. Huachucas (uncommon), Chiricahuas and Santa Ritas (rare), Pena Blanca Lake (rare).	Habitat degradation.	Collection records indicate population sizes fluctuate greatly from year to year. Although no published records exist within the boundaries of CHIR or CORO, there is a good possibility that this species occurs at both sites.
Delicate oligocentrid (Notodontidae: *Oligocentria delicata*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	N.A.	Presence in CHIR and CORO unknown.

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Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Four-spotted skipperling (Hesperiidae: *Piruna polingii*)	NS-imperiled. Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	Moist woodland openings with lush vegetation, meadows, and ravines. Central New Mexico and eastern Arizona, south onto the Mexican Plateau.	Habitat degradation.	Presence in CHIR unknown.
Huachuca giant skipper, Evans' giant skipper (Hesperiidae: *Agathymus evansi*)	FS-S TNC-G1 NS-imperiled Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CHIR ? CORO ?	Known from only a few populations in the Chiricahua and Huachuca Mtns; adults in oak-pine-juniper woodlands above 5900 ft elevation; larvae bore into agave leaves and stems.	Livestock grazing; fire; loss of host plant (*A. parryi* var. *huachucensis*).	Reliant upon presence of host plant, *Agave parryi* var. *huachucensis*; larvae live in agave, but adults probably do not feed. Not yet reported from CHIR or CORO, but very possibly there (e.g., Montezuma and Yaqui Canyons should be surveyed).
Lee's noctuid moth (Noctuidae: *Lithophane leeae*)	None	CHIR ?	Known only from the type locality: Onion Saddle, 7700 ft, Chiricahua Mountains	Habitat degradation.	This apparently rare species was described in 2009 from a single specimen, collected in just before the onset of summer monsoon season. Although not yet reported from CHIR, it may well occur there.
Bluish fritillary, blue silverspot, Nokomis' fritillary (Nymphalidae: *Speyeria nokomis coerulescens*)	FS-S Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CHIR?	Poorly known. "Spring-fed meadows; violet-laden, fern-covered hillsides above moist canyon bottoms in pine forest." Records are all from above 7000 ft.	Degradation of wetlands (e.g., livestock, drought); destruction of habitat (e.g., loss of meadows and violet populations); climate change (e.g., climate drying).	Historically from the Catalinas and Santa Ritas, south through the Huachucas, and on to Durango (Mexico); no confirmed records in the U.S. since 1938 – apparently extirpated north of the border but should be watched for, especially around Silver Spur Spring (CHIR) and Apache Spring (FOBO).

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Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Patagonia eyed silkmoth (Saturniidae: *Automeris patagoniensis*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	N.A.	Presence in CHIR and CORO unknown.
Four-spotted skipperling, Poling's piruna (Notodontidae: *Piruna polingii*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	N.A.	Presence in CHIR and CORO unknown.
Royal moth (Satruniidae: *Sphingicampa raspa*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	N.A.	N.A.	Presence in CORO unknown.
Scudder's duskywing skipper, Arizona duskywing skipper (Hesperiidae: *Erynnis scudderi*)	FS-S TNC-G3 This species has been proposed for both federal and state listing, but too little information exists to make a ruling.	CHIR ? CORO ?	Oak woodlands >2000 ft.	Habitat deterioration.	Records exist from the Dragoon, Huachuca, Chiricahua, Patagonia, Baboquivari, and Animas Mountains. Although no records exist within the boundaries of CHIR or CORO, there is a probability that this species occurs there.

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Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Smith's sphinx moth (Sphingidae: *Sphinx smithi*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	N.A.	N.A.	Presence in CORO unknown.
Spotted skipperling (Hesperiidae: *Piruna polingii*)	FS-S. Collection records suggest it is becoming very rare in southern AZ (still abundant in White Mtns).	CHIR ? CORO ?	6500-6800 ft, in canyons in Chiricahuas and Huachucas; breeds in moist areas.	Drought; climate change (e.g. climate drying).	Although no records exist within the boundaries of CHIR or CORO, there is a probability that this species occurs there.
Sunrise skipper, Prittwitz's skipper (Hesperiidae: *Adopaeoides prittwitzi*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	A ciénega specialist known from springs in SE Arizona and SW New Mexico, including the Gray Ranch. *A. prittwitzi* caterpillars are only known to feed on knotgrass (*Paspalum distichum*).	Drought; climate change (e.g. climate drying); degradation of ciénega & springs habitats.	Presence in CORO undetermined.
Vitelline skipper (Hesperiidae: *Poanes melane vitellina*)	FS-S. Collection records suggest this subspecies is rare.	CHIR ?	~7000 ft. Pinaleños, Chiricahuas, Huachucas, Santa Ritas.	Habitat degradation.	A rare species; usually seen in late spring. Although no records exist within the boundaries of CHIR or CORO, there is a probability that this species occurs at least in CHIR.
Ursine giant skipper (Hesperiidae: *Megathymus ursus ursus*)	TNC-G3 NS-vulnerable This species has been proposed for federal listing, but too little information exists to make a ruling.	CHIR ? FOBO ? CORO ?	High-elevation desertscrub and low-elevation oak woodlands (3937-8406 ft), where the host plants are found (*Yucca schottii* and *Y. baccata*)	Habitat deterioration; loss of yuccas from habitat.	This is a rare species lacking good biological data. Although no published records exist within the boundaries of CHIR, FOBO or CORO, there is a reasonable probability that this species occurs at all three sites. The CHIR Invertebrate Catalog lists one record for this species (1952) but does not give specific locality data.

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Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Dragonflies & Damselflies (Odonata)					
Arizona snaketail (Gomphidae: *Ophiogomphus arizonicus*)	NS-imperiled. Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	N.A.	N.A.	Presence in CORO unknown. A rare species tied to high quality surface waters.
Masked clubskimmer (Libellulidae: *Brechmorhoga pertinax*)	FS-S Collection records indicate this is a very rare species.	CHIR ? CORO ?	Known from only two localities, eastern Chiricahua Mtns (Cave Creek, Herb Martyr) and Grand Canyon; perennial streams.	Loss/degradation of riparian habitat; climate change (e.g. climate drying).	Although no records exist within the boundaries of CHIR or CORO, this is a rare species that should be watched for.
Mexican meadowfly, spot-winged meadowhawk (Libellulidae: *Sympetrum signiferum*)	FS-S NS-imperiled Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	Riparian areas in pine-oak-juniper woodlands, 6000 ft in western Huachucas, down to the headwaters of the Santa Cruz (San Rafael Valley) at ~4700 ft. Breed in sluggish, vegetated pools in clear-water streams. Larvae and adults predaceous on other riparian species;	Loss of riparian habitat; climate change (e.g. climate drying).	Most active in early October. Although no records exist within the boundaries of CHIR or CORO, there is a probability that this species occurs in both parks (e.g., in Yaqui and Montezuma Canyons at CORO, Bonita Creek in CHIR, etc.). NPS invert collection records for "*Sympetrum* sp." from the Chiricahua Mtns may be this species).
Persephone's darner (Aeshnidae: *Aeshna persephone*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	Loss/degradation of surface waters; climate change (e.g. climate drying).	Presence in CHIR unknown.

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Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Pima dancer (Coenagrionidae: *Argia pima*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	Loss/degradation of surface waters; climate change (e.g. climate drying).	Presence in CHIR and CORO unknown.
Mayflies (Ephemeroptera)					
False ameletus mayfly (Ameletidae: *Ameletus falsus*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	High water-quality surface streams and ponds.	Loss/degradation of stream/pond habitat; climate change (e.g. climate drying).	Presence in CHIR unknown.
Peninsular mayfly (Baetidae: *Cloeodes peninsulus*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	High water-quality surface streams and ponds.	Loss/degradation of stream/pond habitat; climate change (e.g. climate drying).	Presence in CHIR unknown.
Caddisflies (Trichoptera)					
Caddisfly (Philopotamidae: *Chimarra primula*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	High water-quality surface streams and ponds.	Loss/degradation of stream/pond habitat; climate change (e.g. climate drying).	Presence in CHIR unknown.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Caddisfly (Leptoceridae: *Nectopsyche dorsalis*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	High water-quality surface streams and ponds.	Loss/degradation of stream/pond habitat; climate change (e.g. climate drying).	Presence in CORO unknown.
Beetles (Coleoptera)					
Arizona water penny (Psephenidae: *Psephenus arizonensis*; = *Stgobromus arizonensis*)	FS-S NS-imperiled Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	So far known only from Cave Creek, near the SW Research Station, Portal; oak woodland, 5800 ft.	Disturbance or loss of riparian habitat (this species is a creek-obligate), e.g. grazing, logging, mining, recreation, etc; climate change (e.g. climate drying).	Although no records exist within the boundaries of CHIR, there is a reasonable probability that this species occurs there.
Chiricahua water scavenger beetle (Hydrophilidae: *Cymbiodyta arizonica*)	FS-S BLM-S NS-imperiled	CHIR ?	Not well known. Shallow pools in creeks, lake shallows.	Over-draft of water, grazing, habitat modification (e.g., logging, erosion, sedimentation, siltation); climate change (e.g. climate drying.	A rare beetle with both larvae and adults tied to their aquatic habitat. Not yet recorded from CHIR, but likely to occur there.
Purple tiger beetle, cow path tiger beetle (Carabidae: *Cicindela purpurea cimarrona*)	FS-S BLM-S NS-vulnerable	CHIR ? FOBO ?	High elevation grasslands with good moisture retention.	Drought and altered hydrologic cycles; off-road driving; invasion by exotic weeds; climate change (e.g. climate drying); possibly fire suppression.	A widespread species; although no records exist within the boundaries of CHIR or FOBO, there is a high probability that this species occurs there. Nine species of *Cicindela* are reported in the CHIR invert data records, none of which are *C. purpurea*.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Maricopa tiger beetle (Carabidae: *Cicindela oregona maricopa*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	Drought and altered hydrologic cycles; off-road driving; invasion by exotic weeds; climate change (e.g. climate drying); possibly fire suppression.	Presence in CHIR unknown. This is the southernmost range extent of this subspecies.
Montane giant tiger beetle, Baron's tiger beetle (Carabidae: *Amblycheila baroni*)	FS-S BLM-S NS-vulnerable	CHIR CORO	Oak grassland (3500-5500 ft) near standing or running water.	Drought and altered hydrologic cycles; off-road driving; invasion by exotic weeds; climate change (e.g. climate drying); possibly fire suppression.	A common species ranging throughout the southeastern Sky Islands Region, including the Peloncillos, Huachucas and Chiricahuas. A species of interest to AZ Game & Fish Heritage Management Program.
Orthopterans (Grasshoppers and their kin)					
Ball's monkey grasshopper, piñon pine monkey grasshopper (Eumastacidae: *Eumorsea balli*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	Piñon pine forests in Santa Rita, Pinaleño, and Huachuca Mountains.	Habitat degradation.	Presence in CORO undetermined.
Chiricahua ceuthophilus (*Ceuthophilus chiricahuae*)	None	CHIR ?	So far as known, endemic to the Chiricahua Mountains.	Habitat degradation; use of pesticides or biological control methods.	Not yet reported from CHIR, but may well occur there.
Chiricahua melanopus (*Melanoplus chiricahuae*)	None	CHIR ?	So far as known, endemic to the Chiricahua Mountains.	Habitat degradation; use of pesticides or biological control methods.	Not yet reported from CHIR, but may well occur there.
Red whiskers grasshopper (Acrididae: *Melanoplus desultorius*)	Identified by the U.S. Forest Service as a "forest-wide species to guide management decisions"	?	Grasslands and oak-grasslands.	Habitat degradation.	Distribution in CHIR, FOBO, and CORO unknown.
Ants (Hymenoptera)					

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Emma's temnothorax (Formicidae: *Temnothorax emmae*; = *Leptothorax emmae*)	None	CHIR ?	Eastern slopes of the Chiricahua Mountains; little is known about the habitat of this rare species.	Habitat disturbance; exotic species (e.g., the imported red fire ant, *Solenopsis invicta*)	Described from the Peloncillo and Chiricahua Mountains in 2000.
Pseudoscorpions (Pseudoscorpionidae)					
Chiricahua cave pseudoscorpion, Spinks cave pseudoscorpion (Syarinidae: *Chitrellina chiricahuae*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	Known only from Spinks (=Sphinx) Cave, Chiricahua Mountains. Specific habitat and biology of this species is not known.	Habitat degradation to cave environment (this is a cave obligate)	Presence in CHIR unknown. Initially described from a single specimen, from Spinks Cave (Cochise Co.), in 1996.
Amphipods (Crustacea: Amphipoda)					
Arizona stygobromus cave amphipod (Crangonyctidae: *Stygobromus arizonensis*)	FS-sensitive. Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO	Known only from a small spring in a mine and from a spring at Flying H Ranch; 5245 ft elevation.	Groundwater pollution or drawdown; climate change (e.g., climate drying).	Described in 1974 from Flying H Ranch and a small spring in a mine at Paradise at 5245 ft (near Fort Huachuca). Presence in CORO unknown.
Gastropods (snails)					
Bearded mountain snail (Oreohelicidae: *Oreohelix barbata*)	NS-critically imperiled. Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	N.A.	Presence in CHIR unknown.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Cave Creek woodland snail (Polygyridae: *Ashmunella chiricahuana*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	N.A.	Presence in CHIR unknown.
Chiricahua mountain snail (Oreohelicidae: *Radiocentrum chiricahuana*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	N.A.	Presence in CHIR unknown.
Chiricahua talus snail (Helminthoglyptidae: *Sonorella virilis*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua Ecosystem Management Area"	CHIR ?	N.A.	N.A.	Presence in CHIR unknown.
Heart vertigo, Hinkley's vertigo (Vertiginidae: *Vertigo hinkleyi*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	N.A.	N.A.	Presence in CORO unknown.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Huachuca springsnail (Hydrobiidae: *Pyrgulopsis thompsoni*)	ESA-C FS-S BLM-sensitive NS-imperiled IUCN-vulnerable. Identified by the U.S. Forest Service as a "species to guide management decisions in the Huachuca Ecosystem Management Area"	CORO ?	Isolated springs in Santa Cruz and San Pedro River watersheds and drainages, 4500 – 7000 ft.	Reduction in standing or subsurface water; drought; springhead modification; disturbance of spring habitat by livestock or farming; pesticide use on nearby landscape; climate change (e.g. climate drying).	Known from just 16 sites, many threatened by habitat degradation. Small populations have been reported from various sites in the Huachuca Mountains, and springs & seeps in CORO should be investigated for its presence there. Recent fieldwork at Peterson Pond, Scotia Canyon (Jan-Feb 2009) found only a few individuals. In February 2009 the Center for Biological Diversity & the Freshwater Mollusk Conservation Society field a scientific petition with the US-FWS to protect this and 41 other species of spring snails.
Las Guijas talus snail (Helminthoglyptidae: *Sonorella sitiens montezuma*; = *S. sitiens comobabiensis*; = *S. sitiens montezuma*)	FS-S	CORO ?	Talus outcrops within pine-oak woodland on the south side of Montezuma Pass. ~5300 ft.	Disturbance to talus outcrop habitats; climate change (e.g. climate drying).	Although not yet reported on the eastern side of Montezuma Pass, this talus snail like occurs there on talus slopes, rock outcrops, or rocky rubble (especially in east-west oriented canyons).
Ramsey Canyon talus snail (Helminthoglyptidae: *Sonorella granulatissima* H.A. Pilsbry, 1905)	NS-vulnerable	CORO ?	Limestone talus outcrops in canyons on the eastern slopes of the Huachuca Mountains.	Disturbance to limestone talus outcrop habitats; climate change (e.g. climate drying).	This endemic snail has been found in multiple canyons on the eastern slopes of the Huachucas; it has not yet been reported from CORO but could occur there in talus outcrops or rock rubble.
Sonoran snaggletooth, (Vertiginidae: *Gastrocopta prototypus*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO	N.A.	N.A.	Presence in CHIR and CORO unknown.

Table C.5. List of invertebrates of conservation concern in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO). (Listed alphabetically by common name within taxonomic groups.) Note: There are no ESA-listed species known to occur in these parks.

Species Common name (family: scientific name)	Status	Occurrence	Habitat	Principal Threats	Comments
Stocky holospira, Ferriss' holospira (Urocoptidae: *Holospira ferrissi*)	Identified by the U.S. Forest Service as a "species to guide management decisions in the Chiricahua & Huachuca Ecosystem Management Areas"	CHIR ? CORO ?	N.A.	N.A.	Presence in CHIR and CORO unknown.
Nematodes (Order Rhabditida)					
Steinernema n. sp. (*Steinernema* sp. 3 of Stock & Gress, 2006)	None	CHIR ?	Soils in oak woodland, 1750-1950 m elevation (Emory oak, AZ white oak, AZ cypress, alligator juniper).	Climate change, especially reduction in soil moisture; exotic species (e.g., the imported red fire ant, *Solenopsis invicta*).	Undescribed species, apparently endemic to Chiricahua Mountains. Not yet reported from CHIR, but very likely to occur there. Species in these genera are likely also endemic to CORO.
Heterorhabditis n. sp. (*Heterorhabditis* sp. 3 of Stock & Gress, 2006)	None	CHIR ?	Soils in oak woodland, 1750-1950 m elevation (Emory oak, AZ white oak, AZ cypress, alligator juniper).	Climate change, especially reduction in soil moisture; exotic species (e.g., the imported red fire ant, *Solenopsis invicta*).	Undescribed species, apparently endemic to Chiricahua Mountains. Not yet reported from CHIR, but very likely to occur there. Species in these genera are likely also endemic to CORO.

Table C.6. Amphibians and Reptiles in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO), in the Arizona (AZ), New Mexico (NM), and Sonroa (SON) portions of the Madrean Archipelago (MA), and in the Sierra Madre Occidental (SMO). Bold symbols in parks columns indicate exotic species

Taxon	Common Name	FOBO	CHIR	CORO	MA-AZ/NM	MA-SON	SMO
CAUDATA							
Ambystomatidae							
Ambystoma rosaceum	Tarahumara salamander					x	x
Ambystoma tigrinum mavortium	tiger salamander	p	x	x	*		
Ambystoma tigrinum stebbinsii					x	x	
ANURA							
Brachycephalidae							
Craugastor augusti (Eleutherodactylus augusti)	barking frog		x		x	x	x
Bufonidae							
Anaxyrus cognatus (Bufo cognatus)	Great Plains toad	x	x	x	x	x	
Anaxyrus debilis (Bufo debilis)	green toad	x	p		x	x	
Anaxyrus microscaphus (Bufo microscaphus)					p	x	
Anaxyrus punctatus (Bufo punctatus)	red-spotted toad	x	x	x	x	x	x
Anaxyrus retiformis (Bufo retiformis)	Sonoran green toad					x	
Anaxyrus woodhousii (Bufo woodhousii)	Woodhouse's toad	p		x	x	x	
Ollotis alvaria (Bufo alvarius)	Sonoran desert toad	p		p	x	x	x
Ollotis mazatlanensis (Bufo mazatlanensis)	Sinaloan toad					x	x
Hylidae							
Hyla arenicolor	canyon treefrog	x	x	x	x	x	x
Hyla wrightorum	mountain treefrog			p	x	x	x
Smilisca baudinii	Mexican tree frog					x	x
Microhylidae							
Gastrophryne olivacea	Great Plains narrow-mouthed toad				x	x	x
Pelobatidae							
Spea bombifrons	plains spadefoot	x	p		x		
Scaphiopus couchii	Couch's spadefoot	x	p	p	x	x	x
Spea multiplicata	Mexican spadefoot	x	x	x	x	x	
Ranidae							
Lithobates blairi (Rana blairi)		p			x		
Lithobates catesbeiana (Rana catesbeiana)	American bullfrog		**p**	**p**	*	*	*

Table C.6. Amphibians and Reptiles in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO), in the Arizona (AZ), New Mexico (NM), and Sonroa (SON) portions of the Madrean Archipelago (MA), and in the Sierra Madre Occidental (SMO). Bold symbols in parks columns indicate exotic species

Taxon	Common Name	FOBO	CHIR	CORO	MA-AZ/NM	MA-SON	SMO
Lithobates chiricahuensis (Rana chiricahuensis)	Chiricahua leopard frog	x		p	x	x	
Lithobates subaquavocalis (Rana subaquavocalis)	Ramsey canyon leopard frog			p	x		
Lithobates tarahumarae (Rana tarahumarae)	Tarahumara frog				x	x	x
Lithobates yavapaiensis (Rana yavapaiensis)	lowland leopard frog				x	x	
TESTUDINATA							
Emydidae							
Terrapene nelsoni	spotted box turtle					x	x
Terrapene ornata	ornate box turtle	x	x	x	x	x	
Trachemys scripta	pond slider					x	x
Kinosternidae							
Kinosternon arizonense (K. flavescens arizonense)	Arizona mud turtle	p			x	x	
Kinosternon sonoriense	Sonoran mud turtle	p		p	x	x	x
Testudinidae							
Gopherus agassizii	desert tortoise	p		p	x	x	x
SAURIA							
Anguidae							
Elgaria kingii	Madrean alligator-lizard	x	x	x	x	x	x
Crotaphytidae							
Crotaphytus collaris	eastern collared-lizard	x	x	x	x	x	
Crotaphytus nebrius	Sonoran collared-lizard				x		
Gambelia wislizenii	long-nosed leopard-lizard	p		p	x	x	
Eublepharidae							
Coleonyx fasciatus	black banded gecko					x	x
Coleonyx variegatus	western banded-gecko	x		p	x	x	
Gekkonidae							
Hemidactylus turcicus	Mediterranean house gecko				*		
Helodermatidae							
Heloderma suspectum	gila monster	x	p	x	x	x	
Iguanidae							
Ctenosaura macrolopha (C. hemilopha macrolopha)	mainland spinytail iguana					x	x

Table C.6. Amphibians and Reptiles in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO), in the Arizona (AZ), New Mexico (NM), and Sonroa (SON) portions of the Madrean Archipelago (MA), and in the Sierra Madre Occidental (SMO). Bold symbols in parks columns indicate exotic species

Taxon	Common Name	FOBO	CHIR	CORO	MA-AZ/NM	MA-SON	SMO
Phrynosomatidae							
Callisaurus draconoides	zebra-tailed lizard	p		p			x
Cophosaurus texanus	greater earless-lizard	x	p	p	x	x	
Holbrookia elegans	elegant earless-lizard				x	x	?
Holbrookia maculata	common lesser earless-lizard	x	x	x	x	x	x
Phrynosoma cornutum	Texas horned-lizard	x	p	p	x	x	
Phrynosoma ditmarsi	rock horned lizard					x	x
Phrynosoma hernandesi (*P. douglasii hernandesi*)	greater short-horned lizard	x	x	x	x	x	x
Phrynosoma modestum	round-tailed horned-lizard	x		p	x	x	
Phrynosoma orbiculare	Madrean horned lizard				x	x	x
Phrynosoma solare	regal horned-lizard	p		p	x	x	x
Sceloporus bimaculosus (S. magister)	twin-spotted spiny-lizard	p		p	x	?	
Sceloporus clarkii	Clark's spiny-lizard	x	x	x	x	x	x
Sceloporus cowlesi (S. undulatus consobrinus)	southwestern fence-lizard	p	x	x	x	?	
Sceloporus jarrovii	Yarrow's spiny-lizard	p	x	x	x	x	x
Sceloporus poinsetti	crevice spiny-lizard				x	x	x
Sceloporus slevini (S. scalaris)	Slevin's bunchgrass-lizard	p	p	x	x		x
Sceloporus virgatus	striped plateau lizard	x	x		x	x	x
Urosaurus ornatus	ornate tree-lizard	x	x	x	x	x	x
Uta stansburiana	common side-blotched lizard	p		p	x		
Scincidae							
Plestiodon callicephalus (Eumeces callicephalus)	mountain skink			x	x	x	x
Plestiodon obsoletus (Eumeces obsoletus)	Great Plains skink	x	x	x	x	x	
Teiidae							
Aspidoscelis arizonae (Cnemidophorus arizonae)	Arizona striped whiptail				x		
Aspidoscelis burti (Cnemidophorus burti)	canyon spotted whiptail	p		p	x	x	x
Aspidoscelis costata (Cnemidophorus costatus)	western Mexico whiptail					x	x
Aspidoscelis exsanguis (Cnemidophorus exsanguis)	Chihuahuan spotted whiptail	x	x	x	x	x	x
Aspidoscelis inornatus (Cnemidophorus inornatus)	little striped whiptail	p			x		
Aspidoscelis opatae (Cnemidophorus opatae)	oputo whiptail					x	

Table C.6. Amphibians and Reptiles in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO), in the Arizona (AZ), New Mexico (NM), and Sonroa (SON) portions of the Madrean Archipelago (MA), and in the Sierra Madre Occidental (SMO). Bold symbols in parks columns indicate exotic species

Taxon	Common Name	FOBO	CHIR	CORO	MA-AZ/NM	MA-SON	SMO
Aspidoscelis sonorae (Cnemidophorus sonorae)	Sonoran spotted whiptail	x	x	x	x	x	
Aspidoscelis tigris (Cnemidophorus tigris)	tiger whiptail	x		p	x	x	
Aspidoscelis uniparens (Cnemidophorus uniparens)	desert grassland whiptail	x	x	x	x	x	
Boidae							
Boa constrictor	boa constrictor					x	x
Colubridae							
Arizona elegans	glossy snake	p	p	p	x		
Coluber bilineatus (Masticophis bilineatus)	Sonoran whipsnake	x	x	x	x	x	
Coluber flagellum (Masticophis flagellum)	coachwhip	x	x	x	x	x	x
Coluber mentovarius (Masticophis mentovarius)	neotropical whipsnake					x	x
Coluber taeniatus (Masticophis taeniatus)	striped whipsnake				p		CH
Diadophis punctatus	ring-necked snake	x	p	x	x	x	x
Drymarchon corais melanurus	Central American indigo snake					x	x
Gyalopion canum	Chihuahuan hook-nosed snake	p	p	x	x	x	x
Gyalopion quadrangulare	thornscrub hook-nosed snake				x		x
Heterodon nasicus	Mexican hog-nosed snake	p	p	x	x	x	
Hypsiglena chlorophaea (H. torquata)	desert nightsnake	x	x	x	x	x	x
Lampropeltis getula	common kingsnake	p	p	x	x	x	
Lampropeltis pyromelana	Sonoran mountain kingsnake	p	x	x	x	x	x
Lampropeltis triangulum celanops	milksnake	p		x	x	x	
Oxybelis aeneus	brown vine snake				x	x	x
Phyllorhynchus browni	saddled leaf-nosed snake				x		
Pituophis catenifer	gophersnake	x	x	x	x	x	x
Rhinocheilus lecontei	long-nosed snake	p		x	x	x	x
Salvadora bairdi	Baird's patch-nosed snake					x	
Salvadora grahamiae	eastern patch-nosed snake	p	x	x	x	x	
Salvadora hexalepis	western patch-nosed snake	x	x	x	x	x	x
Senticolis triaspis	green ratsnake	x	x	p	x	x	x
Sonora semiannulata	western groundsnake	p	x	p	x	x	

Table C.6. Amphibians and Reptiles in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NSH (FOBO), in the Arizona (AZ), New Mexico (NM), and Sonroa (SON) portions of the Madrean Archipelago (MA), and in the Sierra Madre Occidental (SMO). Bold symbols in parks columns indicate exotic species

Taxon	Common Name	FOBO	CHIR	CORO	MA-AZ/NM	MA-SON	SMO
Tantilla hobartsmithi	Smith's black-headed snake	p		p	x	?	
Tantilla nigriceps	plains black-headed snake				x	?	
Tantilla wilcoxi	Chihuahuan black-headed snake			x	x	x	x
Tantilla yaquia	Yaqui black-headed snake	x		p	x	x	x
Thamnophis cyrtopsis	black-necked gartersnake	x	x	x	x	x	x
Thamnophis elegans vagans	wandering gartersnake				x		
Thamnophis eques	Mexican gartersnake			p	x	x	x
Thamnophis marcianus	checkered gartersnake	p	x	p	x	x	
Trimorphodon biscutatus	western lyre snake	x	x	x	x	x	x
Elapidae							
Micruroides euryxanthus	Sonoran coral snake	x	x	x	x	x	x
Leptotyphlopidae							
Leptotyphlops dulcis	Texas blindsnake	p	x	x	x	x	
Leptotyphlops humilis	western threadsnake	p		p	x	x	
Viperidae							
Crotalus atrox	western diamond-backed rattlesnake	x		x	x	x	
Crotalus basiliscus	Mexican west coast rattlesnake					x	x
Crotalus lepidus	rock rattlesnake	p	x	x	x	x	x
Crotalus molossus	black-tailed rattlesnake	x	x	x	x	x	x
Crotalus pricei	twin-spotted rattlesnake			p	x		x
Crotalus scutulatus	Mohave rattlesnake	p		x	x	x	CH
Crotalus tigris	tiger rattlesnake				x	x	
Crotalus viridis cerberus	prairie rattlesnake	p			x		
Crotalus viridis viridis	prairie rattlesnake				p	x	
Crotalus willardi	ridge-nosed rattlesnake			p	x	x	x
Sistrurus catenatus	desert massasauga	p	p	p	x		
Total native species and affinities							

173 total native species

49 with Tropical affinity = 28%, 47 with Sonoran Desert affinity = 27%, 34 with Madrean affinity = 20%, 19 no affinity (generalist) = 11%, 10 with Grassland affinity = 6%, 8 with Chihuahuan Desert affinity = 4%

Table C.7. Mammal species observed or collected in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NHS (FOBO). Grand total of 92 species in the three parks. * = Jaguar specimen taken in 1912 in Bonita Canyon (Cahalene 1939); ? = possible. Species in bold print are non-natives.**

Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Didelphimorphia	Didelphidae	*Didelphis virginiana*	Virginia possum		X	
Insectivora	Soricidae	*Notiosorex crawfordi*	Crawford's desert shrew	X	X	X
		Notiosorex species	Unknown desert shrew	X		
		Sorex arizonae	Arizona shrew	?	?	?
Chiroptera	Phyllostomidae	*Choeronycteris mexicana*	Mexican long-tongued bat	X	X	X
		Leptonycteris curasoae yerbabuenae	Lesser long-nosed bat	X	X	X
	Vespertilionidae	*Antrozous pallidus*	pallid bat	X	?	X
		Corynorhinus townsendii	Townsend's big-eared bat	X	X	X
		Euderma maculatum	spotted bat	?	?	
		Eptesicus fuscus	big brown bat	**X**	**?**	**X**
		Idionycteris phyllotis	Allen's lappet-browed bat	X	?	
		Lasionycteris noctivagans	silver-haired bat	X		
		Lasiurus blossevillii	western red bat	X	?	
		Lasiurus cinereus	hoary bat	X	X	
		Lasiurus ega	southern yellow bat	?	?	
		Myotis auriculus	southwestern myotis	X	X	X
		Myotis californicus	California myotis	X	X	X
		Myotis ciliolabrum (leibii)	western small-footed myotis	X	X	X
		Myotis occultus (lucifugus)	occult little brown bat	X		X
		Myotis thysanodes	fringed myotis	X	X	X
		Myotis velifer	cave myotis	X	?	X
		Myotis volans	long-legged myotis	X	?	X
		Pipistrellus hesperus	western pipistrelle	X	?	X
		Tadarida brasiliensis	Mexican free-tailed bat	**X**	**?**	
	Molossidae	*Nyctinomops macrotis*	big free-tailed bat	X	?	?
		Eumops perotis	western mastiff bat	?	?	?
Carnivora	Ursidae	*Urus americanus*	American black bear	X	X	X
	Procyonidae	*Procyon lotor*	northern raccoon	X	X	X
		Nasua narica	white-nosed coati	X	X	X
		Bassariscus astutus	ringtail	X	X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Carnivora	Mustelidae	*Mustela frenata*	long-tailed weasel	?		
		Taxidea taxus	American badger	X	X	X
	Mephitidae	*Mephitis mephitis*	striped skunk	X	X	X
		Mephitis macroura	hooded skunk	X	X	X
		Conepatus mesoleucus	hog-nosed skunk	X	X	X
		Spilogale gracilis	western spotted skunk	?	X	X
	Canidae	***Canis lupus familiaris***	**feral dog**		X	X
		Canis latrans	coyote	X	X	X
		Urocyon cinereoargenteus	gray fox	X	X	X
		Vulpes macrotis	kit fox	?	?	
	Felidae	***Felis catus***	**feral cat**	X	X	
		Herpailurus yaguarondi	jaguarundi	?	?	?
		Leopardus pardalis	ocelot	?	?	?
		Puma concolor	mountain lion	X	X	X
		Lynx rufus	bobcat	X	X	X
		Panthera onca	jaguar	***	?	?
Rodentia	Sciuridae	*Spermophilus variegatus*	rock squirrel	X	X	X
		Spermophilus spilosoma	spotted ground squirrel	X	X	?
		Spermophilus tereticaudus	round-tailed ground squirrel	?	?	X
		Neotamias dorsalis	cliff chipmunk	X		X
		Sciurus arizonensis	Arizona gray squirrel		X	
		Sciurus nayaritensis	Mexican fox squirrel	X		
		Ammospermophilus harrisii	Harris's antelope squirrel	?		X
	Geomyidae	*Thomomys bottae*	Botta's pocket gopher	X	X	X
		Thomomys umbrinus	southern pocket gopher		X	
	Heteromyidae	*Perognathus amplus*	Arizona pocket mouse	X		X
		Perognathus flavus	silky pocket mouse	X	X	X
		Chaetodipus intermedius	rock pocket mouse	X	X	X
		Chaetodipus hispidus	hispid pocket mouse	X	X	X
		Chaetodipus penicillatus	Sonoran Desert pocket mouse	?	X	X
		Chaetodipus baileyi	Bailey's pocket mouse	?	?	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Rodentia	Heteromyidae	*Dipodomys spectabilis*	banner-tailed kangaroo rat	?	X	X
		Dipodomys ordii	Ord kangaroo rat	X	X	X
		Dipodomys merriami	Merriam's kangaroo rat	X	X	X
	Muridae	*Reithrodontomys montanus*	Plains harvest mouse	X	?	
		Reithrodontomys megalotis	western harvest mouse	X	X	X
		Reithrodontomys fulvescens	fulvous harvest mouse	X	X	X
		Peromyscus eremicus	cactus mouse	X	?	X
		Peromyscus maniculatus	deer mouse	X	X	X
		Peromyscus leucopus	white-footed mouse	X	X	X
		Peromyscus boylii	brush mouse	X	X	X
		Peromyscus truei	pinyon mouse	X		
		Peromyscus difficilis nasutus	northern rock mouse	X		
		Baiomys taylori	northern pygmy mouse	X	X	X
		Onychomys leucogaster	northern grasshopper mouse	X	?	X
		Onychomys torridus	southern grasshopper mouse	X	X	X
		Neotoma albigula	white-throated woodrat	X	X	X
		Neotoma mexicana	Mexican woodrat	X	?	
		Sigmodon hispidus	hispid cotton rat	X		X
		Sigmodon fulviventer	tawny-bellied cotton rat	X	X	
		Sigmodon ochrognathus	yellow-nosed cotton rat	X	X	
		Sigmodon arizonae	Arizona cotton rat	X	X	
		Mus musculus	**house mouse**	X	X	?
	Erethizontidae	*Erethizon dorsatum*	North American porcupine	?	?	X
Lagomorpha	Leporidae	*Lepus californicus*	black-tailed jackrabbit	X	X	X
		Lepus alleni	Antelope jackrabbit	?	?	X
		Sylvilagus floridanus	eastern cottontail	X	?	
		Sylvilagus audubonii	desert cottontail	X	X	X
Artiodactyla	**Bovidae**	***Bos taurus***	**domestic cow**		X	X
	Tayassuidae	*Pecari tajacu*	collared peccary	X	X	X
	Cervidae	*Odocoileus hemionus*	mule deer		X	X
		Odocoileus virginianus	white-tailed deer	X	X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Anseriformes	Anatidae	*Branta canadensis*	Canada goose			X
Galliformes	Phasianidae	*Meleagris gallopavo*	wild turkey	X	X	
	Odontophoridae	*Callipepla squamata*	scaled quail	X	X	X
		Callipepla gambelii	Gambel's Quail	X	X	X
		Cyrtonyx montezumae	Montezuma quail	X	X	X
Ciconiiformes	Ardeidae	*Ardea herodias*	great blue heron			X
		Butorides virescens	green heron			X
	Cathartidae	*Coragyps atratus*	black vulture	?	X	X
		Cathartes aura	turkey vulture	X	X	X
Falconiformes	Accipitridae	*Pandion haliaetus*	osprey	X		X
		Haliaeetus leucocephalus	bald eagle	X	X	X
		Circus cyaneus	northern harrier	X	X	X
		Elanus leucurus	white-tailed kite		X	
		Accipiter striatus	sharp-shinned hawk	X	X	X
		Accipiter cooperii	Cooper's hawk	X	X	X
		Accipiter gentilis	northern goshawk	X	X	
		Buteogallus anthracinus	common black-hawk	X	X	X
		Parabuteo unicinctus	Harris's hawk	?	X	
		Buteo swainsoni	Swainson's hawk	X	X	X
		Buteo albonotatus	zone-tailed hawk	X	X	X
		Buteo jamaicensis	red-tailed hawk	X	X	X
		Buteo regalis	ferruginous hawk	X		X
		Buteo lagopus	rough-legged hawk	X		X
		Aquila chrysaetos	golden eagle	X	X	X
	Falconidae	*Falco sparverius*	American kestrel	X	X	X
		Falco columbarius	merlin	?	X	X
		Falco peregrinus	peregrine falcon	X	X	X
		Falco mexicanus	prairie falcon	X	X	X
Gruiformes	Gruidae	*Grus canadensis*	sandhill crane	X		X
Charadriiformes	Scolopacidae	*Gallinago gallinago*	common snipe		X	
		Tringa flavipes	lesser yellowlegs			X
		Actitis macularia	spotted sandpiper			X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Charadriiformes	Charadriidae	*Charadrius vociferus*	killdeer	X		X
Columbiformes	Columbidae	***Columba livia***	**rock pigeon**		X	
		Patagioenas fasciata	band-tailed pigeon	X	X	X
		Zenaida asiatica	white-winged dove	X	X	X
		Zenaida macroura	mourning dove	X	X	X
		Columbina inca	inca dove		X	
		Columbina passerina	common ground-dove	X	X	X
Cuculidae	Cuculidae	*Coccyzus americanus*	yellow-billed cuckoo		X	
		Geococcyx californianus	greater roadrunner	X	X	X
Strigiformes	Tytonidae	*Tyto alba*	barn owl	X	X	X
	Strigidae	*Otus flammeolus*	flammulated owl	X	X	
		Megascops kennicottii	western screech-owl	X	X	X
		Megascops trichopsis	whiskered screech-owl	X	X	
		Bubo virginianus	great horned owl	X	X	X
		Glaucidium gnoma	northern pygmy-owl	X	X	
		Strix occidentalis	Mexican spotted owl	X	X	X
		Micrathene whitneyi	elf owl	X	X	X
		Aegolius acadicus	northern saw-whet owl	X		
		Asio otus	long-eared owl			X
Caprimulgiformes	Caprimulgidae	*Chordeiles minor*	common nighthawk	X	X	X
		Chordeiles acutipennis	lesser nighthawk			X
		Phalaenoptilus nuttallii	common poorwill	X	X	X
		Caprimulgus vociferus	whip-poor-will	X	X	X
Apodiformes	Apodidae	*Aeronautes saxatalis*	white-throated swift	X	X	X
		Chaetura vauxi	Vaux's swift	X		X
	Trochilidae	*Heliomaster constantii*	plain-capped starthroat		X	
		Cynanthus latirostris	broad-billed hummingbird	X	X	X
		Hylocharis leucotis	white-eared hummingbird	X	X	
		Lampornis clemenciae	blue-throated hummingbird	X	X	
		Eugenes fulgens	magnificent hummingbird	X	X	X
		Calothorax lucifer	Lucifer hummingbird	X	X	X
		Archilochus alexandri	black-chinned hummingbird	X	X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Apodiformes	Trochilidae	*Calypte anna*	Anna's hummingbird	X	X	X
		Calypte costae	Costa's hummingbird		X	X
		Amazilia violiceps	violet-crowned hummingbird	X	X	
		Amazilia beryllina	Beryline hummingbird	X		
		Stellula calliope	calliope hummingbird	X	X	X
		Selasphorus platycercus	broad-tailed hummingbird	X	X	X
		Selasphorus sasin	Allen's hummingbird		X	
		Selasphorus rufus	rufous hummingbird	X	X	X
Trogoniformes	Trogonidae	*Trogon elegansa*	elegant trogon	X	X	
		Euptilotis neoxenus	eared trogon	X		
Coraciiformes	Alcedinidae	*Ceryle alcyon*	belted kingfisher	X		X
Piciformes	Picidae	*Melanerpes lewis*	Lewis's woodpecker		X	X
		Melanerpes formicivorus	acorn woodpecker	X	X	X
		Melanerpes uropygialis	Gila woodpecker	X	X	X
		Sphyrapicus thyroideus	Williamson's sapsucker	X	X	X
		Sphyrapicus nuchalis	red-naped sapsucker	X	X	X
		Sphyrapicus ruber	red-breasted sapsucker		X	
		Sphyrapicus varius	yellow-bellied sapsucker		X	X
		Picoides scalaris	ladder-backer woodpecker	X	X	X
		Picoides villosus	hairy woodpecker	X	X	
		Picoides arizonae	Arizona woodpecker	X	X	
		Colaptes auratus	northern flicker	X	X	X
		Colaptes chrysoides	gilded flicker		X	
Passeriformes	Tyrannidae	*Camptostoma imberbe*	northern beardless-tyrannulet	X		
		Contopus cooperi	olive-sided flycatcher	X		X
		Contopus pertinax	greater pewee	X	X	X
		Contopus sordidulus	western wood pewee	X	X	X
		Empidonax traillii	willow flycatcher	X	X	X
		Empidonax hammondii	Hammond's flycatcher	X	X	X
		Empidonax wrightii	gray flycatcher	X	X	X
		Empidonax oberholseri	dusky flycatcher	X	X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Tyrannidae	*Empidonax occidentalis (difficilis)*	western flycatcher	X	X	X
		Empidonax occidentalis	cordilleran flycatcher	X	X	
		Sayornis nigricans	black phoebe	X	X	X
		Sayornis saya	Say's phoebe	X	X	X
		Pyrocephalus rubinus	vermilion flycatcher	X	X	
		Myiarchus tubercilifer	dusky-capped flycatcher	X	X	X
		Myiarchus cinerascens	ash-throated flycatcher	X	X	X
		Myiarchus tyrannulus	brown-crested flycatcher	X	X	X
		Myiodynastes luteiventris	sulphur-bellied flycatcher	X	X	
		Tyrannus vociferans	Cassin's kingbird	X	X	X
		Tyrannus verticalis	western kingbird	X	X	X
	Laniidae	*Lanius ludovicianus*	loggerhead shrike	X	X	X
	Vireonidae	*Vireo vicinior*	gray vireo	X		X
		Vireo bellii	Bell's vireo		X	X
		Vireo plumbeus	plumbeous vireo	X	X	X
		Vireo cassinii	Cassin's vireo		X	
		Vireo huttoni	Hutton's vireo	X	X	X
		Vireo gilvus	warbling vireo	X	X	X
	Corvidae	*Cyanocitta stelleri*	Steller's jay	X	X	X
		Aphelocoma californica	western scrub-jay	X	X	X
		Aphelocoma ultramarina	Mexican jay	X	X	X
		Gymnorhinus cyanocephalus	pinyon jay	X	X	X
		Nucifraga columbiana	Clark's nutcracker	X		X
		Corvus cryptoleucus	Chihuahuan raven	X	X	X
		Corvus corax	common raven	X	X	X
	Alaudidae	*Eremophila alpestris*	horned lark	X	X	X
	Hirundinidae	*Progne subis*	purple martin	X		
	Hirundinidae	*Tachycineta thalassina*	violet-green swallow	X	X	X
		Stelgidopteryx serripennis	northern rough-winged swallow	X		X
		Petrochelidon pyrrhonota	cliff swallow	X		X
		Hirundo rustica	barn swallow	X	X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Paridae	*Poecile gambeli*	mountain chickadee	X		
		Poecile sclateri	Mexican chickadee	X		
		Baeolophus wollweberi	bridled titmouse	X	X	X
		Baeolophus ridgwayi	juniper titmouse	X		X
	Remizidae	*Auriparus flaviceps*	verdin	X	X	X
	Aegithalidae	*Psaltriparus minimus*	bushtit	X	X	X
	Sittidae	*Sitta canadensis*	red-breasted nuthatch	X		
		Sitta carolinensis	white-breasted nuthatch	X	X	X
		Sitta pygmaea	pygmy nuthatch	X		
	Certhyiidae	*Certhia americana*	brown creeper	X	X	X
	Troglodytidae	*Campylorhynchus brunneicapillus*	cactus wren	X	X	X
		Salpinctes obsoletus	rock wren	X	X	X
		Catherpes mexicanus	canyon wren	X	X	X
		Thryomanes bewickii	Bewick's wren	X	X	X
		Troglodytes aedon	house wren	X	X	X
	Regulidae	*Regulus calendula*	ruby-crowned kinglet	X	X	X
	Sylviidae	*Polioptila caerulea*	blue-gray gnatcatcher	X	X	X
		Polioptila melanura	black-tailed gnatcatcher		X	X
	Turdidae	*Sialia sialis*	eastern bluebird	X	X	
	Turdidae	*Sialia mexicana*	western bluebird	X	X	X
		Sialia currucoides	mountain bluebird	X	X	X
		Myadestes townsendi	Townsend's solitaire	X	X	X
		Catharus ustulatus	Swainson't thrush		X	X
		Catharus guttatus	hermit thrush	X	X	X
		Ixoreus naevius	varied thrush		X	
		Turdus migratorius	American robin	X	X	X
	Mimidae	*Dumetella carolinensis*	gray catbird		X	
		Mimus polyglottos	northern mockingbird	X	X	X
		Oreoscoptes montanus	sage thrasher			X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Mimidae	*Toxostoma crissale*	crissal thrasher	X	X	X
		Toxostoma curvirostre	curve-billed thrasher	X	X	X
		Toxostoma bendirei	Bendire's thrasher	X	X	X
	Sturnidae	*Sturnus vulgaris*	European starling			X
	Motacillidae	*Anthus rubescens*	American pipit			X
	Bombycillidae	*Bombycilla cedrorum*	cedar waxwing	X	X	X
	Ptilogonatidae	*Phainopepla nitens*	phainopepla	X	X	X
	Parulidae	*Vermivora celata*	orange-crowned warbler	X	X	X
		Vermivora ruficapilla	Nashville warbler	X	X	X
		Vermivora virginiae	Virginia's warbler	X	X	X
		Vermivora luciae	Lucy's warbler	X	X	X
		Dendroica petechia	yellow warbler	X	X	X
		Dendroica coronata	yellow-rumped warbler	X	X	X
		Dendroica coronata auduboni	Audubon's warbler	X		
		Dendroica nigrescens	black-throated gray warbler	X	X	X
		Dendroica virens	black-throated green war-bler	X	X	
		Dendroica townsendi	Townsend's warbler	X	X	X
		Dendroica occidentalis	hermit warbler	X	X	X
		Dendroica graciae	Grace's warbler	X		
		Seiurus aurocapilla	ovenbird		X	
		Seiurus noveboracensis	Northern waterthrush			X
		Setophaga ruticilla	American redstart	X		
		Oporomis tolmiei	MacGillivray's warbler	X	X	X
		Geothlypis trichas	Common yellowthroat			X
		Wilsonia pusilla	Wilson's warbler	X	X	X
		Cardellina rubrifrons	red-faced warbler	X	X	
		Myioborus pictus	painted redstart	X	X	
		Icteria virens	yellow-breasted chat		X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Thraupidae	*Piranga flava*	hepatic tanager	X	X	
		Piranga ruba	summer tanager	X	X	X
		Piranga ludoviciana	western tanager	X	X	X
	Emberizidae	*Pipilo chlorurus*	green-tailed towhee	X	X	X
		Pipilo maculatus	spotted towhee	X	X	X
		Pipilo fuscus	canyon towhee	X	X	X
		Pipilo aberti	Abert's towhee		X	
		Aimophila carpalis	rufous-winged sparrow		X	
		Aimophila cassinii	Cassin's sparrow	X	X	X
		Aimophila texana or botterii	Botteri's sparrow	X	X	X
		Aimophila ruficeps	rufous-crowned sparrow	X	X	X
		Spizella passerina	chipping sparrow	X	X	X
		Spizella breweri	Brewer's sparrow	X	X	X
		Spizella atrogularis	black-chinned sparrow	X	X	X
		Pooecetes gramineus	vesper sparrow	X	X	X
		Chondestes grammacus	lark sparrow	X	X	X
		Passerculus sandwichensis	savannah sparrow		X	X
		Amphispiza bilineata	black-throated sparrow	X	X	X
		Calcarius ornatus	chestnut-collared longspur		X	
		Calamospiza melanocorys	lark bunting		X	X
		Passerella iliaca	fox sparrow	X	X	X
		Melospiza melodia	song sparrow		X	X
		Melospiza lincolnii	Lincoln's sparrow	X		X
		Ammodramus savannarum	grasshopper sparrow	X	X	X
		Ammodramus bairdii	Baird's sparrow			X
		Melospiza georgiana	swamp sparrow		X	
		Melospiza lincolnii	Lincoln's sparrow		X	
		Zonotrichia albicollis	white-throated sparrow		X	X

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Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Emberizidae	*Zonotrichia leucophrys*	white-crowned sparrow	X	X	X
		Junco hyemalis	dark-eyed junco	X	X	X
		Junco hyemalis meamsi	pink-sided junco	X	X	X
		Junco hyemalis dorsalis	gray-headed junco	X	X	X
		Junco hyemalis oreganus	Oregon junco	X	X	X
		Junco phaeonotus	yellow-eyed junco	X	X	X
	Cardinalidae	*Cardinalis cardinalis*	northern cardinal	X	X	X
		Cardinalis sinuatus	pyrrhuloxia	X	X	X
		Pheucticus ludovicianus	rose-breasted grosbeak	X	X	X
		Pheucticus melanocephalus	black-headed grosbeak	X	X	X
		Passerina caerulea	blue grosbeak	X	X	X
		Passerina amoena	lazuli bunting	X	X	X
		Passerina ciris	painted bunting	X		X
		Passerina cyanea	Indigo bunting		X	
	Icteridae	*Sturnella magna lilianae*	eastern meadowlark	X	X	X
		Sturnella neglecta	western meadowlark	X	X	X
		Agelaius phoeniceus	red-winged blackbird	X		
		Euphagus cyanocephalus	Brewer's blackbird			X
		Quiscalus mexicanus	great-tailed grackle			X
		Molothrus aeneus	bronzed cowbird	X	X	X
		Molothrus ater	brown-headed cowbird	X	X	X
		Icterus cucullatus	hooded oriole	X	X	X
		Icterus bullockii	Bullock's oriole	X	X	X
		Icterus parisorum	Scott's oriole	X	X	X
		Icterus pustulatus	streak-backed oriole		X	
	Fringillidae	*Carpodacus cassinii*	Cassin's finch	X	X	
		Carpodacus mexicanus	house finch	X	X	X
		Carpodacus purpureus	purple finch		X	

Table C.8. Bird species observed or collected in Chiricahua NM (CHIR), Coronado NMem (CORO), and Fort Bowie NHS (FOBO). Species in bold print are non-natives.

Order	Family	Scientific Name	Common Name	CHIR	CORO	FOBO
Passeriformes	Fringillidae	*Loxia curvirostra*	red crossbill	X		
		Carduelis pinus	pine siskin	X	X	X
		Carduelis tristis	American goldfinch	X	X	
		Carduelis psaltria	lesser goldfinch	X	X	X
		Coccothraustes vespertinus	evening grosbeak	X		X
	Passeridae	***Passer domesticus***	**house sparrow**	X	X	X

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