National Park Service
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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Great Sand Dunes National Park and Preserve

Natural Resource Report NPS/ROMN/NRR—2017/1402

ON THE COVER
View of the dunes from above Medano Creek
Photograph by: Colorado Natural Heritage Program

Natural Resource Condition Assessment

Great Sand Dunes National Park and Preserve

Natural Resource Report NPS/ROMN/NRR—2017/1402

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program is administered by National Park Service's (NPS) Water Resources Division, and is intended to provide documentation about current conditions of important park natural resources through a spatially explicit, multi-disciplinary synthesis of existing scientific data and knowledge. The NRCA for Great Sand Dunes National Park and Preserve (GRSA) was initiated in September 2009, and 14 focal study natural resources were chosen for assessment. These resources were arranged into a framework with three broad categories: landscape level processes, biological integrity, and supporting environment.

The Great Sand Dunes National Monument was designated in 1932 to preserve the unique and scenic character of the dunefield (containing the tallest dunes in North America), as well as some of the oldest known archeological sites in the country. In November 2000, the Great Sand Dunes National Park and Preserve Act upgraded the designation to National Park and expanded the boundaries of the former monument by nearly 70,000 acres (23,828 ha) and established the Great Sand Dunes National Preserve from about 41,646 acres (16,853 ha) of the Rio Grande National Forest. The 149,611 acres (60,545 ha) of the park and preserve encompass a representative slice of the characteristic San Luis Valley/Sangre de Cristo Mountains landscape in the Southern Rocky Mountain ecoregion. Because the park and preserve range from semi-desert valley floor to alpine peak, GRSA supports an impressive variety of high-quality native ecosystems within a relatively small area.

Landscape level processes for GRSA were assessed at two levels. The extent and condition of the natural landscape include the focal study resources of landscape condition, composition, and connectivity. Current landscape condition, as measured by anthropogenic disturbance extent and intensity, is good, especially for GRSA and other public lands surrounding the San Luis Valley. GRSA is part of a diverse landscape of regional ecosystem types, and acts as a key connection in the connectivity of core areas within the Sangre de Cristo Mountains. Although connectivity of this range with the San Juan Mountains to the west is impaired, there are a few remaining connections between GRSA and other areas across the valley floor. Landscape conditions are generally stable, with local and regional conservation and management efforts offsetting the agricultural and renewable resource development that has impacted the area.

Four landscape level natural processes were also assessed: hydrology, the dune system, fire, and forest pests/pathogens. Hydrology was assessed as being of moderate concern, although the condition of the dune system remains good. Attention to the effects of hydrological alterations in the area, together with extensive court proceedings and modeling have thus far enabled the NPS to preserve the hydrologic factors on which the dune system depends. However, changing climatic conditions are likely to impact the dunes and the hydrology of the area in the coming decades. Current groundwater monitoring, as well as a focus on vigilant management of the dune system and attendant hydrologic resources, should help managers prepare adaptive strategies for changing conditions as they arise. Fire conditions for GRSA within the landscape context appear to be good, with only a small amount of acreage in significant departure from natural conditions, and extent and frequency of fires similar to that of the surrounding area. Native forest damage-causing agents also appear to be within the

range of natural variation. However, the introduced fungus that causes white pine blister rust is present and warrants moderate concern.

Biological integrity focal resources assessed represent both ecosystem- and species-level resources. Native ecosystems were assessed in seven groups: alpine, forests, shrublands, grasslands, dunefield-sandsheet-sabkha, wetland-riparian in the preserve, and wetland-riparian in the park. Overall, native ecosystems within GRSA are in good condition, especially those of higher elevations in the preserve. Grasslands and wetland-riparian areas of lower elevations are of moderate concern, largely due to a legacy of disturbance from previous ranching use, as well as ongoing ungulate grazing.

Species-level resources were grouped into endemic insects, herptiles, other species of concern, and invasive species. Endemic insects are considered in good condition, only a single species was not reported during the most recent survey effort. Furthermore, the sandy habitat required by these insects is extensive both within and near GRSA. Although GRSA does not have extensive habitat for all of its herptile species, most appear to be present, if at unknown population levels. Additional inventory could clarify the current moderate concern score for this resource. Other rare animal and plant species at GRSA are generally in good and improving condition. Various inventory and survey work in the area since the mid-1990s has provided good baseline information for many species, although repeat observations of many of these species of concern would help establish trend information for the future. Due to ongoing regional conservation efforts, including the enlargement of the former monument into the park and preserve, these species are probably now more protected than at any time since settlement. There are enough invasive introduced species present in or near GRSA to pose a threat to the composition and function of plant communities, and, by extension, the wildlife species that use them. Weed mapping and subsequent control efforts have so far prevented significant deterioration of park resources due to invasive species, but this resource warrants moderate concern and continued attention.

GRSA's supporting physical environment was assessed via three focal study resources: air quality, night sky, and soundscapes and acoustic resources (natural sounds). These resources represent not only abiotic factors that affect the survival of components of biological integrity, but also the extent to which park visitors are able to experience the environment of the park as intended. The condition of night skies and natural soundscapes is good, GRSA represents a primarily unaltered natural environment, and is situated in an area where there are few impacts to these resources from outside the park. Air quality at GRSA is of moderate concern, primarily due to sources of pollution outside the park and preserve.

Acknowledgments

We thank the staff of Great Sand Dunes National Park and Preserve, especially Fred Bunch, Phyllis Pineda Bovin, and Andrew Valdez, for their assistance in developing this assessment. Likewise, the staff of the Rocky Mountain I & M Network, especially Billy Schweiger, provided helpful feedback and information. Additional NPS personnel who provided data and feedback which improved this assessment include Jim Harte at the Water Resources Division, and Chad Moore and Jeremy White of the Night Skies Team. We also thank Jeff Albright, program lead of the Natural Resource Condition Assessment Program, Water Resources Program Center, National Park Service, for providing programmatic insight and guidance on project development and review.

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Acronyms and Abbreviations

ALR	Anthropogenic Light Ratio
BLM	Bureau of Land Management
CCD	Charge-coupled Device
CDOW	Colorado Division of Wildlife (now CPW, Colorado Parks and Wildlife)
CDPHE	Colorado Department of Public Health and Environment
CDWR	Colorado Division of Water Resources
CFWE	Colorado Foundation for Water Education
CNHP	Colorado Natural Heritage Program
CODA	Colorado Department of Agriculture
CODNR	Colorado Department of Natural Resources
COGCC	Colorado Oil and Gas Conservation Commission
CSU	Colorado State University
CWCB	Colorado Water Conservation Board
DOI	Department of the Interior
EIA	Ecological Integrity Assessment
EPA	Environmental Protection Agency
FQA	Floristic Quality Assessment
FQI	Floristic Quality Index
GIS	Geographic Information System
GPS	Global Positioning System
GRSA	Great Sand Dunes National Park and Preserve
HRV	Historical range of variation
I&M	Inventory and Monitoring
LDI	Landscape Disturbance Index
MPB	Mountain Pine Beetle
NAAQS	National Ambient Air Quality Standards
NAIP	National Agriculture Imagery Program
NPS	National Park Service
NPS-ARD	National Park Service Air Resources Division
NRCA	Natural Resource Condition Assessment
NRPC-BRMD	Natural Resource Stewardship and Science Directorate-- Biological Resources Division
NSNSD	Natural Sounds and Night Skies Division
RGCT	Rio Grande cutthroat trout
ROMN	Rocky Mountain Inventory and Monitoring Network
SLV	San Luis Valley
SOC	Semi-volatile Organic Compounds
SQM	Sky Quality Meter
SWReGAP	Southwest Regional Gap Analysis Project
TNC	The Nature Conservancy
USDA	United States Department of Agriculture
USFS	United Stated Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VCC	Vegetation Condition Class
WPBR	White Pine Blister Rust
WRCC	Western Regional Climate Center

Chapter 1: NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

> ***NRCAs Strive to Provide…***
>
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.
Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves 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 existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

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 both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park’s desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[6]An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2: Introduction and Resource Setting

In this document, Great Sand Dunes National Park and Preserve is referred to collectively as GRSA, or "Great Sand Dunes." Great Sand Dunes National Preserve (only) is referred to as "the preserve," and the Great Sand Dunes National Park (only) is referred to as "the park."

2.1 Introduction

2.1.1 Enabling Legislation

The Great Sand Dunes National Monument was designated in 1932 by President Hoover under authority granted to him by the Antiquities Act of 1906 to preserve areas of scenic, scientific, and educational interest for current and future generations (Geary 2012, Great Sand Dunes National Park and Preserve Act of 2000). Primary reasons for establishing the monument were to preserve the unique and scenic character of the dunefield (containing the tallest dunes in North America), as well as some of the oldest known archeological sites in the country, from degradation from mining, artifact looting, and encroaching development. National monument designation was strongly supported by the nearby city of Alamosa and many residents of the San Luis Valley as a way to preserve an area of unique local heritage and beauty and a valuable tourist attraction (Geary 2012).

The Great Sand Dunes National Monument went through a number of boundary revisions. The original monument designation included about 46,034 acres (18,630 ha). In 1946, President Harry Truman officially reduced the size of the monument to 44,810 acres (18,134 ha), apparently due to an error in the original survey, and a 1956 boundary change authorized by President Dwight D. Eisenhower reduced the monument to about 37,000 acres (14,974 ha) (Geary 2012).

In November 2000, Congress approved the expansion of the monument, and on November 22, President Bill Clinton signed Public Law 106-530, the Great Sand Dunes National Park and Preserve Act of 2000. This Act upgraded the monument to a park, expanded the boundaries by nearly 70,000 acres (23,828 ha) and established the Great Sand Dunes National Preserve from about 41,646 acres (16,853 ha) of the Rio Grande National Forest. The Act also authorized the purchase of the Baca Ranch to fulfill the requirement that the new park possess "sufficient land having a sufficient diversity of resources." The acquisition of the Baca Ranch was eventually accomplished after several years of complex legal wrangling between a variety of interested parties, and in September 2004, both the Great Sand Dunes National Park and Preserve and the Baca National Wildlife Refuge were officially designated (Geary 2012).

The expansion to nearly 150,000 acres (60,545 ha) was made to better preserve the hydrologic and geologic processes that support the dunefield, as well as the surrounding wildlife habitat and scenic values, from encroaching development and water extraction (Geary 2012, Great Sand Dunes National Park and Preserve Act of 2000).

2.1.2 Geographic Setting

Great Sand Dunes National Park and Preserve encompasses 149,611 acres (60,545 ha) in the San Luis Valley of south-central Colorado (Figure 2.1.1). The San Luis Valley is part of the Rio Grande Rift, a progressive thinning of the continental plate that extends from central Colorado south into

Mexico. The valley is bounded by the steep Sangre de Cristo Mountains to the east, and the more broad and meandering San Juan Mountains to the west. Within the valley, the Great Sand Dunes formed from sands left by ancient lake beds and driven by prevailing southwesterly winds to a natural crook in the Sangre de Cristo Mountains. Opposing winds coming off the mountains during storms work against the prevailing wind to lift the sands into dunes (NPS 2012). The dunefield itself is approximately 19,000 acres (7,690 ha).

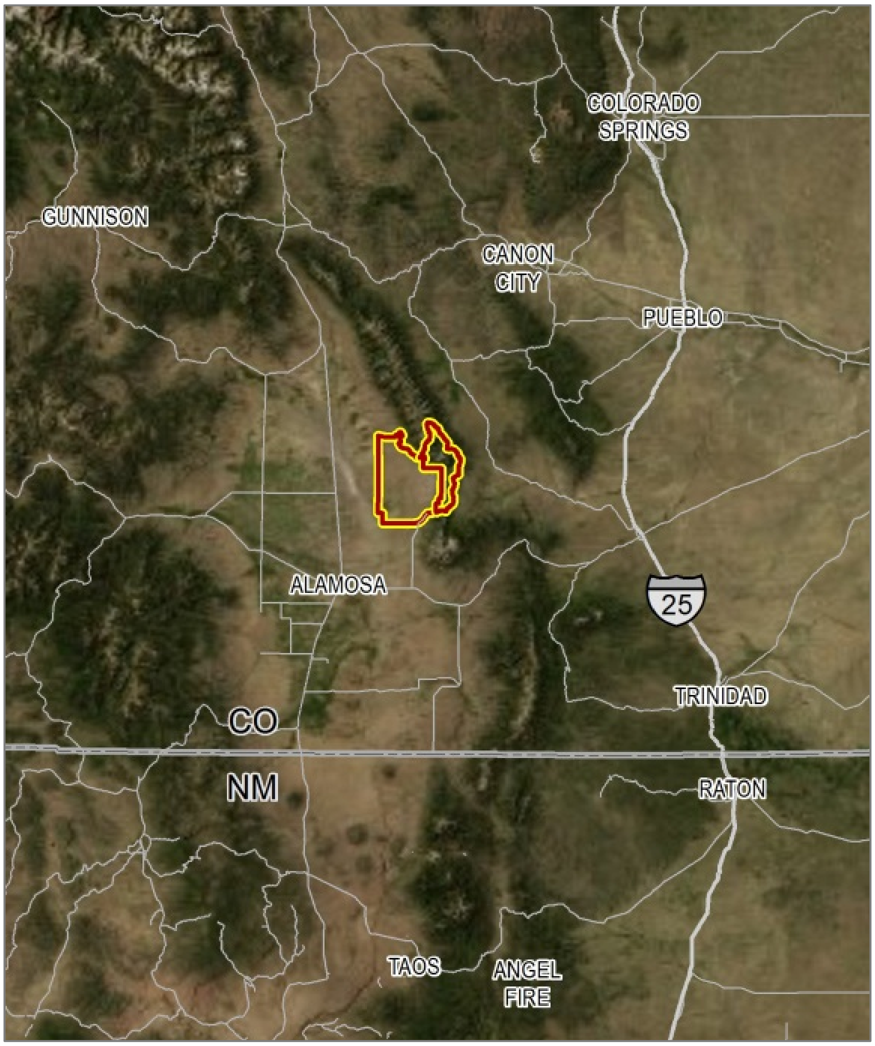

Figure 2.1.1. GRSA location.

GRSA consists of two connected units, the park and the preserve. The park portion of GRSA is primarily situated on the valley floor, while the preserve encompasses the portion of the adjacent Sangre de Cristo Mountains from the head of the Sand Creek drainage in the north to the ridge north of Carbonate Mountain in the south. The lowest elevation in the park is 7,525 ft (2,993 m), at the southwest corner near San Luis Lake. The ridgeline of the Sangre de Cristos forms the eastern boundary of the Park and Preserve and the Baca National Wildlife Refuge and San Luis Lakes State Park and Wildlife Area on the valley floor form the western boundary. County Lane 6 North forms the southern boundary and private property and the Rio Grande National Forest abut GRSA to the north. GRSA lies across the Alamosa/Saguache county line and extends to the eastern border of both counties.

The San Luis Valley has been occupied for at least the last 6,000 years. Initially, occupation by Native Americans appears to have been for seasonal hunting and gathering only. Spanish settlement in the late 16th century introduced grazing livestock into the valley, and gold mining along the Sangre de Cristo Mountains began in the 17th century. Permanent settlements were not established in the valley, however, until the 1800s, by a then independent Mexico (Geary 2012). Land grants established by the Mexican government initiated a land use pattern of farms and ranches throughout the valley that largely continues today. The San Luis Valley has a long history of agriculture and much of the area west and southwest of GRSA is dotted with center pivot irrigation systems Approximately one fourth of the valley (roughly 500,000 acres) is currently in irrigated agriculture, with the major crops being irrigated hay and pasture, potatoes, barley, small grains, and wheat (CODNR 2010). Other land uses in the region include livestock grazing on public and private lands and federal and state land managed as wildlife preserves.

GRSA is located in a sparsely populated area. In 2010, Alamosa County and Saguache County had populations of 15,445 and 6,108, respectively. The closest population center to GRSA is the city of Alamosa, population of 8,780, which accounts for 57% of the population of Alamosa County (U.S. Census Bureau 2010).

2.1.3 Visitation Statistics

Over the last 30 years, GRSA has received an average of over 250,000 visitors each year (Figure 2.1.2). Visitation levels have not been constant, however, with the early to mid-1980's seeing some of the lowest number of visitors in several decades, and well over 300,000 visitors in the mid-1990s. Visitation levels for the last five years have been reasonably steady, with an average of 280,000 visitors. Typically, the majority of visits occur during June through August with an average of 52,700 visitors each month, with another 25,000-40,000 in the shoulder season months of May and September. But even in the winter, several thousand visitors come through each month.

The vast majority of visitors come in through the main park entrance, with only a small fraction of traffic entering via the Medano Pass Road, and then only in the summer and fall under good weather when the road is accessible. Over 80% of visits are day-trips. Types of camping allowed include RV, tents at improved campgrounds, and backcountry camping. All statistics are from the NPS Public Use Statistics Office (2012).

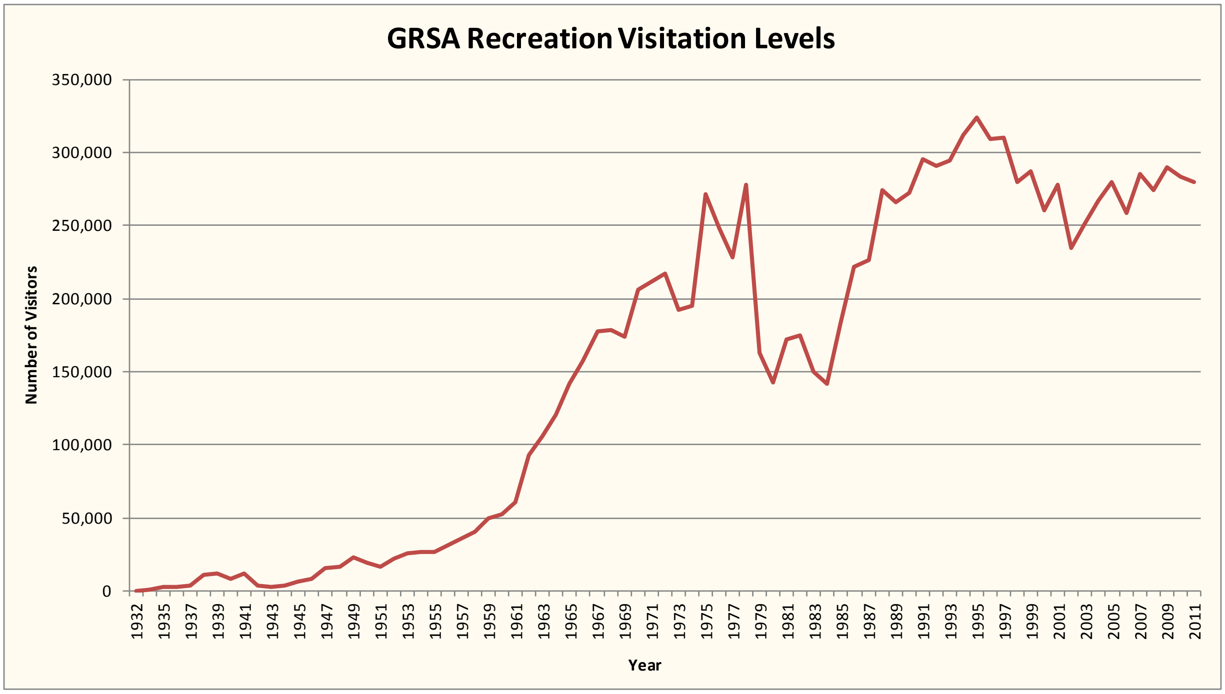

Figure 2.1.2. GRSA visitation levels.

2.2 Natural Resources

2.2.1 Ecological Units and Watersheds

GRSA is broadly within the Southern Rocky Mountains ecoregion as defined by The Nature Conservancy (2001, modified from Bailey 1998). The Southern Rocky Mountain ecoregion includes the north-south trending mountain ranges with their intervening valleys and parks from southern Wyoming to northern New Mexico, and, in Colorado, more westerly mountain ranges and high plateaus (Neely et al. 2001). The national park portion of GRSA on the valley floor lies within the Northern Rio Grande Basin Section of the Great Plains and Palouse Dry Steppe Province. The preserve portion lies within the Southern Parks and Range Section of the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province (Bailey 1998).

GRSA is within the San Luis sub-basin of the Rio Grande River Basin. However, since it is a part of the San Luis Valley Closed Basin, there is no natural flow from this sub-basin into the Rio Grande River. San Luis Creek flows from the northern edge of the San Luis Valley and feeds into San Luis Lake, just outside the southwest boundary of the park. The main waterways within GRSA are Medano Creek and Sand Creek, both of which start high in the preserve and flow into the sandsheet within the park. In especially wet years, Sand Creek can flow past the western boundary of the park before disappearing, but Medano Creek rarely makes it beyond the southern edge of the dune field.

2.2.2 Resource Descriptions

Valley to mountains landscape

GRSA encompasses a representative slice of the characteristic San Luis Valley/Sangre de Cristo Mountains landscape in the Southern Rocky Mountain ecoregion. Because the park and preserve range from valley floor to alpine peak, GRSA supports an impressive variety of native plant communities within a relatively small area (Figure 2.2.1). Connectivity both within GRSA and between GRSA and the surrounding landscape enable the operation of natural processes and ecosystem dynamics across the scale from small patch to landscape matrix.

Figure 2.2.1. Valley to mountains landscape at GRSA. Photo credit: CNHP.

Hydrology

Because GRSA is situated within a closed basin (Figure 2.2.2), the area has an essentially self-contained complete hydrologic cycle. The formation and persistence of the dunes themselves is closely tied to local and regional hydrology, including both surface and groundwater.

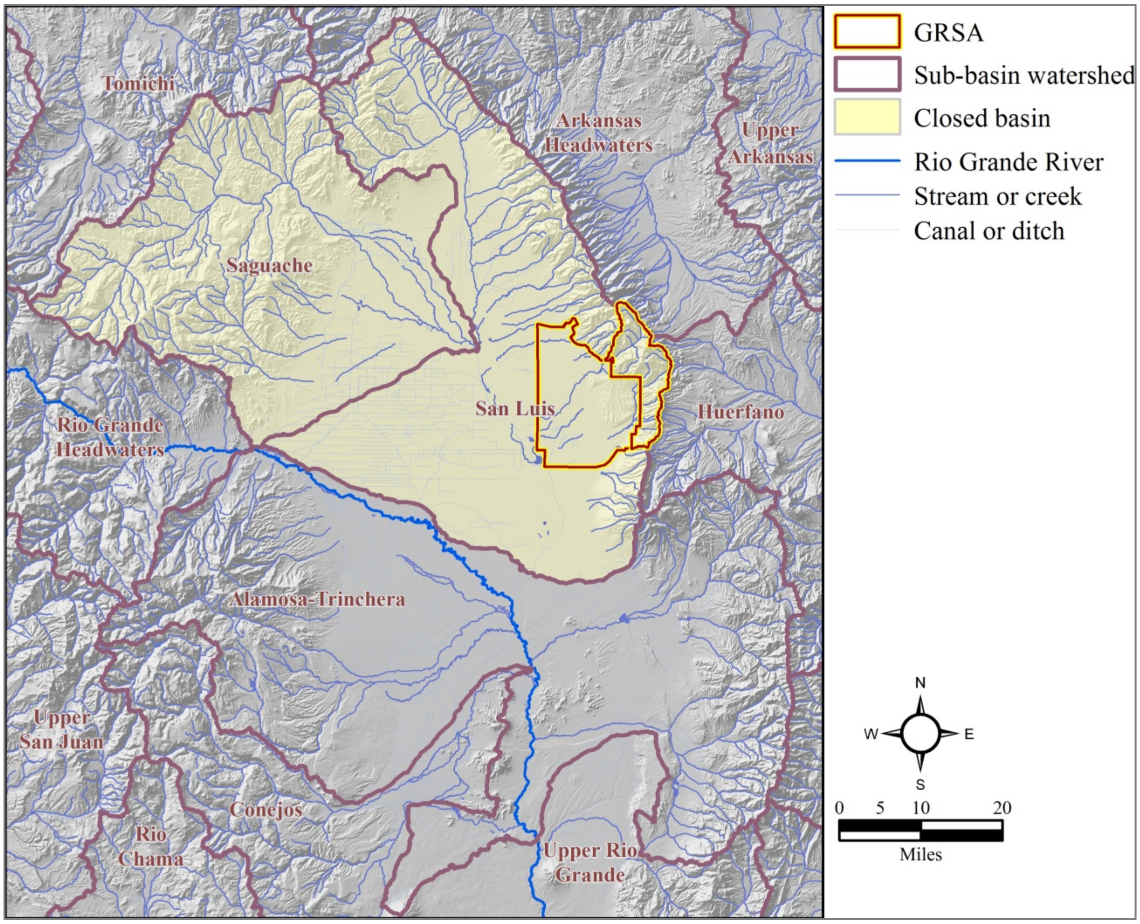

Figure 2.2.2. Hydrologic units in the vicinity of GRSA.

Surface water is generally understood to mean any water that remains above ground, and includes rivers and streams, lakes, reservoirs, ponds, and other impoundments, etc., or any waters whose surface is naturally exposed to the atmosphere (Nevada Division of Water Planning 2012). Groundwater, which originates as surface water, includes all subsurface water. Water in the soil that is not lost to evaporation eventually percolates down to the zone of saturation whose upper level defines the water table. This saturated reservoir of groundwater is called an aquifer, and is typically composed of sand and gravel deposits, sandstone, limestone, or fractured, crystalline rock geologic units (Topper et al. 2003). Aquifers store and transmit water from areas of recharge to areas of discharge. An unconfined aquifer, whether completely or incompletely saturated, is recharged by the infiltration and percolation of surface water that starts out as rain and snow, and lateral and/or upward movement of other unconfined aquifer water and/or confined aquifer water. A confined aquifer is completely saturated, and overlain by low-permeability geologic units that act to prevent the movement of water between layers. Both a shallow unconfined aquifer and a deeper confined aquifer are present in the San Luis Valley and at GRSA (Rupert and Plummer 2004).

A water-dependent resource

The dunefield (Figure 2.2.3) is maintained by prevailing winds in the area that transport sand toward the Sangre de Cristo Mountains. At the same time, Sand Creek and Medano Creek carry sand away from the mountain front and around the perimeter of the dunes, depositing it on the upwind side, where it can again be picked up by the wind (Rupert and Plummer 2004). It appears that the rate of sand transport by wind is generally equal to the rate of sand transport by water, so that the dune field is maintained in its current size (Chatman et al. 1997).

Figure 2.2.3. Aerial view of the main dunefield at GRSA.

Medano and Sand creeks usually terminate in the dunefield, although with sufficient water from snowmelt runoff or monsoonal rains, Sand Creek may flow all the way to Head Lake and San Luis Lake (Jim Harte, NPS hydrologist, personal communication). The water they carry eventually percolates into the shallow unconfined aquifer. The persistence of the dune field depends on groundwater levels in the shallow aquifer remaining at approximately historic levels. A significant reduction in local groundwater levels would shorten the distance over which the flowing creeks are able to transport sand before their water infiltrates into the shallow unconfined aquifer, threatening the long-term viability of the dune field (Rupert and Plummer 2004).

Water use in the San Luis Valley

Irrigation is the leading water use in Colorado, where on an annual basis, about two thirds of all allocated surface water goes to this use (CDWR 2012a). In the San Luis Valley, this figure approaches 95% in most years (Figure 2.2.4). Stream appropriation in the valley began in the 1850s. By 1900, decades before the establishment of the original monument, the natural flow on all surface streams in the valley was over-appropriated. Because the construction of reservoirs for surface water storage was hindered by a series of embargos on federal lands in the region, crop growers began using the unconfined aquifer as a storage reservoir through the practice of subirrigation, substantially elevating the water table in the closed basin (Kuenhold 2006).

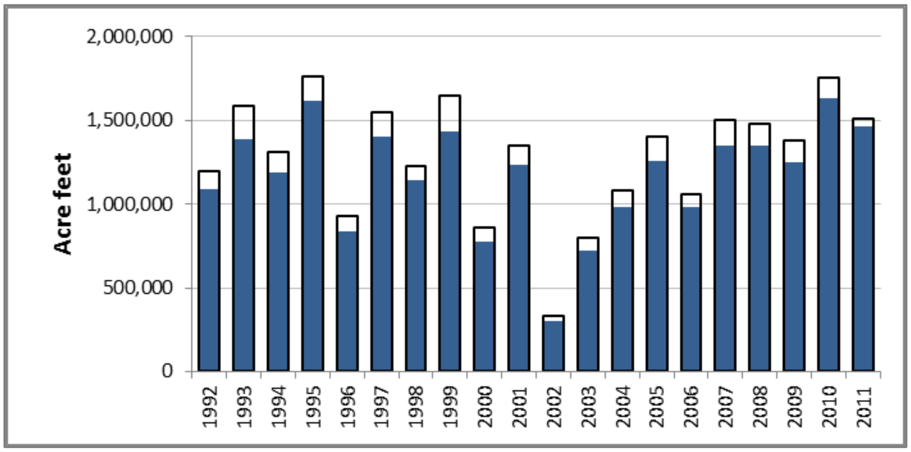

Figure 2.2.4. Irrigation as a proportion of total water use in the Rio Grande headwaters (Colorado Water Division 3).

Eventually, the combination of reduced diversions to the closed basin and increased groundwater pumping lowered the groundwater table, eliminating the possibility for subirrigation. Consequently, groundwater became an important source of irrigation water, especially with the adoption of center pivot sprinklers (Figure 2.2.5). Center pivot irrigation depends primarily on wells in the underground aquifers, where natural levels of recharge are not equal to withdrawals. In addition to natural recharge from surface streams within the closed basin, the aquifers have historically been recharged by surface water imported into the basin from the Rio Grande (Kuenhold 2006).

Significant development of the groundwater from the unconfined aquifer for irrigation did not begin until the 1930s. By 1981, new appropriations from both the confined and unconfined aquifers had been completely curtailed by a moratorium on the issuance of well permits. Subsequent policies of the State Engineer's office also prevented increased use of groundwater by declining to issue permits to deepen existing wells, to drill supplemental wells, or to drill alternate points of diversion for wells, without the applicant first obtaining a judicial confirmation of the absence of material injury (Kuenhold 2006). Irrigated acreage in the San Luis Valley appears to have more-or-less stabilized at a level somewhat below its peak in the 1990s (Figure 2.2.6).

Legal considerations

By Colorado law, all surface and groundwater in Colorado is a public resource for beneficial use by public agencies and private persons, and the ownership of a decreed water right permits a variety of beneficial uses, diversions, storage, and transportation of the allocated water associated with the right, subject to water availability under the legal framework of the prior appropriation system (CFWE 2004). In the San Luis Valley the requirements of the Rio Grande Compact with New Mexico and Texas also affect the allocation of water. The prior appropriation system regulates the use of both surface water and tributary groundwater connected to a river basin, such as the unconfined aquifer. Groundwater that has no measurable connection to surface waters (non-tributary) is not regulated, although wells to access such water still require a permit from the State Engineer's office. If, as would be the case in the San Luis Valley, this nontributary groundwater is outside of a designated groundwater basin, it is available to the overlying landowner at a rate of 1 percent per year, assuming a 100-year life of the aquifer (CFWE 2004).

Figure 2.2.5. Center pivots in the San Luis Valley. Photo credit: CNHP/Renée Rondeau

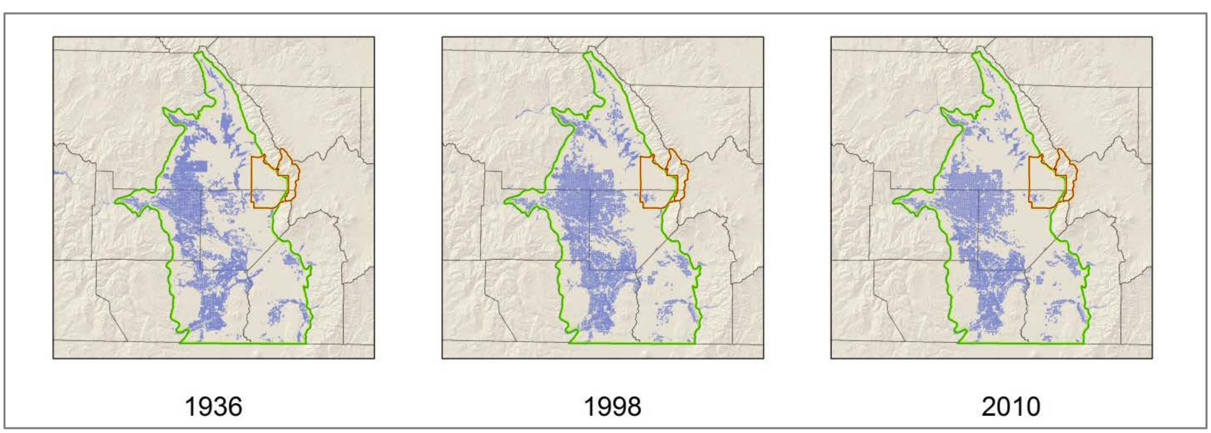

Figure 2.2.6. Change in irrigated land in the San Luis Valley from 1936 to 2010 (CWCB 2012).

The question of connectivity between the confined and unconfined aquifer has loomed large in the recent hydrological story of the San Luis Valley and GRSA. A number of lengthy and intricate trials in regional water court and before the Colorado Supreme Court, have weighed the evidence and determined that "The surface streams, the unconfined aquifer, and the confined aquifer are all tributary water. The confined aquifer, unconfined aquifer and surface streams in the San Luis Valley are all hydrologically connected in a complex way" (Kuenhold 2006). Consequently, the groundwater of the confined aquifer is subject to regulation under the prior appropriation system.

The 2000 enabling legislation for the expansion of Great Sand Dunes National Monument directed the Secretary of the Interior, through the National Park Service, to obtain and exercise water rights to fulfill the purposes of the new National Park (Public Law 106-530-Nov. 22, 2000). The Act specifies that GRSA's water rights "shall be appropriated, adjudicated, changed, and administered pursuant to the procedural requirements and priority system of the State of Colorado." In 2008, the NPS obtained an *in situ* water right decree in Colorado Division 3 Water Court to maintain groundwater levels, surface water levels, and stream flows on, across, and under GRSA. The water right is subject to the prior appropriation system, and subordinate to more senior water rights in the San Luis Valley, including the Bureau of Reclamation's Closed Basin Division project (HRS Water Consultants 2009).

Dune system

The sand dunes are the central and defining feature of GRSA. Although the exact age of the active dunefield has not yet been determined, Madole et al. (2008) concluded that the dunes began forming sometime during the period after Lake Alamosa began draining (~440,000 years ago), and before the end of the Bull Lake glaciation (~130,000 years ago). This contrasts with the previous widely accepted estimate that the dunes are geologically fairly recent, dating from the end of the Pleistocene, or about 12,000 years old (e.g., Johnson 1967, Janke 2002). The movement of sand in the dunefield is affected by several factors, including aridity, sand supply, wind patterns, the topography of the Sangre de Cristo Mountains, and surface flow in Medano and Sand Creeks at the dunefield perimeter (Forman et al. 2006). Wind-transported sand is deposited at an embayment in the Sangre de Cristo Mountains where prevailing winds exit the valley at Mosca, Medano, and Music passes. Groundwater levels, together with the sand transporting actions of Medano Creek and Sand Creek (Figure 2.2.7), and the presence or absence of vegetation, also play a key role in maintaining the dune system (Valdez 2007).

Although most visitor attention is focused on the dunefield, the area of high, unvegetated dunes is but a single component of the Great Sand Dunes geological system. Andrews (1981) divided the aeolian deposits in the San Luis Valley into three provinces. Province I corresponds to the sabkha, Province II is the sandsheet, and Province III represents the main dunefield (Figure 2.2.8a). With the addition of the adjacent mountain watershed, these three primary components work in concert to maintain this complex system (NPS 2012, Andrews 1981):

Figure 2.2.7. Medano Creek flowing around the dunefield edge. Photo credit: CNHP/Renée Rondeau

Mountain watershed: The mountain watershed is the portion of the Sangre de Cristo Mountains to the east of the dunefield where annual accumulated precipitation runs off into the dunefield and vicinity. Flowing creeks modify the perimeter of the dunefield by eroding sand from the upper margins and transporting it to the lower margins where it reenters the dunefield. As a result, large dune forms develop adjacent to the streams. Some are erosional and others are the result of the consistent sand supply. The curved trend of the mountain range, and the arrangement of peaks and valleys within this curve also affect wind patterns over the dunes by funneling southwesterly winds toward the passes, permitting wind from the northeast to blow through the Sangre de Cristo Mountains into the San Luis Valley at ground level (Valdez 2007).

Dunefield: The active dunefield covers close to 30 square miles of sands that are subject to movement by the action of wind and water. Opposing wind directions (southwesterly and northeasterly), and the recycling action of flowing creeks maintain the dunes in their current location. The varied wind directions act to build vertically growing dunes that are up to 230 m (750 feet) tall. The most common dune types are reversing dunes and star dunes (Valdez 2007).

Sandsheet: The sandsheet (Figure 2.2.8b) is the largest component of the Great Sand Dunes geological system, and consists of sand that has been stabilized by vegetation (sparse grass and dwarf-shrubland). It extends around three sides of the dunefield, and is the primary source of sand for the active dunes. Small parabolic dunes form here and migrate toward the main dunefield at an average rate of 10 m/year (Marín et al. 2005). The sandsheet transitions into sand ramps where the sand deposits are inclined from lapping onto the mountain front (Valdez 2007).

Sabkha: The sabkha (Figure 2.2.8c) forms in places where sand is seasonally saturated by rising groundwater. Subsequent evaporation forms areas of carbonate-cemented sand. The sabkha at GRSA is found in the large wetland region south and west of the dunes. As delineated by Andrews (1981) the sabkha covers about 450 km^2 in the lowest portion of the closed basin north of the Rio Grande (the "sump" area). Madole et al. (2008) describe the sump as being a 4–15 km wide low, flat area between the edge of the Rio Grande fan on the west and the foot of the Sangre de Cristo Mountains to the east. The topographic and hydrologic divide between the Dry Lakes and the Rio Grande marks the southern boundary of the sump. Madole et al. (2008) proposed that the sump area is the immediate source of aeolian sand in the vicinity of GRSA. The majority of this area lies outside the GRSA boundary.

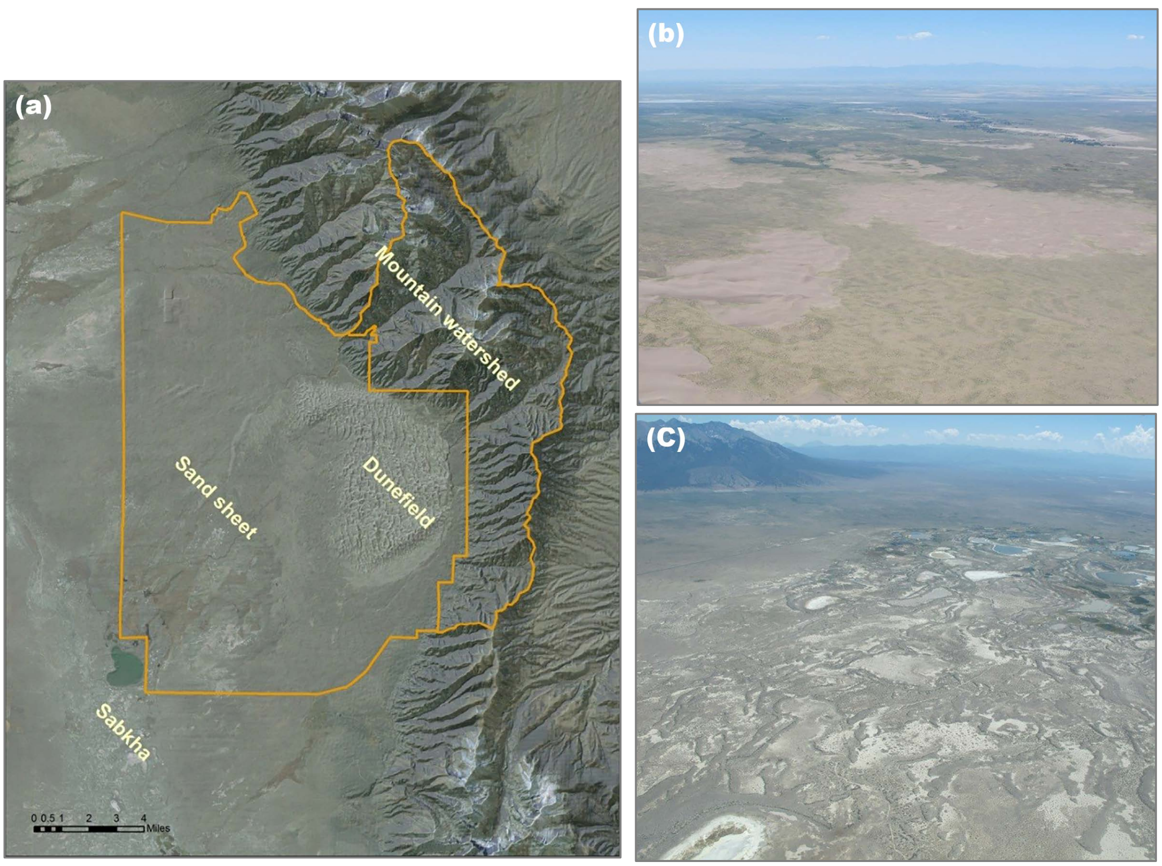

Figure 2.2.8. Dune system components (a), sandsheet (b), and sabkha (c).

<u>Fire</u>

With the enlargement of the original Great Sand Dunes National Monument into the National Park and Preserve, the park acquired both an administratively complex mixture of lands and an extensive tract of fire-prone ecosystems (Figure 2.2.9). In 2005, the Greater Sand Dunes Interagency Fire Management Plan Environmental Assessment / Assessment of Effect was completed (NPS et al.

2005). The assessment addresses alternative fire management strategies and their expected environmental consequences for resources across the planning area. Although wildfires can be suppressed, and fuel treatments implemented under the plan, the strategy is also intended to allow fire to assume its natural role in the landscape (NPS et al. 2005). The dunes themselves are not a fire-driven ecosystem, however, most of the upland ecosystems including forests, woodlands, shrublands, and grasslands are believed to be dependent on periodic fire (Rondeau 2001, Loftin 1999).

Figure 2.2.9. Medano Fire of 2010. Photo: NPS.

<u>Forest pests and pathogens</u>

The preserve contains extensive acreage of forest ecosystems not previously included within NPS administrative boundaries of the former monument. Primary forest damage agents in the vicinity of GRSA include the western spruce budworm (*Choristoneura freemani*) (Figure 2.2.10a), which, in lower elevation forests of the southern Rockies, attacks Douglas-fir (*Pseudotsuga menziesii*) (McKnight 1969, Hadley and Veblen 1993) and white fir (*Abies concolor*) (Baker and Veblen 1990). In the southern Rocky Mountains, the mountain pine beetle (*Dendroctonus ponderosae*) primarily attacks ponderosa and lodgepole pine (Veblen and Donnegan 2005). Other bark beetles that may be present include Douglas-fir beetle (*D. pseudotsugae*), fir engraver (*Scolytus ventralis*), and other engraver beetles (*Ips* spp.). In Colorado, the primary insect damage agents on quaking aspen are larvae of the western tent caterpillar (*Malacosoma californicum*) and the large aspen tortrix (*Choristoneura conflictana*). Both can cause defoliation of variable intensity depending upon climate, site characteristics, and stand age (Dahms and Geils 1997). Recent research suggests that aspen decline is largely tied to warm and dry climate conditions (Hanna and Kulakowski 2012), and that the most vulnerable stands are generally on the fringe of the species' realized climate niche (Rehfeldt et al. 2009).

Most forest damage is a consequence of natural ecological processes, involving the interactions of coadapted species, and is not necessarily harmful to the long-term health and survival of these treed ecosystems. Climate change may amplify the effects of these processes, enabling them to alter the distribution and composition of forested ecosystems in the long term. However, one particular introduced disease, white pine blister rust (WPBR), is a primary management concern (Figure 2.2.10b) for GRSA. *Cronartium ribicola*, the fungus that causes WPBR, is native to Asia and was accidentally introduced into the Pacific Northwest in the early 20th century on infected nursery stock. The complex lifecycle of this fungus involves five different spore stages and an alternate host, primarily currants and gooseberries in the genus *Ribes* (Burns 2006), although non-*Ribes* hosts have recently been reported (Zambino et al. 2007). Pine host species in GRSA are limber pine (*Pinus flexilis*) and Rocky Mountain bristlecone pine (*P. aristata*). An infection of WPBR causes cankers that kill the portion of the branch or stem above the canker, weakening the tree and decreasing its reproductive potential (Burns 2006).

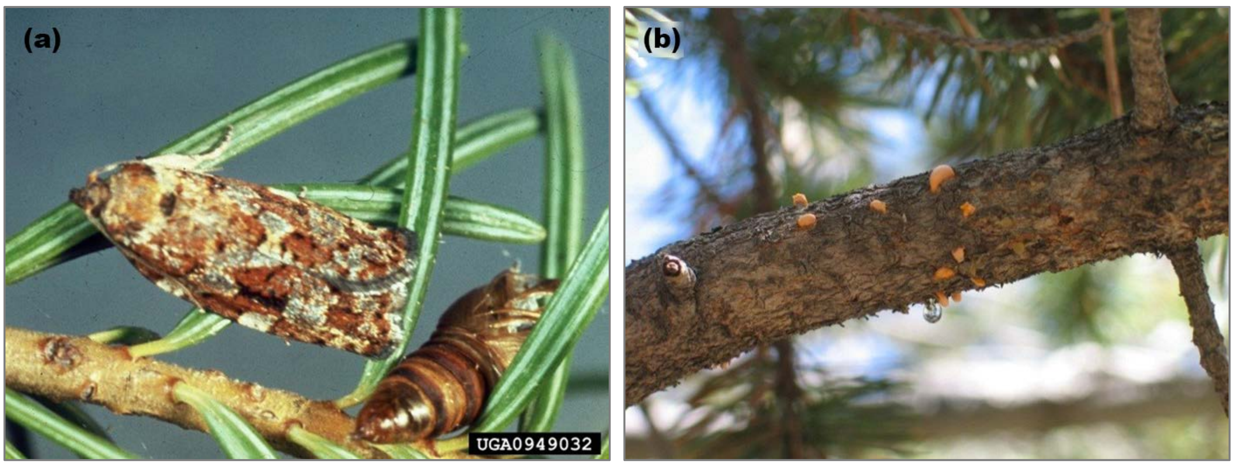

Figure 2.2.10. Western spruce budworm (a) and white pine blister rust branch cankers (b). Left photo: USDA Forest Service Region 4 – Intermountain Archive, USDA Forest Service, Bugwood.org. Right photo: NPS.

Following the discovery of WPBR at GRSA and other infections found in the Wet Mountains and Sangre de Cristo Mountains in southern Colorado (Burns 2006), the National Park Service, U.S. Forest Service, and Colorado State University researchers established ongoing research into methods to reduce losses of bristlecone and limber pines in the Great Sand Dunes National Park and Preserve (Vander Meer and Jacobi 2005, Crump et al. 2011). In addition to the establishment of monitoring transects (Burns 2006), ongoing studies are investigating both short- and long-term methods of control (Table 2.2.1).

Table 2.2.1. Summary and timeline of ongoing WPBR research at GRSA.

Year	Description
2003	WPBR found at GRSA White Pine Blister Rust initially discovered in the park by Colorado State University Staff and US Forest Service Staff.
2004	Long-term monitoring transects USFS established transects throughout the park and surrounding USFS lands in both limber pine and bristlecone pine forests, and in both infested and non-infested areas (USFS funding). The objective is to follow up on these transects at 5-year intervals, and measure the current infestation's progress, and identify areas that are "newly infested," and the rate of infestation spread.
2004	Short-term management techniques Colorado State University and USFS researchers begin an experimental management plan whose objective is to find out whether certain management techniques can be used to remove individual (per tree) infestations (where possible) or reduce the chance of infestation on other trees. These management techniques included: 1) pruning all infestations off of trees; 2) pruning lower branches from trees in an attempt to decrease the likelihood that a tree will become infected by falling spores; 3) "Scribing" (removing the cambium layer) around branches that have the infection (at their connection with the bole (trunk) so that it does not move into the main part of the tree. The overarching objective is to find out whether these techniques can serve to prolong the life of the tree so that it continues to reproduce seed cones. The treatment will be evaluated at 5- or 6-year intervals. In this sort of ecological setting, these trees can take up to 50 years to begin bearing seed cones.
2006-2013	Long-term management techniques – resistance screening Dr. Anna Schoettle (USFS), using transect data from 2003, and CSU/USFS tree health data from 2004, identifies trees that are "putatively resistant" – that is, *in situ* trees which are exhibiting either a resistance (no visible infestation in an area with infested trees) or tolerance (infected, but growing happily despite the infection). From these trees, seed cones are collected. A total of 60 trees or "seed families" are collected from the park. Trees have been tagged and GPSed, and that information is carefully maintained with the seed collections. See Shoettle et al. 2011. Tree seedlings are grown for two years at the USFS Dorena Genetics Research Center in Cottage Grove, Oregon, then inoculated with WPBR. Several thousand seedlings (including those from Great Sand Dunes) will be evaluated over a five-year period.
2009	Long-term management techniques – planting techniques Dr. Bill Jacobi (CSU) begins a five year study to identify "best planting techniques" at GRSA Preserve in the most infected area (Mosca Pass). This is a field test with resistant "regional" seedling stock that is planted on site using different planting techniques, to identify how tree seedlings should be placed in the field to ensure their survivability. The seedlings will be removed after the study is completed.
2009	NPS (Bovin, GRSA) submits a request to the Forest Health Protection proposal process (USFS) for funding to protect the seed trees (those from which we have collected cones) from beetle kill.
2010	Dr. Jacobi (CSU) begins a follow-up on the 2004 "Short-term management techniques" to determine whether the treatments done in 2004 appear to be effective. However, the high-intensity fire in Medano Canyon (June 2010; declared dead December 2010) interrupted this process.
2010	No funding to protect seed trees (see 2009 note) was made available. However, consultation with Dr. Schoettle (USFS) may re-define which trees should be prioritized for protection given updated information from the resistance screening research.
2011	Dr. Jacobi (CSU) returns to complete the follow up that began in 2010. Initial findings are that the WPBR infestation in Mosca Canyon is so established that many of the trees that underwent pruning treatment in 2004 have been re-infected. Other trees tagged in this study have died, are infected in the bole of the tree (usually imminent mortality), or are more severely infected compared to the initial evaluation made in 2004.

Table 2.2.1 (continued). Summary and timeline of ongoing WPBR research at GRSA.

Year	Description
2012	Dr. Jacobi's (CSU) "best-planting techniques" study was completed by a master's candidate. A final round of data gathering occurred in July 2012. Results of study are presented in Casper (2012), and will be publically available at the expiration of a 1-year embargo.
2012	Dr. Burns (USFS) follows up on transects placed in 2004. Results pending.

Native ecosystems

As used herein, the term native ecosystem corresponds to the ecological system concept as defined by Comer et al. (2003). Native ecosystems in GRSA represent a broad ecological gradient ranging from the valley floor to the crest of the Sangre de Cristo Mountains (Figure 2.2.11). Terrestrial types include a dunefield-sandsheet-sabkha complex on the valley floor, as well as grasslands, shrublands, foothill to subalpine forests and woodlands, and alpine. Riparian and wetland types include characteristic montane riparian and wetland plant communities, and a variety of wetland ecosystems on the valley floor. Native ecosystems are described in more detail below.

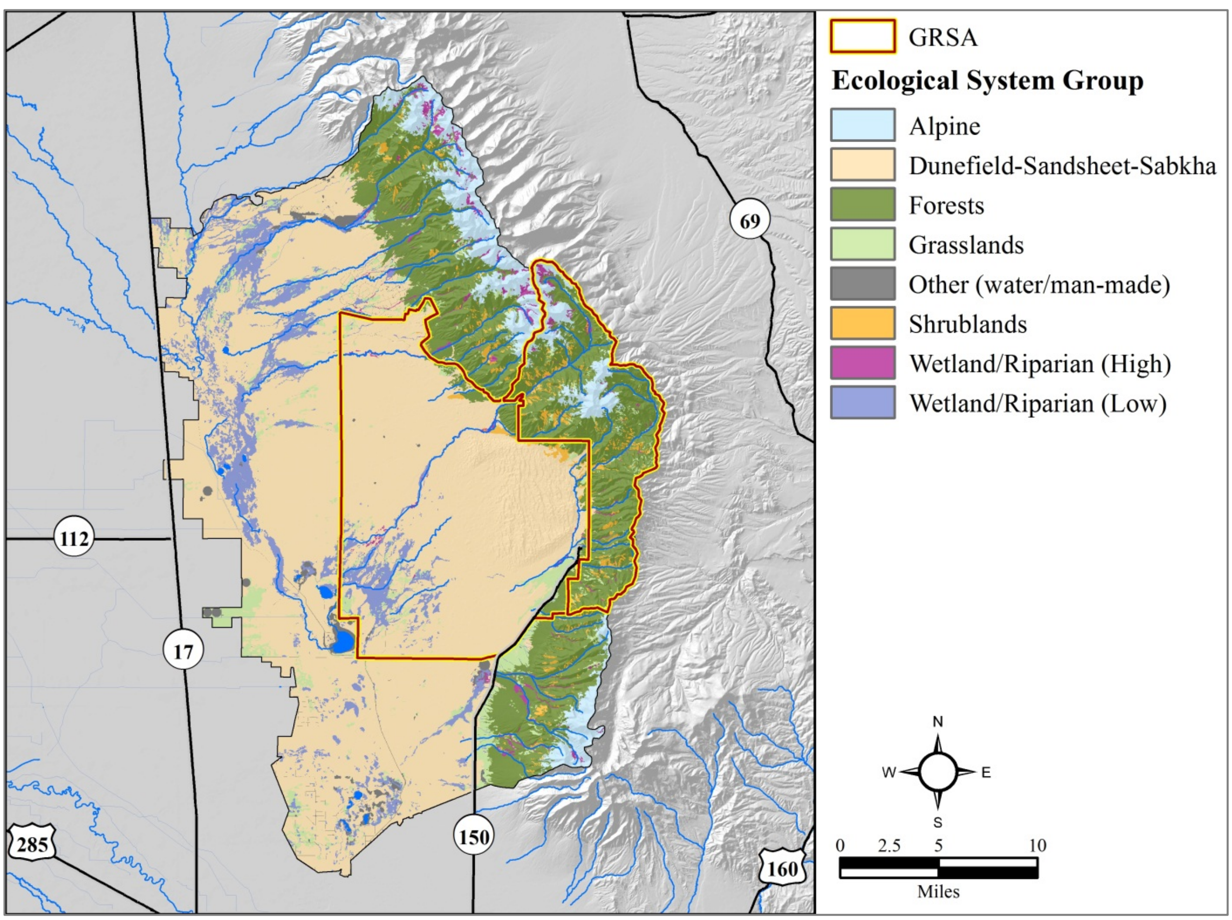

Figure 2.2.11. Vegetation mapping area and ecosystem groups.

Alpine communities

The relatively narrow span and steepness of the Sangre de Cristo Mountains in the vicinity of GRSA acts to limit the areal extent of alpine communities in comparison with those of other Colorado ranges, such as at Rocky Mountain National Park to the north. Alpine communities at GRSA occur at elevations from 10,190 ft to 14,306 ft (3,106-4,360 m), and are confined to the higher elevations of the Preserve. Alpine types cover a continuous stretch running northwest along the crest of the Sangre de Cristo Mountains from Cleveland Peak. The Sand Creek drainage separates this stretch from the alpine areas associated with Mount Herard and the upper reaches of the Medano Creek drainage. Between Medano and Mosca passes, elevations are generally too low to support alpine communities of significant extent. On the ridge north of Carbonate Mountain, contiguous stretches of alpine types resume along the mountain range crest south to the Blanca Peak massif.

There are four alpine ecosystem types in GRSA. Alpine turf vegetation (Figure 2.2.12a) is common, and is found on gentle to moderate slopes, flat ridges, valleys, and basins where the soil has become stabilized by vegetation. Sites are windswept and snow pack is thin and melts relatively early in spring. The vegetation is characterized by a dense cover of low-growing, perennial graminoids and forbs. Alpine fell fields are often intermixed with dry turf, but occur on more exposed areas and generally have higher cover of bare ground and vegetation dominated by sparse to moderate cover of cushion plant species. Because of the steepness of the alpine areas at GRSA, the most common alpine ecosystem is barren and sparsely vegetated alpine bedrock, talus, and scree slopes (Figure 2.2.12b). Alpine plants may be present in cracks and in protected microsites and are often diverse. Unvegetated glacier and ice field account for a small portion of alpine area at GRSA.

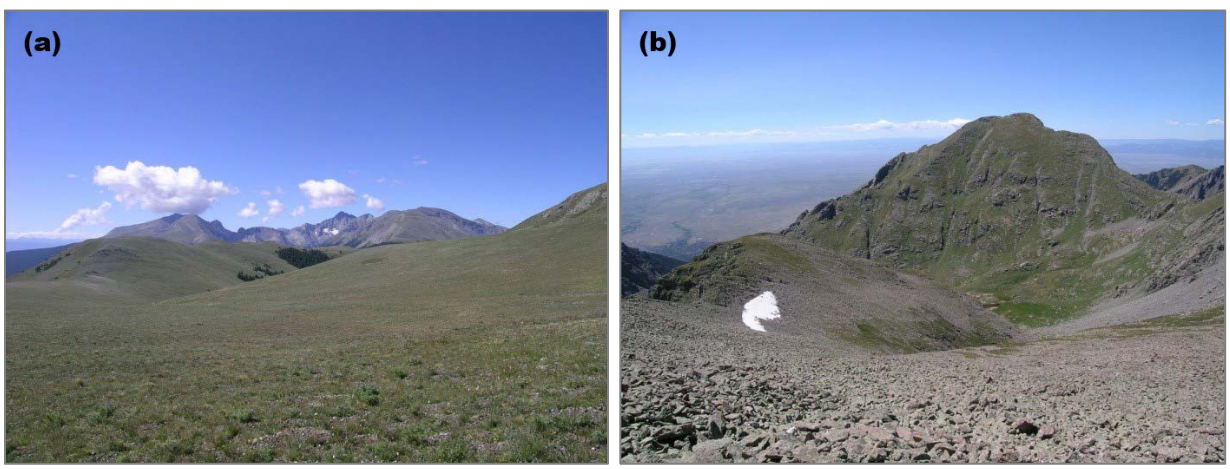

Figure 2.2.12. Alpine turf (a) and sparsely vegetated (b). Photo credits: CNHP.

Forests

Forests and woodlands are characteristic of the eastern portion of GRSA, where they form the primary vegetation type in foothills to subalpine elevations. Transition between the various woodland and forest types with increasing elevation is nicely displayed on the western flank of the Sangre de Cristos here.

Nine tree-dominated ecosystem types were identified during the vegetation mapping. At the lowest elevations pinyon-juniper woodlands occupy slopes, ridges, and alluvial fans at the base of the Sangre de Cristos (Figure 2.2.13a). Elevations are 7,690 ft to 11,095 ft (2,344-3,382 m). These open to moderately dense stands are dominated by pinyon (*Pinus edulis*) and Rocky Mountain juniper (*Juniperus scopulorum*), with a variety of understory types that may be shrubby, grassy, or sparsely vegetated. Above the pinyon-juniper, at elevations of 7,905 ft to 11,729 ft (2,409-3,575 m), ponderosa pine woodlands occur on the lower montane slopes (Figure 2.2.13b). These are open to moderately dense woodlands dominated by ponderosa pine (*Pinus ponderosa*) with scattered Rocky Mountain juniper and occasional pinyon. Scattered Douglas-fir (*Pseudotsuga menziesii*) may be present. Understories are variable and may be shrubby or grassy.

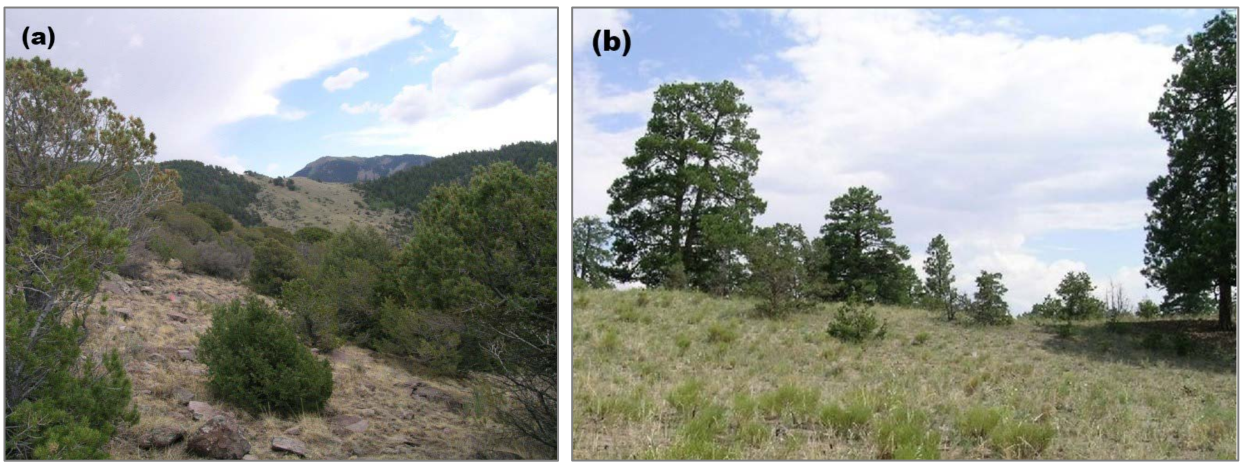

Figure 2.2.13. Pinyon-juniper (a) and ponderosa (b) woodlands. Photo credits: CNHP.

Montane elevations are characterized by a mixture of deciduous and coniferous forests and woodlands, including mixed conifer forests where Douglas-fir and white fir (*Abies concolor*) are typical co-dominants (Figure 2.2.14a). White fir is more common on relatively mesic mid to low slopes whereas Douglas-fir tends to dominate relatively drier/cooler higher elevation sites. A number of other tree species are typically present, including blue spruce (*Picea pungens*), bristlecone pine (*Pinus aristata*), pinyon, limber pine (*P. flexilis*), ponderosa pine, aspen (*Populus tremuloides*), Rocky Mountain juniper, and at higher elevations, Engelmann spruce (*Picea engelmannii*). In areas where aspen is prevalent, forest stands may be dominated by aspen alone (Figure 2.2.14b), or in combination with a variety of the same conifers, from ponderosa pine at lower elevations to Engelmann spruce at higher elevations.

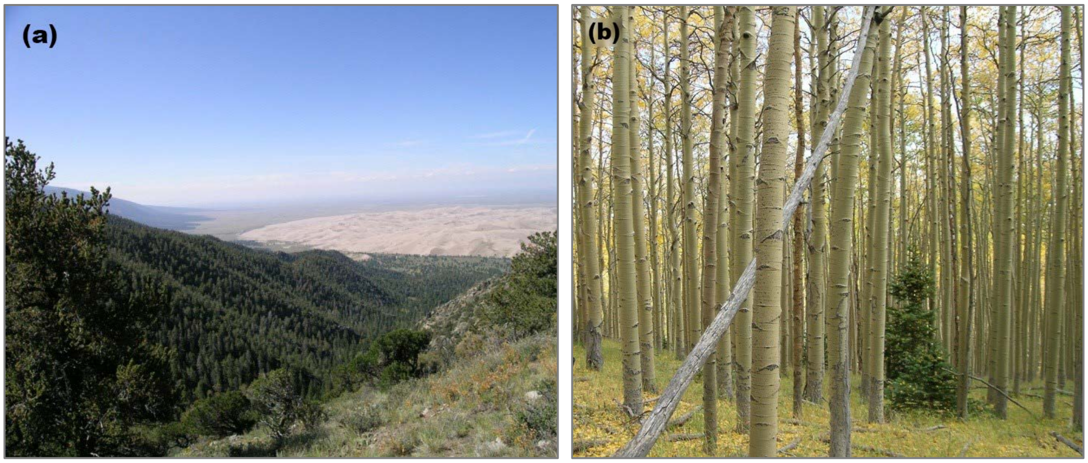

Figure 2.2.14. Mixed conifer (a), and aspen (b) forests. Photo credits: CNHP.

Above the montane mixed forests, subalpine areas at elevations ranging from 9,665 ft to 11,867 ft (2,946 - 3,617 m) on both dry and mesic sites (including avalanche chutes) are characterized by spruce-fir forests (Figure 2.2.15a) that typically have more Engelmann spruce than subalpine fir (*Abies lasiocarpa*), frequently with spruce strongly dominating the tree canopy. Understory may be sparse or moderately dense. Common species include Thurber fescue (*Festuca thurberi*)*,* common juniper (*Juniperus communis*), tall fringed bluebells (*Mertensia ciliata*), whortleberry (*Vaccinium myrtillus*), or moss.

Also present at the subalpine-alpine transition on relatively small, harsh sites often with rocky substrates are woodlands dominated by limber pine and/or bristlecone pine. Higher-elevation occurrences are found on wind-blasted, mostly west-facing slopes and exposed ridges at elevations ranging from 8,858 ft-11,811 ft (2,700-3,600 m) elevation. Limber pine stands occur in subalpine and extend down into the montane zone. Bristlecone pine stands typically occur on dry, rocky ridges and upper slopes in the subalpine zone (Figure 2.2.15b) up to treeline and may transition into krummholz. (Salas et al. 2011).

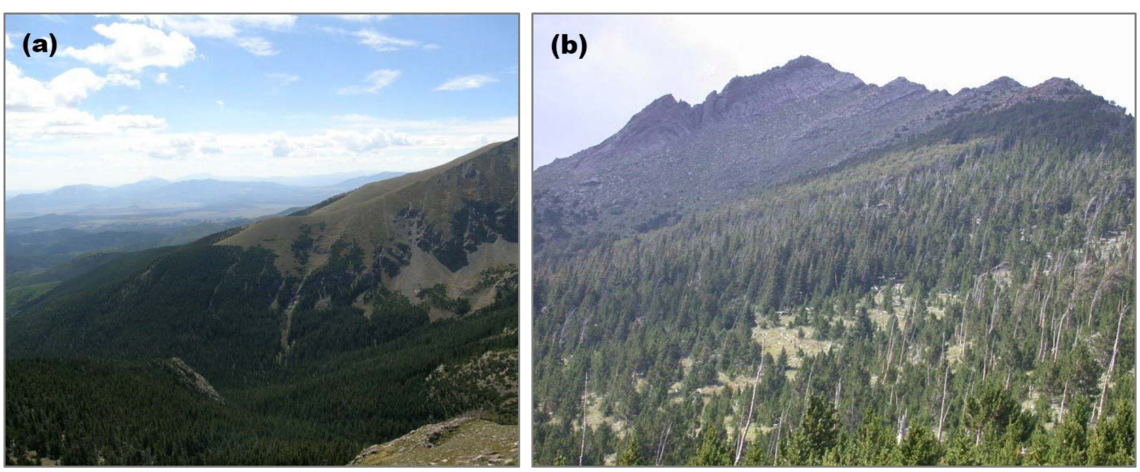

Figure 2.2.15. Spruce-fir (a) and bristlecone (b) forests. Photo credits: CNHP.

Near upper treeline at elevations of 11,571 ft-12,303 ft (3,527-3,750 m), dwarfed, shrubby conifers including subalpine fir, Engelmann spruce and/or bristlecone pine form a krummholz zone on harsh, windswept sites. Sites are nearly level to steeply sloping.

Shrublands

Non-sandsheet shrublands at GRSA are primarily montane-foothill shrublands at elevations of 7,794 ft-12,547 ft (2,376-3,824 m) and characterized by a variety of shrub species including mountain mahogany (*Cercocarpus montanus*), hillside oceanspray (*Holodiscus dumosus*), green rabbitbrush (*Chrysothamnus viscidiflorus*), Parry's rabbitbrush (*Ericameria parryi*), skunkbush sumac (*Rhus trilobata*), chokecherry (*Prunus virginiana*), currant (*Ribes* spp.), Woods' rose (*Rosa woodsii*), and mountain snowberry (*Symphoricarpos oreophilus*). Scattered trees or inclusions of grassy patches may be present. These shrublands are typically associated with dry, rocky, exposed sites where tree growth is limited (Figure 2.2.16a).

Other shrublands within the mapping area belong to the semi-desert shrub type and occur as open shrubland with patchy open grass or herbaceous understory on alluvial fans. Stands are dominated by winterfat (*Krascheninnikovia lanata*) with scattered fringed sagebrush (*Artemisia frigida*), rabbitbrush (*Chrysothamnus* and *Ericameria*) species, and prickly pear (*Opuntia polyacantha*). Historically, these dwarf-shrub communities throughout the San Luis Valley were dominated by winterfat. As a consequence of anthropogenically induced changes in grazing Green's rabbitbrush (*C. greenei*) is now the dominant shrub in the San Luis Valley, although the wetter areas still have significant amounts of winterfat (Figure 2.2.16b).

(a) (b)

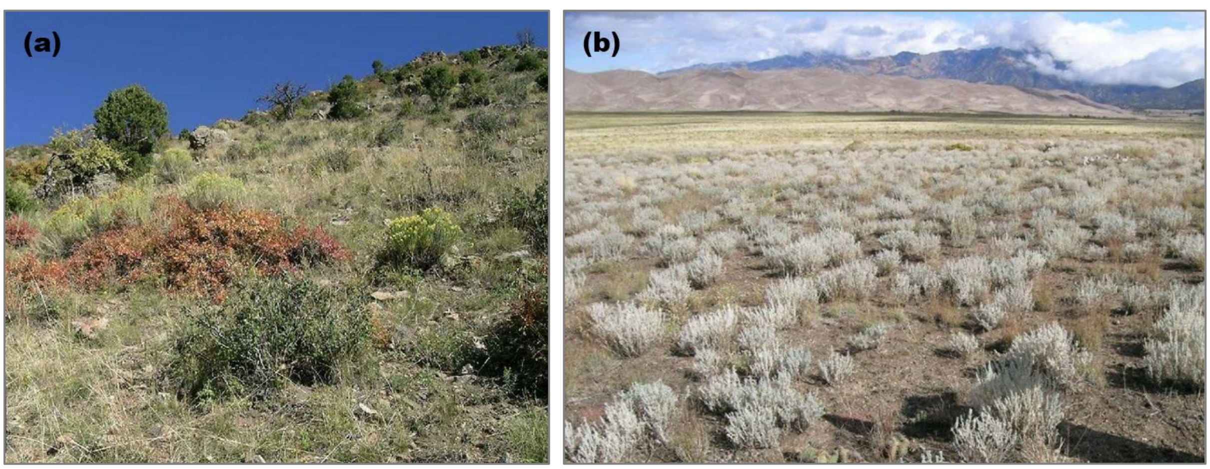

Figure 2.2.16. Montane shrubland (a) and semi-desert winterfat shrubland (b). Photo credits: CNHP.

Grasslands

Grassland ecosystems at GRSA include semi-desert grasslands occurring on rocky alluvial fans above the sandsheet on the valley floor (Figure 2.2.17a) and in openings within pinyon-juniper woodlands. Characteristic species include blue grama (*Bouteloua gracilis*), needle-and-thread (*Hesperostipa comata*), and others. Scattered rabbitbrush and prickly-pear cacti are often present. These grasslands are found at elevations of 7,511 ft-9,952 ft (2,289-3,033 m). At higher elevations, montane-subalpine grasslands occur between 7,524 ft and 12,371 ft (2,293-3,771 m) in elevation on gentle to steep colluvial slopes, ridgetops, and less commonly in valley bottoms and along upper stream terraces. Highest elevation sites are restricted to warm southerly aspects. Montane stands are typically dominated by Arizona fescue (*Festuca arizonica*), mountain muhly (*Muhlenbergia montana*), and blue grama, whereas Thurber fescue or Parry's oatgrass (*Danthonia parryi*) dominate subalpine stands. Stands may include forb dominated upland meadows. These small and large-patch grasslands are intermixed with matrix stands of spruce-fir, montane mixed conifer forests, and aspen forests (Figure 2.2.17b).

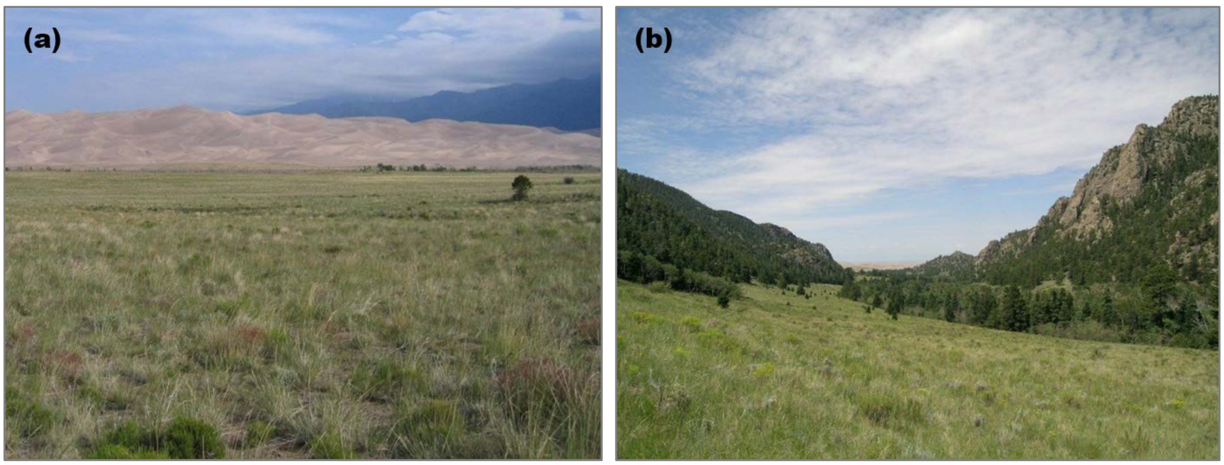

Figure 2.2.17. Semi-desert (a) and montane (b) grasslands. Photo credits: CNHP.

Dunefield-Sandsheet-Sabkha

Active and stabilized dune areas include a range of sparsely vegetated plant alliances and communities as well as barren or near barren (<5% total plant cover) portions of active sand dunes and sandsheet blowouts where scattered individuals of early seral species such as blowout grass (*Redfieldia flexuosa*) and lemon scurf-pea (*Psoralidium lanceolatum*), and sometimes Indian ricegrass (*Achnatherum hymenoides*) are the only vegetation (Figure 2.2.18a). These essentially barren areas form the heart of the dunefield.

The sandsheet alliances include limited areas with woodlands of narrowleaf cottonwood or ponderosa pine on otherwise sandy areas, as well as both shrubby and grassy areas where vegetation is acting to anchor dunes. Shrub dominated plant communities of the sandsheet (Figure 2.2.18b) are shrub steppe or shrublands dominated by rabbitbrush (*Ericameria nauseosa*) or greasewood (*Sarcobatus vermiculatus*) that may also include green rabbitbrush, snakeweed (*Gutierrezia sarothrae*), gray horsebrush (*Tetradymia canescens*), or winterfat. The typically sparse herbaceous layer is dominated by bunchgrasses including Indian ricegrass, needle-and-thread, sandhill muhly (*Muhlenbergia pungens*), or alkali sacaton (*Sporobolus airoides*). In early seral stages, vegetated dunes and sandsheet areas where shrubs are absent may be characterized by an herbaceous layer typically dominated by scurfpea and/or blowout grass, while in late seral stages Indian ricegrass, needle-and-thread or sand muhly are typical.

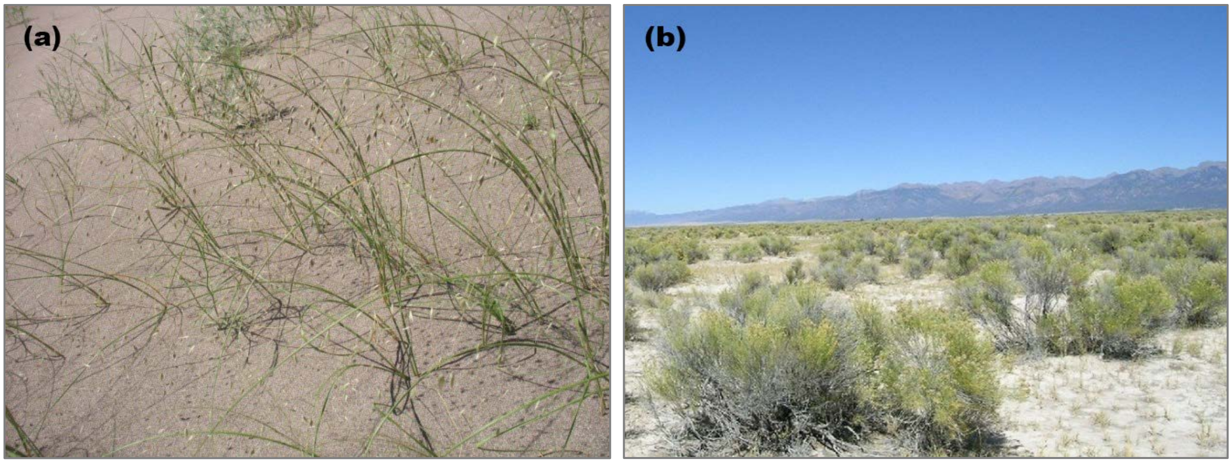

Figure 2.2.18. Sparse dune vegetation (a) and rabbitbrush shrubland (b).

On the carbonate-cemented sand substrates of the sabkha, plant communities tolerant of saline and alkaline conditions dominate. Greasewood shrublands (Figure 2.2.19a) or steppe with scattered rabbitbrush are typical. Herbaceous areas are characterized by small grassy patches dominated by saltgrass (*Distichlis spicata*) (Figure 2.2.19b) or alkali sacaton and larger areas of mesic meadows.

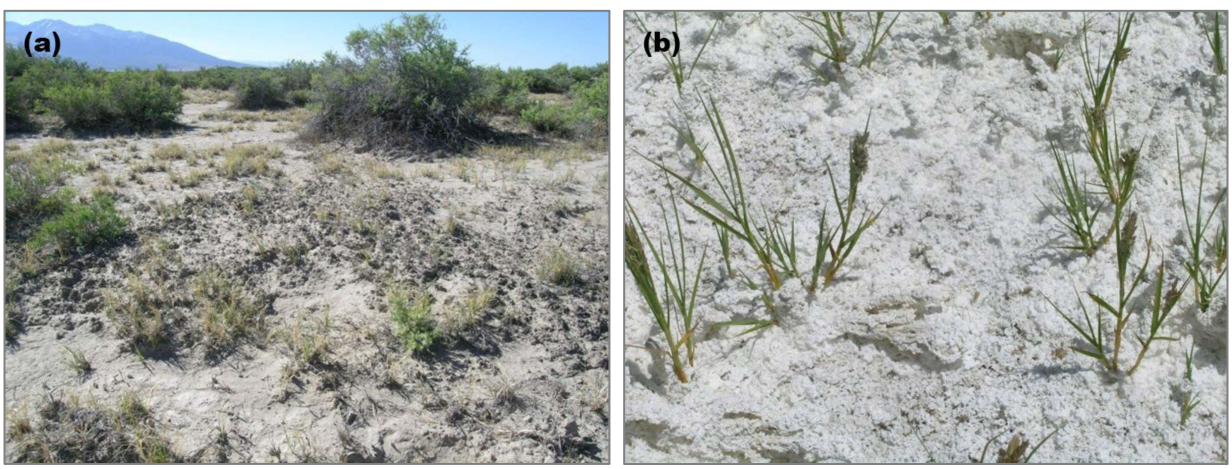

Figure 2.2.19. Greasewood shrubland (a) and saltgrass (b).

Wetland / Riparian (foothill to alpine)

Stream terraces of the lower montane and foothill elevations (and often extending onto the sandsheet), support riparian woodlands of narrowleaf cottonwood (*Populus angustifolia*) (Figure 2.2.20a). Other trees present may include aspen and scattered white fir, Douglas-fir, ponderosa pine, or Rocky Mountain juniper. These woodlands typically have an understory of shrubs and herbaceous plants. Other riparian woodlands occur as narrow bands of tall shrubs along streams and on alluvial terraces. Typical species include gray alder (*Alnus incana)*, water birch (*Betula occidentalis),* chokecherry *(Prunus virginiana),* Bebb willow *(Salix bebbiana)*, Drummond's willow (*S. drummondiana),* park willow *(S. monticola)* at lower elevations and tall planeleaf willow (*S. planifolia*) at higher elevations.

Riparian areas of the subalpine are seasonally flooded forests of floodplains and stream terraces in narrow valleys where conifers or deciduous trees dominate, or short shrublands of broad, subirrigated, snowmelt-fed alpine basins and surrounding lower slopes, and narrow bands of dense shrubs lining lakeshores and stream banks and terraces, where they are often adjacent to herbaceous wetlands (Figure 2.2.20b). Herbaceous wetlands at montane to lower subalpine elevations occur as graminoid-dominated wet meadows or narrow bands bordering ponds, lakes, and streams.

Finally, wetlands of the highest elevations include patches of short willows (*Salix planifolia* and *S. brachycarpa*) found in mesic sites such as seep areas below snow fields, and herbaceous alpine wetlands characterized by a typically dense herbaceous layer dominated or co-dominated by alpine or subalpine wetland species.

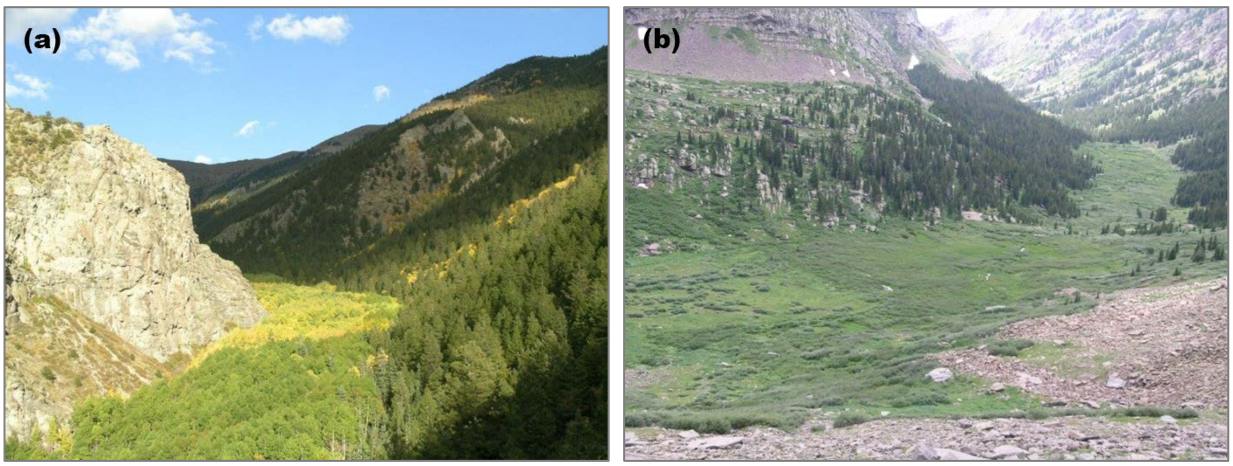

Figure 2.2.20. Lower montane riparian forest (a), and subalpine riparian shrubland (b).

Wetland / Riparian (valley floor)

Although the valley floor is generally lacking in trees, stands of narrowleaf cottonwood are associated with some streams on the sandsheet. In places the sandsheet riparian areas also support shrublands of tall willows including coyote willow (*Salix exigua*), strapleaf willow (*Salix ligulifolia*), or shining willow (*Salix lucida* ssp. *caudata*) and other tall riparian shrub species (Figure 2.2.21a). Other stream channels and washes lack riparian trees or shrubs (Figure 2.2.21b) and are characterized by herbaceous vegetation with scattered shrubs.

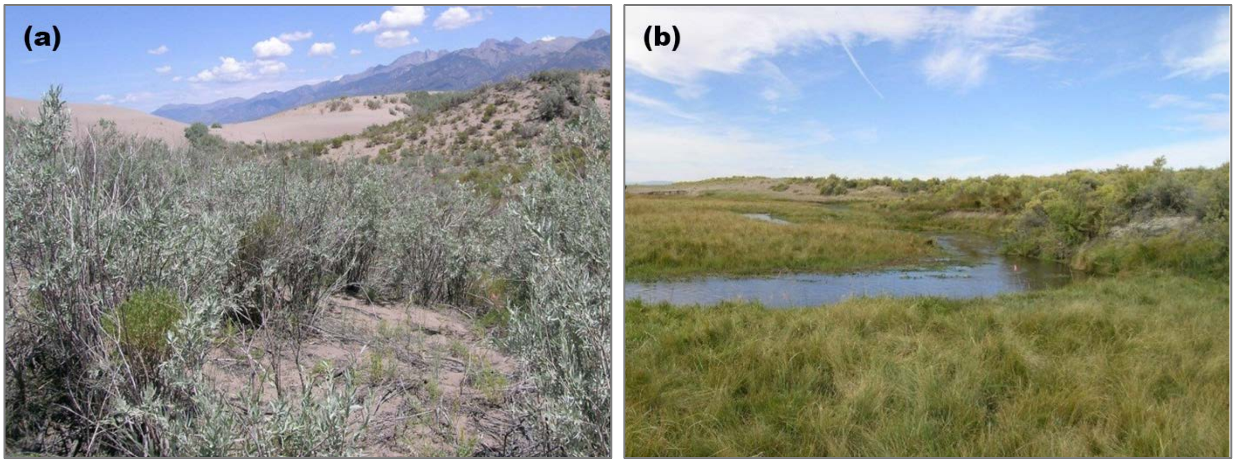

Figure 2.2.21. Sandsheet willow shrubland (a), herbaceous wetland on Big Spring Creek (b). Photo credits: CNHP.

Wetlands of the valley floor represent a selection of environments that are perennially or seasonally flooded, or subirrigated. Emergent marshes are typically associated with springs, stream terraces, and pond shores. Areas where the water table is close to the surface may have open water during all or part or the year. Vegetation is dominated by wetland sedge (*Carex*), spikerush (*Eleocharis*) and rush (*Juncus*) species, or by cattail (*Typha* spp.). Interdunal swales support groundwater-fed wetlands that have open water during part of the year (Figure 2.2.22a). Dominant species include mesic and wetland obligate graminoids, or occasionally stands of coyote willow. Other seasonally flooded or naturally subirrigated areas of the sandsheet and sabkha support mesic-graminoid dominated meadows or vegetation gradients typical of playas (Figure 2.2.22b).

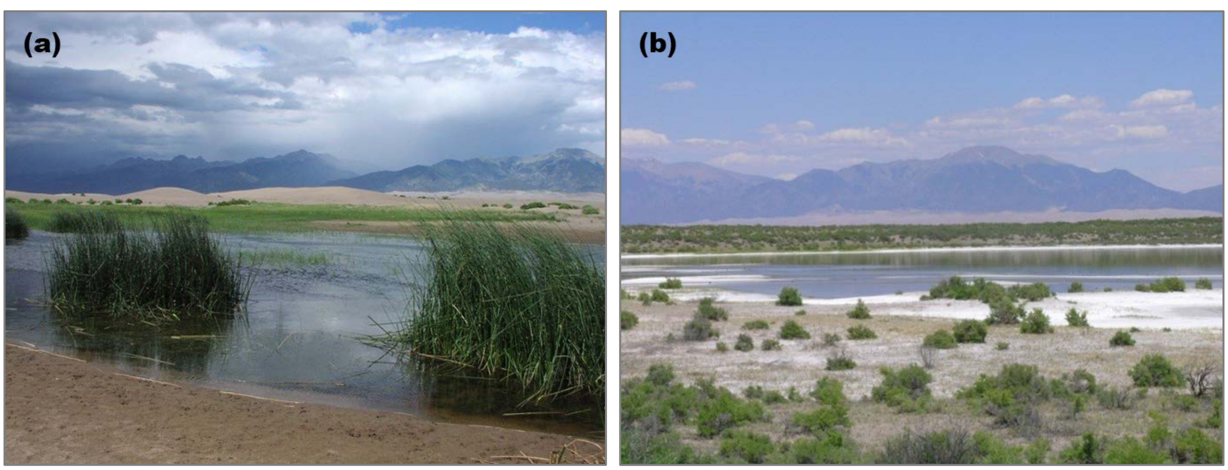

Figure 2.2.22. Interdunal wetland (a), and playa (b). Photo credits: CNHP.

Endemic Insects

Among the hundreds of more common insects, there are five beetle species and one fly believed to be endemic to the vicinity of GRSA, a species of moth that is known from only one other locale, and a camel cricket that is a regional endemic. These species are described briefly below.

Great Sand Dunes tiger beetle (*Cicindela theatina*)

Cicindela theatina (Figure 2.2.23a) is a predatory beetle that inhabits sandy areas of active dunes, sandy blowouts, or shifting sands with vegetative cover between 0.20 and 15.04 percent (Pineda and Kondratieff 2003). The beetle is typically encountered in sparsely vegetated sandy habitats where successional species like blowout grass and lanceleaf scurfpea have become established. The species is endemic to the San Luis Valley (Kippenhan 1994). Its range is restricted to about 110 mi^2 (290 km^2) (Pineda and Kondratieff 2003), due in part to the lack of additional dunefield habitat within a reasonable dispersal distance. Adult beetles as well as larvae are predatory. The adults are swift flyers and actively forage on the sand, while larvae are sedentary, ambushing passing prey from the tops of their burrows (Pineda 2002). Prey items include a variety of arthropods such as ants, small beetles, and mites crawling on the sand surface, and the adults will scavenge freshly dead insects (Pineda 2002).

Clown beetle (*Hypocaccus* undescribed species)

Tiny, black, round-bodied clown beetles (also known as hister beetles) are found in grassy margins or sandy areas of the dunes (Figure 2.2.23b). Although the adult beetles are scavengers, the larvae are predatory, probably preying on weevils (Curculionidae), scarab beetles (Scarabaeidae), and fly larvae on decaying grasses and other non-woody plants (Arnett 1968, NPS 2012).

Figure 2.2.23. Great Sand Dunes tiger beetle (a), and clown beetle (b). Photo credits: left – NPS/Phyllis Pineda Bovin, right – NPS/Patrick Myers.

Circus beetle (*Eleodes hirtipennis*)

Eleodes hirtipennis (Figure 2.2.24a), whose specific epithet means hairy wings, is a 0.5 -0.75 in (1-2 cm) long scavenging beetle of sandy habitats where vegetation is sparse (Triplehorn 2005). When threatened, a circus beetle typically lifts its abdomen so that it appears to be standing on its head, and emits a pungent chemical as a defense mechanism. The collection from which this species was described was made in a "scrubby" area near the dunes (Triplehorn 2005).

Triplehorn's Ant-like Flower Beetle and Werner's Ant-like Flower Beetle (*Amblyderus triplehorni* and *A.werneri*)
The two *Amblyderus* species (Figure 2.2.24b) are very small, light yellowish-brown colored scavenging beetles that inhabit sandy, sparsely vegetated habitats (Weissmann and Kondratieff 1999). These little-studied beetles apparently feed on insect parts that collect in small depressions in the sand. The original collection of *A. triplehorni* was made in blowout areas of the dunes (Triplehorn 2005), and Weissmann and Kondratieff (1999) reported encountering large numbers of this species in debris pockets on the southeast (downwind) side of dunes where bits of organic debris are dropped by the wind. Collections of *A. werneri* have been made in the far northwestern portion of the dune mass, and in areas adjacent to the park on the north (Weismann and Kondratieff (1999).

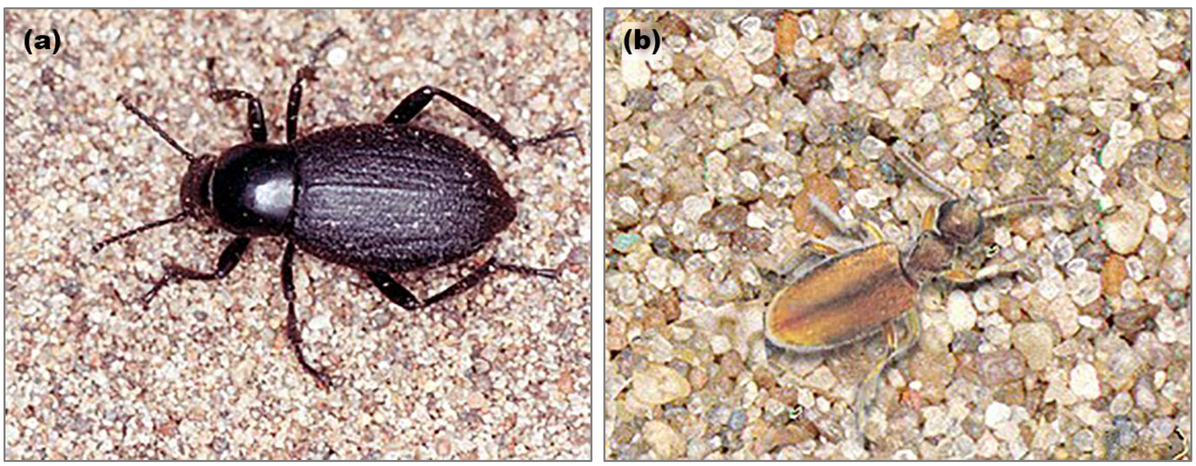

Figure 2.2.24. Circus beetle (a), and Werner's Ant-like Flower Beetle (b). Photo credits: left – NPS/Phyllis Pineda Bovin, right – NPS.

A noctuid moth (*Copablepharon pictum*)
Not much is known about this recently described noctuid moth (Figure 2.2.25a). The species has been reported from Dinosaur National Monument as well as the San Luis Valley, so is not strictly endemic to GRSA (Lafontaine 2004). Adult moths are a soft, very pale yellow color with a wingspan of about 1.5 in (3.5 cm), and are found in the sparsely vegetated and grassy margins of the dunes.

Robber fly (*Proctacanthus* undescribed species)
This large predatory insect (measuring nearly 1in or 2.5 cm in length) is found in a variety of sandy habitats, including sand/grass, sand/shrub, and bare sand environments. Robber flies prey on other flying insects (wasps, bees, and flies) during the heat of the day, after all crawling insects have taken cover from the extreme heat of the sand (Figure 2.2.25b).

Giant sand treader camel cricket (*Daihinibaenetes giganteus*)
This large camel cricket (Figure 2.2.25c) is one of the most characteristic species of the dunes and, although not endemic, was first described from GRSA (Tinkham 1962). The species was

subsequently documented in northern New Mexico and southern Utah. Weismann (1997) reported that the crickets are generally nocturnally active on the sand surface, and spend the day in subsurface burrows. They feed on both living and dead plant and animal material, and may travel up to 200 meters a night while foraging for food (Weismann 1995, 1997). Males appear to defend temporary small groups of females, as well as suitable burrowing areas, a complex mating strategy that allows them to maximize mating opportunities in the shifting dune environment (Weismann 1997).

Figure 2.2.25. Noctuid moth (a), robber fly (b), and giant sand treader camel cricket (c). Photo credits: (a) NPS, (b) NPS, (c) Photo courtesy of Dr. Whitney Cranshaw.

<u>Amphibians and reptiles</u>
Six amphibian species and seven reptile species (Table 2.2.2) have been documented from the vicinity of GRSA, and several additional species are reported from the San Luis Valley (Hahn 1968, Hammerson 1999, Muths and Street 2002). Some GRSA species, such as the tiger salamander, plateau lizard, western terrestrial garter snake, and western rattlesnake, occur in a wide variety of habitats; others are much more restricted (Hammerson 1999). In general, habitats for specialist herptile species at GRSA are relatively uncommon.

Table 2.2.2. Amphibian and reptile species documented within GRSA.

Family	Species	Common Name
Amphibians		
Ambystomatidae	*Ambystoma tigrinum*	Tiger Salamander
Bufonidae	*Anaxyrus (=Bufo) cognatus*	Great Plains Toad
Bufonidae	*Anaxyrus (=Bufo) woodhousii*	Woodhouse's Toad
Hylidae	*Pseudacris triseriata*	Striped Chorus Frog
Ranidae	*Lithobates (=Rana) pipiens*[1]	Northern Leopard Frog
Pelobatidae	*Spea (=Scaphiopus) bombifrons*	Plains Spadefoot Toad
Reptiles		
Colubridae	*Pituophis catenifer*[2]	Bullsnake
Colubridae	*Lampropeltis triangulum*	Milk Snake
Colubridae	*Thamnophis elegans*	Western Terrestrial Garter Snake
Iguanidae	*Phrynosoma hernandesi*[3]	Short-horned Lizard
Iguanidae	*Scelorporus undulatus*	Plateau Lizard
Scinidae	*Plestiodon multivirgatus epipleurotus*[4]	Variable Skink
Viperidae	*Crotalus viridis*[5]	Western Rattlesnake

[1] possibly extirpated within GRSA

[2] listed as conspecific with *P. melanoleucus* in some publications

[3] previously reported as *P. douglassii*

[4] formerly *Eumeces gaigeae* or a subspecies of *E. multivirgatus*

[5] expected to be present, but lacks conclusive documentation

<u>Other species of concern</u>

Vascular plant inventories at GRSA have documented over 600 species from the park and preserve, and there is the possibility that several hundred additional as-yet-undocumented plant species may be present (Spackman Panjabi et al. 2004, Salas et al. 2011). There are no threatened or endangered plants known to be present within GRSA. Occurrences of several rare plant species in GRSA include *Draba smithii* (Smith's draba), *Cleome multicaulis* (slender spiderflower), and James catseye (*Oreocarya pustulosa* =*Cryptantha cinerea* var. *pustulosa*).

About sixty mammal species have been documented within GRSA. Species of particular management concern include the vulnerable alpine dwelling American pika (*Ochotona princeps*) and several large ungulate species. Bison (*Bison bison*) are present on areas managed by The Nature Conservancy, and a large elk (*Cervus elaphus*) herd uses both valley and montane habitats (Figure 2.2.26). Bighorn sheep (*Ovis canadensis*) inhabit rocky open areas of the preserve, and American black bears (*Ursus americanus*) may be encountered in foothill to subalpine habitats. The park portion of GRSA is closed to hunting, but licensed hunters may hunt in Great Sand Dunes National Preserve during designated legal seasons.

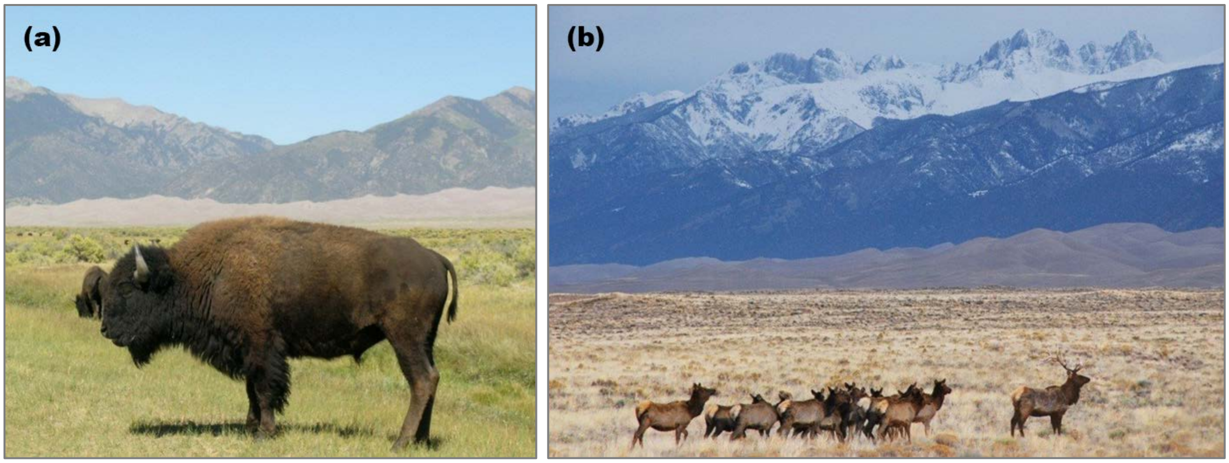

Figure 2.2.26. Bison (a), and elk (b) at GRSA. Photo credits: left – CHNP, right – NPS/Patrick Myers.

No threatened or endangered animal species are known to be present within GRSA. Native fish present within GRSA include the Rio Grande cutthroat trout (*Salmo clarki virginalis*), the Rio Grande sucker (*Castostomus plebeius*), and the Rio Grande chub (*Gila pandora*). The Rio Grande cutthroat trout is a candidate for listing, and has been reintroduced within GRSA as part of recovery efforts for the species. GRSA supports occurrences of two subspecies of pocket mouse and a subspecies of pocket gopher that are endemic to the San Luis Valley.

Invasive Species

A number of non-native plant and animal species have been documented in the vicinity of GRSA, and are discussed in more detail in chapter 4, section 4.11. Invasive plant species of primary concern at GRSA include cheatgrass (*Bromus tectorum*), Canada thistle (*Cirsium arvense*), halogeton (*Halogeton glomeratus*), perennial pepperweed (*Lepidium latifolium*), mullein (*Verbascum thapsus*), and whitetop (*Cardaria draba*). Vegetation structure and composition have a direct impact on wildlife habitat suitability. Invasion of non-native plant species is recognized as one of the most serious threats to National Park lands across the country, with approximately 5% of park lands being dominated by invasive plants (NPS 2009).

Air Quality

The National Park Service is directed by the NPS Organic Act, Wilderness Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA) of 1970 (42 U.S.C. 7401 et seq. U.S. Federal Register 1970), to protect air quality and resources that might be adversely affected by air pollution. The Organic Act directs the NPS to conserve the resources and values of parks in a way that will leave them "unimpaired" for the enjoyment of future generations, and the Wilderness Act contains a similar mandate (NPS-ARD 2011). One of the primary purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value." Under the stipulations of the CCA, GRSA is a Class I air quality area, due to its size and inclusion of wilderness areas. Class I areas receive the greatest protection and strictest regulation.

Air quality is important for both natural resources and human health. Air pollutants of concern to NPS include ground-level ozone, fine particles, sulfate, nitrate, ammonia, heavy metals (for example, mercury), and toxic organic compounds. Anthropogenic air pollution sources include mobile sources (e.g., automobiles, airplanes, trains, and other means of transportation), stationary sources (e.g., power plants, oil refineries, and other industrial facilities), and area sources (e.g., cities, agriculture). Air pollution may also come from natural sources including wind-blown dust and wildfires. All of these pollutants can have serious effects on air quality, wildlife, vegetation, lakes, streams, soils, and visibility (NPS-ARD 2002).

Figure 2.2.27. Haze in the San Luis Valley. Photo credit: CNHP/ Renée Rondeau

The Regional Haze Rule (64 Federal Register 35713, July 1, 1999, see also 40 CFR 51.300-309) requires states with mandatory Federal Class I areas (e.g., GRSA) to develop state implementation plans (SIPs) that include reasonable progress goals for improving visibility in each mandatory Federal Class I area and emission reduction measures to meet those goals (US EPA 2003). The initial control strategy SIP set reasonable progress goals for improving visibility from the 2000-2004 baseline conditions to 2018 (represented by 2014 to 2018) for each Class I area in the state, including GRSA (CDPHE 2007). Goals are to: 1) provide for an improvement in visibility for the most impaired (i.e., 20% worst) days over the period of the implementation plan, and 2) ensure no degradation in visibility (Figure 2.2.27) for the least impaired (i.e., 20% best) days over the same period. The reasonable progress goals provide for a rate of improvement sufficient to attain natural conditions by 2064.

Night sky and natural sounds
A number of National Parks including GRSA provide access to starry night skies and natural darkness, allowing the public to experience this endangered resource. The location of GRSA in a sparsely populated area of Colorado has resulted in remarkably good night sky quality (Figure 2.2.28). GRSA is an easily accessible dark sky viewing location. Natural lightscapes are essential for

nighttime scenic experiences, such as viewing a starry sky, and are also critical for maintaining nocturnal habitat.

Figure 2.2.28. GRSA night sky panorama. Photo credit: NPS/Dan Duriscoe.

National Park Service management policies define park natural soundscape resources as encompassing "all the natural sounds that occur in parks, including the physical capacity for transmitting those natural sounds and the interrelationships among park natural sounds of different frequencies and volumes" (NPS 2006), and direct the service to preserve these natural soundscapes to the greatest extent possible. Natural sounds are a park's acoustical resources and are vital to both wildlife survival and visitor experiences (Lynch et al. 2011), and are monitored by the NPS Natural Sounds and Night Skies Division (Figure 2.2.29).

Figure 2.2.29. Sound monitoring equipment at GRSA. Photo credit: NPS.

2.2.3 Resource Issues Overview

The most recent GRSA General Management Plan (NPS 2007) groups the fundamental natural resources of GRSA under two primary headings: 1) the dune system, and 2) natural diversity. These crucial topics are reflected in the treatment of natural resource condition assessments in this document.

Many resource management issues at GRSA are related to water. The dunefield-sandsheet-sabkha system which forms the iconic natural resource of GRSA is closely tied to and dependent on the functioning of natural hydrologic processes. Extensive study and litigation has highlighted the need for GRSA to maintain groundwater levels at elevations sufficient to protect the dune system resources. Management efforts to restore natural hydrologic conditions are ongoing. The quantity, quality, and distribution of water resources in GRSA also drives the extent and pattern of both native ecosystems and the species that depend on them.

The size and natural diversity of GRSA, together with its varied history of land ownership and use are a significant source of other resource management concerns. Lands on the west side of the dunefield have a history of ranching use, and the cumulative impacts of past use and continuing ungulate grazing by ranched bison and wild elk continue to be of concern in this area. Areas that have been subject to anthropogenic disturbance are also targets of control efforts for invasive plant species. The inclusion of varied foothill to subalpine forest and woodland types previously managed by the U.S. Forest Service presents new management challenges related to dynamic processes such as fire and the cycles of forest pests/pathogens. Connectivity between the preserve and adjacent USFS and USFWS lands has led to the implementation of an interagency fire-management plan for the area. The alpine portion of the preserve also includes ecosystems and species that are especially vulnerable to disturbance, pollution, and changing climate. Alpine lakes in particular are being monitored for acidification. Additional resource management concerns at the species level are the preservation of rare and endemic plants and animal species within the area.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

Prior to the 2000 expansion Great Sand Dunes National Monument operated under a master plan that was approved in 1977 (NPS 2007). Development of a new general management plan (GMP), including a wilderness study (WS) and environmental impact statement (EIS), was postponed until after the expansion, and completed in 2007. The new GMP adopted the NPS preferred alternative (Alternative 2). The former national monument already included the 35,955 acre Great Sand Dunes Wilderness Area (established by Congress in 1976), located within the former national monument. With expansion, the new national preserve includes approximately 40,000 acres of designated wilderness established in 1993 as part of the Sangre de Cristo Wilderness Area and formerly administered by the U.S. Forest Service (NPS 2007). The GMP/WS/EIS is the primary planning document providing a framework to help park managers guide programs and set priorities for resource stewardship, visitor understanding, partnerships, facilities, and operations, and is intended to guide management of the park for the next 15 to 20 years (NPS 2007). A number of other pertinent planning documents were available or in progress at the time of this assessment (Table 2.4.1).

Table 2.3.1. Planning documents available or in progress for the GRSA NRCA.

Completed	In Progress
• Water resources management plan (1997) • Greater Sand Dunes Interagency Fire Management Plan (2006) • GMP/WS/EIS (2007) • Boundary Piezometer Installation EA (2009) • Baca Mountain Tract Amendment #6 & Camino Chamisa Access Road EA (2009, with USFS) • Restoration of Gravel Pits along Sand Creek within Great Sand Dunes National Park and Preserve, Saguache County, Colorado (2010)	• Ungulate Management Plan/EIS • Sangre de Cristo National Heritage Area Management Plan

In addition to the 2007 GMP/WS/EIS, and other planning documents, the Rocky Mountain Inventory and Monitoring Network (ROMN) program has produced a vital signs monitoring plan (Britten et al. 2007) that identifies high-priority vital signs addressed in this assessment (Table 2.4.2).

Table 2.3.2. ROMN high-priority and additional vital signs. Shaded vital signs are addressed in this assessment. Signs marked by * are candidate signs, of lesser priority.

National Level 1	National Level 2	National Level 3	ROMN Vital Sign
Landscapes (Ecosystem Pattern and Processes)	Landscape Dynamics	Land Cover and Use	Landscape Dynamics
	Fire and Fuel Dynamics	Fire and Fuel Dynamics	Fuel*
	Viewscape	Viewscape/Dark Night Sky	Dark Night Sky *
Air and Climate	Air Quality	Wet and Dry Deposition	Wet and Dry Deposition
	Weather and Climate	Weather and Climate	Weather and Climate
Water	Hydrology	Groundwater Dynamics	Groundwater Dynamics
		Surface Water Dynamics	Surface Water Dynamics
	Water Quality	Aquatic Macro-invertebrates and Algae	Freshwater Communities
		Water Chemistry	Water Chemistry
Geology and Soils	Geomorphology	Stream/River Channel Characteristics	Surface Water Dynamics
		Soil Function and Dynamics (Alpine)	Vegetation Composition, Structure, and Soils
		Soil Function and Dynamics (Grasslands)	Vegetation Composition, Structure, and Soils
Biological Integrity	Focal Species or Communities	Freshwater Communities	Freshwater Communities
		Riparian Communities	Freshwater Communities
		Wetland Communities	Wetland Communities
		Sparsely Vegetated Communities (Alpine)	Vegetation Composition, Structure, and Soils
		Grassland Vegetation	Vegetation Composition, Structure, and Soils
		Vegetation Communities*	Vegetation Composition and Structure*
		Insect Communities	GRSA Endemic Insects
		Mammals	Beaver
			Elk
		Amphibians and Reptiles	Reptiles (assemblages)*
	Invasive Species	Invasive/Exotic Animals	Invasive/Exotic Aquatic Biota
		Invasive/Exotic Plants	Invasive/Exotic Aquatic Biota
			Invasive/Exotic Plants
	Infestations and Disease	Animal Diseases, Insect Pests, and Plant Diseases	Pathogens*

2.3.2 Status of Supporting Science

Many of the resource topics included in this assessment have ongoing pertinent research. Wherever possible, the most recent data available was used to assess condition or to develop reference conditions. In some instances, data from current research was not available in an appropriate format or timely manner for the assessment, and surrogates were developed. Data and publications from park staff, ROMN Program staff, research by other scientists and programs, and subject matter experts provided significant information pertaining to all sections of this assessment.

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Chapter 3: Study Scoping and Design

This Natural Resource Condition Assessment is a collaborative project between GRSA, ROMN, and Colorado Natural Heritage Program (CNHP) staff. The purpose is to provide an evaluation of park resource trends and conditions for the period during which information was collected. Resources to be evaluated were identified and agreed on by the project team. Project findings will contribute to staff efforts to:

- Prioritize upcoming management activities
- Engage in regional partnership and education efforts
- Conduct park planning (e.g., compliance, Resource Stewardship Strategy, resource management plans)

3.1 Preliminary Scoping

Participants in the initial scoping conference included park natural resources staff, ROMN network staff, Natural Resource Stewardship and Science Directorate- Biological Resources Division (NRSS-BRD) staff, Colorado Natural Heritage Program ecologists, and cooperators from NatureServe and Sound-Science. During subsequent meetings, the list of resources to include in this assessment was developed and revised. Primary tasks were:

1. Preparation of a detailed summary of important resource management issues for park staff, and subsequent identification of resources that could be evaluated within the scope of the NRCA. This was accomplished during an onsite meeting at the park that included park and network staff and CNHP ecologists.
2. Selection and revision of a framework under which the assessment could be conducted and results presented. This task was accomplished through a series of conference calls and meetings involving NatureServe, Sound-Science, GRSA staff, ROMN staff, and CNHP ecologists.
3. Identification of data sources and analysis techniques for each resource. Data sources were identified both during the previous two tasks, and by CNHP staff during analysis.
4. Scope or “footprint” of the assessment. The scope of the assessment was first discussed at the original meeting, and acknowledged as variable depending on resource and data. Analysis areas were finalized during subsequent discussions.
5. Park natural resource staff, network staff, and CNHP staff participated in project development, planning, and writing. Additional subject matter experts reviewed interim and final products. For a complete list of team members and contributors, please see Appendix A.

3.2 Study Design

3.2.1 Indicator Framework, Focal Study Resources and Indicators

During meetings, we first used the NatureServe EIA framework as a tool to focus our preliminary analysis in the identification of stressors and reference conditions, and to ensure that all park environments were considered during the identification of potential resource assessments. In the interests of clarity and conciseness, resource components identified under the EIA framework were subsequently grouped into the NPS NRCA framework option (NPS 2009) adapted from "The State of the Nation's Ecosystems" Initiative (Heinz Center, 2008).

For the purposes of this assessment, we grouped 14 resources into six categories under three broad topics (Table 3.2.1). Reporting categories for the assessment follow the NPS framework.

Biological assessment (including natural resource assessment) is driven by comparison of current condition to "natural" conditions, that is, conditions in the absence of human disturbance. The reference condition concept is closely interwoven with a number of topics in ecology and natural resource assessment (e.g., ecoregion delineation, Bermans 2002; restoration, Shinneman et al. 2008; adaptive management, Baron et al. 2009). Defining a reference condition for a particular natural resource requires an understanding of the biological components, patterns, and dynamics that differentiate the resource within the background environment. This description or characterization is used to identify indicators of trend and condition, potential thresholds, and metrics that are responsive to change in condition. Reference condition implies a comparison with conditions at other times or places, thus, a period and/or site of reference is typically a component. Finally, the reference condition is meant to provide a target or focus for management goals and objectives.

The delineation of a reference time-period links reference conditions directly to the concept of the historical range of variation (HRV) and related ideas. Historical ecology can be useful for placing both individual species and vegetation communities in a larger context of temporal and spatial dynamics and clarifying the separation of natural and cultural changes (Swetnam et al. 1999). Increasing discussion of HRV has led to the explicit realization that the choice of reference period has a significant impact on the related reference condition (Jackson 2006, 2012). Scale is also a key determinant of reference condition (Turner et al. 1993, Hayward et al. 2012). Moreover, the reference condition concept is inextricably bound to human alteration of the landscape, which has varied in extent, timing, and intensity (Vance 2009), often in undocumented fashion. The realization that human-disturbance gradients can help define reference conditions has led many researchers to adopt definitions based on Stoddard et al. (2006).

A number of NPS programs, including the NRCA program, have adopted the following formal definition of reference condition (NPS 2012):

> *Reference Condition: A quantifiable or otherwise objective value or range of values for an Indicator or Specific Measure of Condition that is intended to provide context for comparison with the Current Condition values. The Reference Condition is intended to represent an acceptable resource condition, with appropriate information and scientific or scholarly*

consensus. The Reference Condition might be based on a regulatory or program standards, historical data, data from relatively undisturbed sites, predictive models, or expert opinion.

Table 3.2.1. Final GRSA NRCA framework.

Topic	Resource	Indicators and Measures
Landscape Level Patterns		
Extent & condition of natural landscape	Landscape condition	• Landscape disturbance index score
	Landscape composition and connectivity	• Ecosystem diversity • Presence of large patches • Connectivity
Natural processes	Hydrology	• Surface water flows and hydrograph phenology • Groundwater elevations and dynamics
	Dune system	• Period of record data for wind and precipitation • Current size and distribution of dune system components
	Fire	• Fire extent and frequency – regional and local • Proportion of each ecosystem group in condition classes
	Forest pests and pathogens	• Native forest-damage causing agents: natural patterns within a historic range of variation. • Presence of WPBR, and levels of infection
Biological Integrity		
Native ecosystems	Alpine Forests Shrublands Grasslands Dunefield-Sandsheet-Sabkha Wetland - Riparian (preserve) Wetland - Riparian (valley floor)	• Representation of regional native ecosystem types • Condition of native ecosystem types • Landscape context of native ecosystem types • Floristic quality index (Mean C), biodiversity, fine-scale mosaic (exotics)
Species	Endemic insects	• Presence/absence of individuals • Presence/extent of sparsely vegetated sandy habitat
	Amphibians and reptiles	• Presence/absence of individuals • Presence of suitable habitat
	Other species of concern	• Presence of individuals • Presence/extent of suitable habitat for rare plant species
	Invasive / exotic plants and aquatics	• Presence of species with high invasive potential • Presence or dominance of other non-native species
Supporting Environment		
Air quality	Air quality	• Visibility haze index • Level of ozone • Atmospheric wet deposition in total N and total S
Visitor experience	Night sky	• Bortle Dark-Sky Scale • Typical Limiting Magnitude • Sky brightness (SQM) • Anthropogenic Light Ratio (ALR)

Table 3.2.1 (continued). Final GRSA NRCA framework.

Topic	Resource	Indicators and Measures
Supporting Environment (continued)		
Visitor experience (continued)	Soundscapes and Acoustic Resources	• Day/Night median dBA • Percent of time aircraft and other extrinsic noise audible • Percent of time sound levels exceed thresholds.

For this assessment, reference conditions are intended to provide a benchmark that will allow comparison of current conditions with: a) past or desired conditions, and b) conditions at some point in the future. For most resources, we attempted to identify reference conditions that represent either a baseline of current conditions, or a set of desired conditions. For landscape condition, connectivity, and natural vegetation, minimally disturbed condition (*sensu* Stoddard et al. 2006) is the basis of our reference condition. Because most indicators used in this assessment do not have established quantifiable reference conditions available, we attempted to present current conditions at the park in a regional context. For resources lacking explicit ranking direction provided by NPS, and for which multiple indicators were used, we adopted the approach of using the lowest rank among indicators as the overall resource condition.

3.2.2 Reporting Areas

Results were summarized at several scales, and relative comparisons made across a number of land units (Figure 3.2.1). Landscape-scale analyses (sections 4.1 and 4.2) were done at a regional level that encompassed the four sub-basin (8-digit Hydrologic Unit Code) watersheds of the San Luis Valley (San Luis, Saguache, Alamos-Trinchera, and Conejos) that were then buffered out by 5 miles in order to include the full mountain ranges on either side of the valley. This area is approximately 5.4 million acres in size. Additional landscape-level processes (sections 4.3 through 4.6) were evaluated at approximately the same scale, depending on data availability and appropriateness.

Our second primary analysis level was the boundary of the vegetation map created by Salas et al. (2011). This area is approximately 413,000 acres in size and reflects the U.S. Forest Service fire management plan area. The final level of summary was the modern park and preserve boundary itself. Which level was used depended on the scale and scope of the data being used.

At the landscape-scale level, summary comparisons were made between the full analysis area, the San Luis Valley (the area of the valley bottom within Colorado), the full boundary of GRSA, just the park, and just the preserve. At the vegetation map level, summary comparisons were made between the full GRSA boundary, the park, the preserve, and the area of the vegetation map boundary outside of GRSA.

3.2.3 General Approach and Methods

This Natural Resource Condition Assessment involved collecting existing park documents, data, geospatial information, and literature for each of the resources listed in the framework (Table 3.2.1). Available information was used to determine indicators and measures that could be evaluated for each resource. Data were analyzed and summarized for graphical or spatial representation as appropriate. Qualitative statements comparing the current condition(s) to reference condition(s) were used to summarize the resource.

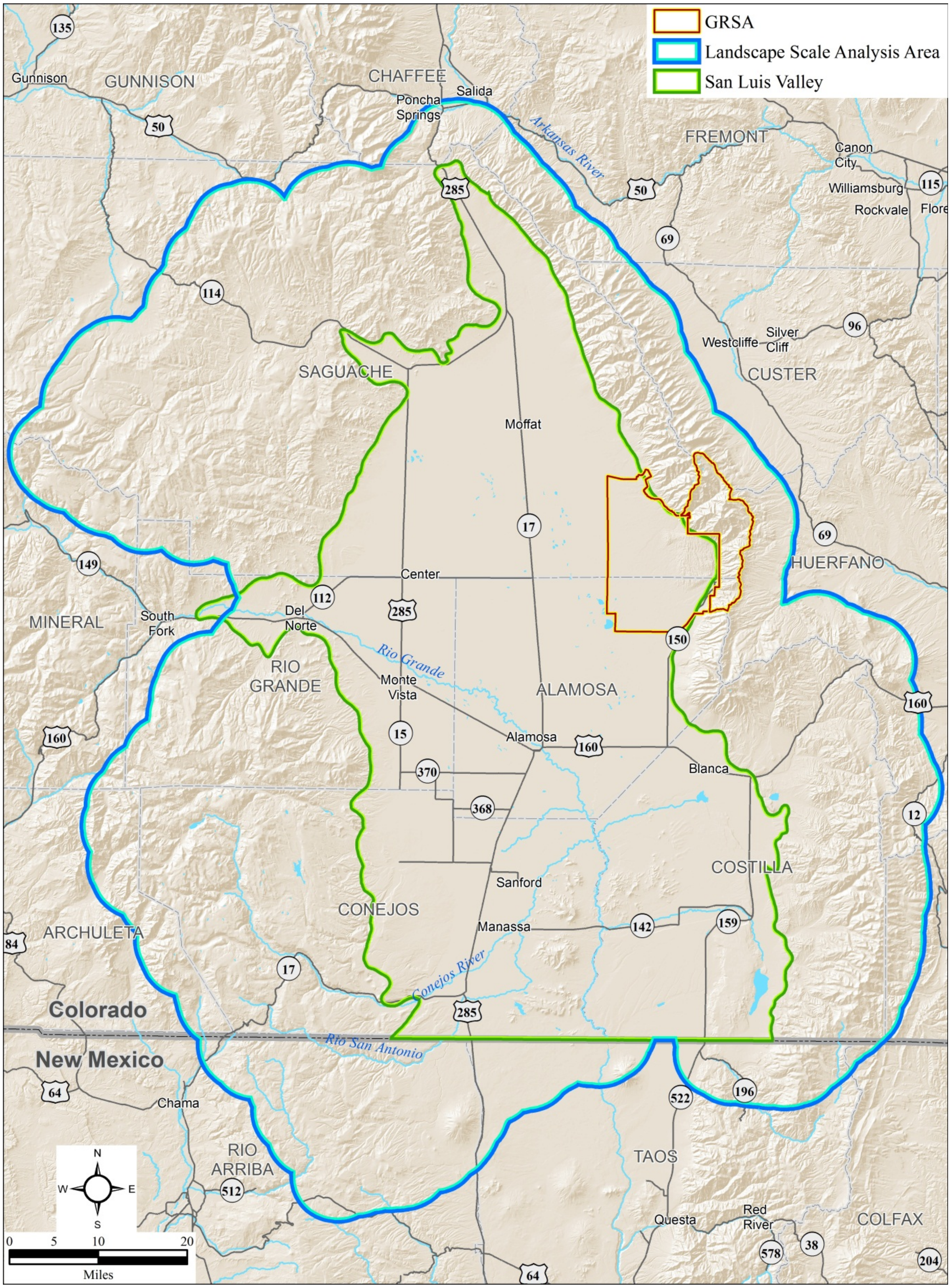

Figure 3.2.1. GRSA analysis boundaries.

Review of Assessments

Draft assessment chapters were reviewed by subject matter experts, network staff, and park staff, and comments or revisions were incorporated as received. The completed document was also reviewed by network and park staff. The final assessments represent the most relevant current data available for each resource topic, based on the recommendations and insight provided by park staff, researchers, subject matter experts, and assessment writers.

Assessment Format

Resource condition assessments are presented in a standard format. At the head of each chapter, the indicators and measures for that resource are summarized as bullets, and a condition/trend graphic provides a quick visual reference for the condition, trend, and confidence level of the indicators and measures. Figure 3.2.2 shows the condition/trend scorecard used to describe each indicator/measure, and the examples of interpretation.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low
Examples of how the symbols should be interpreted:					
	Resource is in good condition; its condition is improving; high confidence in the assessment.				
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.				
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.				

Figure 3.2.2. Condition, trend, and confidence level key used in the GRSA NRCA.

Circle colors indicate condition or concern. Red circles signify that a resource is of significant concern to park management; yellow circles signify that a resource is of moderate concern to park management; green circles indicate that an indicator is currently in good condition. Within each circle, arrows show the trend in condition for the resource indicator. Arrows inside of the circles signify the trend of the indicator/measure's condition. Upward pointing arrows signify that the indicator is improving; two-way horizontal pointing arrows signify that the indicator's condition is currently stable; downward pointing arrows indicate that the indicator's condition is deteriorating. Finally, the border of the circle indicates the confidence level in the assessment of trend and condition. A solid thick border signifies high confidence; a solid thin border indicates a moderate confidence level; a dashed border signifies low confidence.

Background and Importance

This section provides information regarding the relevance of the resource to the park. This section also explains the characteristics of the resource that help the reader understand subsequent sections of the document.

Data and Methods

This section describes the existing datasets used for evaluating the indicators/measures. Methods used for processing or evaluating the data are also discussed where applicable. The indicators/measures are listed in this section as well, describing how we measured or qualitatively assessed the natural resource topic.

Reference Conditions

This section explains the reference conditions that were used to evaluate the current condition for each indicator. Additionally, explanations of available data and literature that describe the reference conditions are located in this section.

Condition and Trend

This section provides a summary of the condition and trend of the indicator/measure at GRSA based on available literature, data, and expert opinions. This section highlights the key elements used in defining the condition and trend designation, represented by the condition/trend graphic, located at the beginning of each resource topic.

The level of confidence and key uncertainties are also included in the condition and trend section. This provides a summary of the unknown information and uncertainties due to lack of data, literature, and expert opinion, as well as our level of confidence about the presented information.

Sources of Expertise

Individuals who were consulted for the focal study resources are listed in this section, along with their agency affiliation, title, and contribution to the assessment.

Literature Cited

This section lists all of the referenced sources. When possible, links to websites are also included.

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Chapter 4: Natural Resource Conditions

Sub-headings in this chapter present the background and importance, methods, and condition assessment for each natural resource evaluated for GRSA. Resource condition indicators with their condition/trend/confidence symbol are summarized below (Table 4.1), and page numbers for each resource section are shown.

Table 4.1. Summary of Natural Resource Conditions at GRSA.

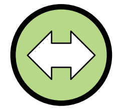
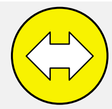
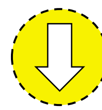
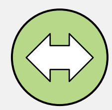
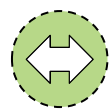
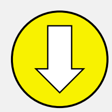
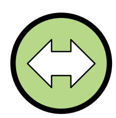
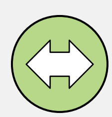
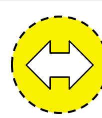
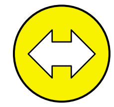
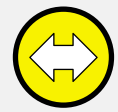
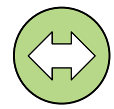
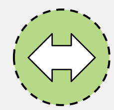
Resource	Indicator	Status/Trend/ Confidence
Landscape condition	• Landscape disturbance index score	
Landscape composition and connectivity	• Ecosystem diversity • Presence of large patches • Connectivity	
Hydrology	• Surface water flows and hydrograph phenology • Groundwater elevations and dynamics	
Dune system	• Period of record data for wind and precipitation • Current size and distribution of dune system components	
Fire	• Fire extent and frequency – regional and local • Proportion of each ecosystem group in condition classes	
Forest pests & pathogens	• Native forest-damage causing agents: natural patterns within a historic range of variation. • Presence of WPBR, and levels of infection	
Native ecosystems	• Representation of regional native ecosystem types • Condition of native ecosystem types • Landscape context of native ecosystem types • FQI, biodiversity, fine-scale mosaic (exotics)	
Endemic insects	• Presence/absence of individuals • Presence/extent of sparsely vegetated sandy habitat	
Amphibians & reptiles	• Presence/absence of individuals • Presence of suitable habitat	
Other species of concern	• Presence of individuals • Presence/extent of suitable habitat for rare plant species	

Table 4.1 (continued). Summary of Natural Resource Conditions at GRSA.

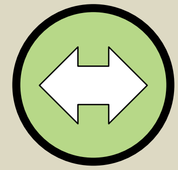
Resource	Indicator	Status/Trend/ Confidence
Invasive / exotic plants and aquatics	• Presence of species with high invasive potential • Presence or dominance of other non-native species	
Air quality	• Visibility haze index • Level of ozone • Atmospheric wet deposition in total N and total S	
Night sky	• Bortle Dark-Sky Scale • Typical Limiting Magnitude • Sky brightness (SQM) • Anthropogenic Light Ratio (ALR)	
Soundscapes and Acoustic Resources	• Day/Night median dBA • Percent of time aircraft and other extrinsic noise audible • Percent of time sound levels exceed thresholds.	

4.1 Landscape Condition

Indicators / Measures

- Landscape Disturbance Index

Condition – Trend



4.1.1 Background and Importance

Pickett and White (1985) defined disturbance as

> *any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." Natural disturbance in terrestrial ecosystems due to wildfire, severe weather events (wind, flooding, etc.), drought, landslide, animal activity, or other factors is an ongoing process and determinant of patterns in functioning ecosystems, communities, and populations. Natural disturbance regimes have now in many locations been disrupted, overlain, or replaced by a variety of anthropogenic disturbances that may have different extents, impacts, and frequencies than those that pertained to an area before human settlement* (Walker 2011).

The recognition that the most viable habitats are likely to be located in areas least altered by human activity highlights the importance of considering the landscape context of GRSA's natural resources. Landscape condition is an integrated measure of the quality of the ecological processes maintaining the natural resources of an area. Ecological processes are often not amenable to direct measurement or modeling, especially over large landscapes. As a surrogate for directly measuring the condition of the landscape, we modeled the location and intensity of anthropogenic disturbances in the landscape, making the broad assumption that these disturbances are affecting the quality and quantity of the landscape processes, and, by extension, having an impact on the elements of biodiversity supported by that area. Furthermore, we assume that the effects of anthropogenic changes to the landscape extend by varying degrees some distance out into the surrounding environment, beyond the actual footprint of disturbance. The effect generally decreases with increasing distance, conforming to Tobler's first law of geography: "*Everything is related to everything else, but near things are more related than distant things.*" (Tobler 1970, p.236).

While spatially displayed data are several steps removed from "reality," and cannot fully replace on-the-ground evaluation of conservation targets, GIS can provide a powerful tool for spatial modeling of landscape condition, one that is especially useful for analysis at a landscape scale. A variety of data can be used to develop such a model. We focused on mappable forms of anthropogenic disturbance such as roads, mines, oil wells, tilled land, etc., in combination with a spatial analysis method known as "distance decay" that incorporates a decrease in effect of these disturbances with increasing distance, to produce a model of landscape disturbance. The distance-decay model of landscape disturbance is a cumulative, continuous surface of relative impact, not merely a present vs.

absent depiction of a particular disturbance. Although we cannot directly address historical rates of disturbance through this method, the method includes disturbances that are currently mappable, and may have been in place for many decades.

We used a landscape disturbance index score to evaluate the condition of the landscape at GRSA, both within the park and preserve and in comparison to the entire analysis area.

4.1.2 Data and Methods

The methods used in this assessment were originally developed for statewide and ecoregional landscape disturbance/integrity models (Tuffly and Comer 2005, Neely et al. 2006, Beh et al. 2009, Rondeau et al. 2011). Methods used in this assessment are discussed in greater detail in Appendix B. These methods are applicable at varying scales, with adjustment in weights and distance decay curves as needed to represent local conditions. However, the state- and nation-wide datasets previously generated are at a scale that is inappropriate for analysis at the level of the San Luis Valley. Consistent, complete, appropriately scaled, and relevant spatial datasets rarely exist for multi-county areas, particularly if they cross state boundaries as well. Therefore, our first focus was on evaluating available datasets representing anthropogenic disturbance and modifying them as necessary to correct for errors in accuracy and precision within our landscape-scale analysis boundary for this project.

After evaluating available data, we decided to include datasets representing urban and industrial development, resource extraction and development (including oil and gas wells, solar installations, and surface mining), tilled agriculture, and roads. Transmission lines (telephone/ data and electricity) and pipelines were considered but not included because readily available datasets are of poor quality and coarse scale. Many, but not all, transmission lines follow roads, so the inclusion of roads may be sufficient. Known locations of wind turbines were reviewed and determined not to be present in the area of concern. Hydrological modifications, such as canals, dams, diversions, and water wells are known to be a significant anthropogenic disturbance to the natural hydrology of the San Luis Valley. The effects of these modifications, however, do not manifest as surface disturbances in the same way as housing development, agriculture, or surface mining. Most canals are bounded by maintenance roads, which we took care to represent in the roads component. Inputs for oil and gas as well as tilled agriculture also largely account for the surface disturbance of water wells, diversions, and canals.

The selected input data layers (Table 4.1.1) are not mutually exclusive in the impacts they represent, but were chosen to complement one another in order to compensate for incomplete or inaccurate source data. For example, urban and industrial development does not exist in the absence of roads, but the increasing prevalence of exurban, or dispersed, housing development is not by itself spatially represented except by the presence of roads. Likewise, every gas well has a road leading up to it, but such rapidly and recently created roads are not represented in available spatial datasets. In our modifications to datasets, it was far more efficient to digitize not otherwise represented well pads than their roads, and so the distance decay curve used for wells was designed to represent not just the impact of the well pad itself, but to serve as a proxy for the impact of the road to it as well.

Table 4.1.1. Data sources used as inputs in a Landscape Disturbance Index model for the San Luis Valley.

Impact Type	Data Source	Date	Citation	Type
Urban/Industrial Development - CO	Basinwide	2004	CDOW 2004	Raster
Urban/Industrial Development - NM	Southwest Regional GAP	2004	USGS 2004	Raster
Cultivated agriculture - CO	CVCP	2004	CDOW 2004	Raster
Cultivated agriculture - NM	Southwest Regional GAP	2004	USGS 2004	Raster
Other agricultural use	Southwest Regional GAP	2004	USGS 2004	Raster
Roads	TIGER/Line	2011	USCB 2011	Polyline
Oil and Gas Wells	CO Oil and Gas Wells	2012	COGCC 2012	Point
	NM Oil and Gas Wells	2009-2010	NMSLO 2009 BLM 2010	Point
Surface Mines	Mineral Resources Dataset	2012	USGS 2012	Point
Solar Plants	CNHP created	2012	CNHP 2012	Polygon

Each dataset was reviewed against recent aerial photography (Microsoft 2010 and NAIP 2011) and manually edited as necessary to create as accurate a spatial representation of each impact as was practical within the time and budget constraints of the project. The final datasets used in the landscape disturbance model are still only an approximation of actual impacts, but we felt that the effort spent reviewing and editing them allowed for a better product than would have been possible using unaltered broad-scale data (Figure 4.1.1). We analyzed landscape condition as scored by a landscape disturbance metric, within a regional context only, and did not develop a separate park-level landscape disturbance surface. The cumulative disturbance scores from the combined datasets were re-classified (Table 4.1.2) from no impact (0) to very high impact (>100).

Table 4.1.2. Classification of anthropogenic disturbance.

Disturbance Level	Impact Weight
None	0
Very Low	> 0 - 25
Moderate-Low	> 25 - 50
Moderate-High	> 50 - 75
High	> 75 - 100
Very High	> 100

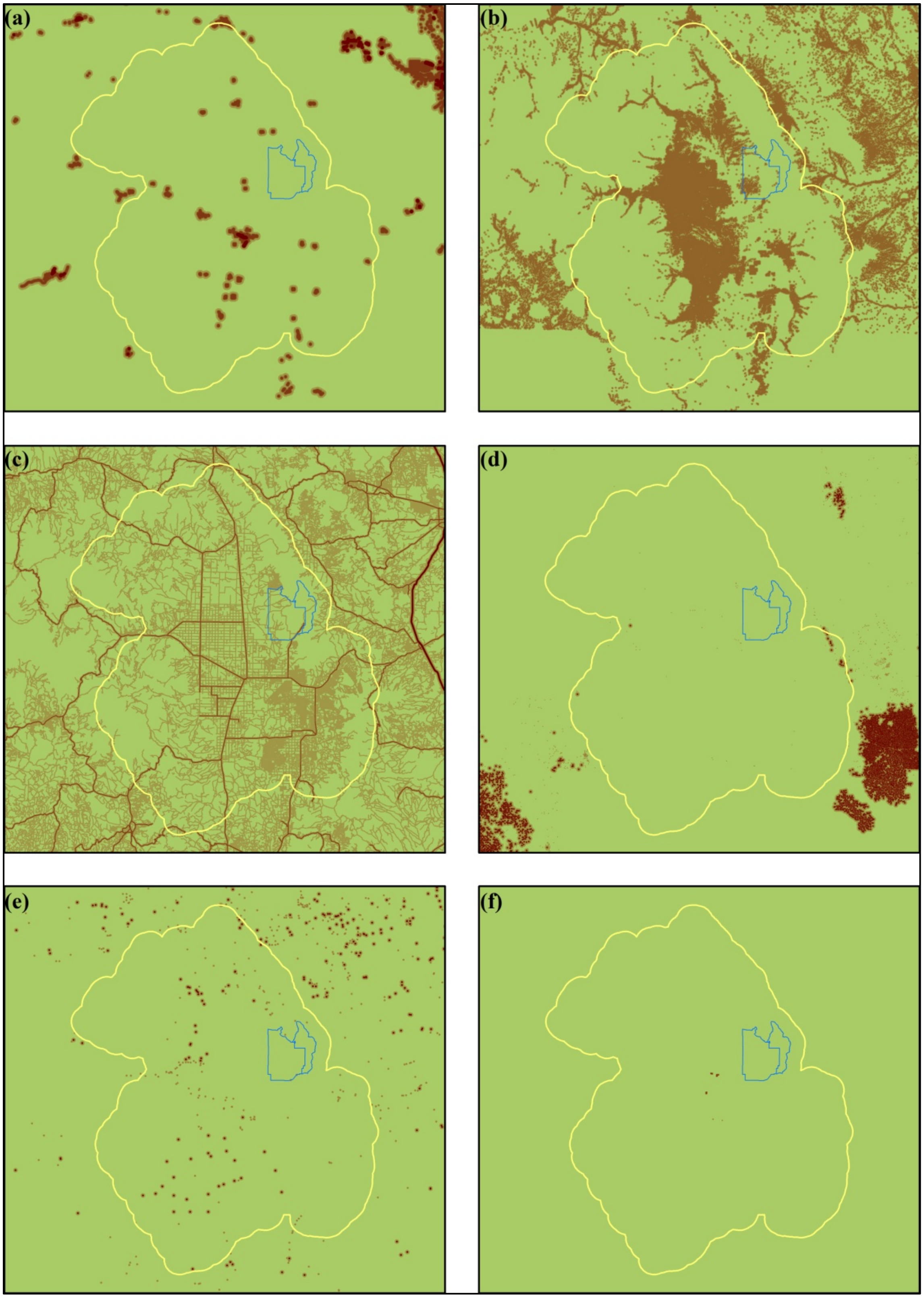


Figure 4.1.1. Final data input layers: (a) urban/industrial development, (b) agriculture, (c) roads, (d) oil and gas wells, (e) surface mines, (f) solar plants.

4.1.3 Reference Conditions

This analysis is made at the landscape level, focusing on the condition of GRSA within the regional landscape of the upper Rio Grande watershed. Individual ecosystem groups are evaluated within the park and preserve in section 4.7 below. A disturbance score of 0 represents best possible landscape condition. Such areas are believed to have essentially no significant anthropogenic impacts present. Since not all impacts can be spatially represented in our analysis, for the purposes of this assessment, the index scores obtained by using the best available representations of a subset of known anthropogenic disturbances are regarded as the baseline reference condition. Data that could be used to estimate trends are not available, so we evaluate expected future changes in the GRSA landscape through a narrative format.

Because about 49% of the park and preserve are managed as wilderness area, we expected a substantial portion of GRSA to have essentially no disturbance. In addition, non-wilderness lands outside the small developed area should have low to moderate levels of disturbance. We also expected the park and preserve to have noticeably less disturbance than the San Luis Valley and the analysis area as a whole. Based on these expectations, we evaluated the condition of the landscape according to the criteria in Table 4.1.3. We considered that landscape condition was good if the percent of acreage with a Landscape Disturbance Index (LDI) score of 0-25 (none to low disturbance) was equal to the percentage managed as wilderness, and very little area (1% or less) had an LDI greater than 75 (high to very high disturbance). Criteria for the moderate concern level are based on achieving 90% of the good condition level, with a slight increase allowed in highly disturbed acreage. An increase in disturbance from the moderate concern levels would warrant significant concern.

Table 4.1.3. Criteria for landscape condition scoring.

Condition Assessment	Park	Preserve	All GRSA
Resource is in Good Condition	At least 30% of acreage with no or very low disturbance, and no more than 1% of acreage in high or very high disturbance	At least 97% of acreage with no or very low disturbance, and no more than 1% of acreage in high or very high disturbance	At least 49% of acreage with no or very low disturbance, and no more than 1% of acreage in high or very high disturbance
Warrants Moderate Concern	27-30% of acreage with no or very low disturbance, and no more than 2% of acreage in high or very high disturbance	87-97% of acreage with no or very low disturbance, and no more than 2% of acreage in high or very high disturbance	44-49% of acreage with no or very low disturbance, and no more than 2% of acreage in high or very high disturbance
Warrants Significant Concern	<27% of acreage with no or very low disturbance, and/or more than 2% of acreage in high or very high disturbance	<87% of acreage with no or very low disturbance, and/or more than 2% of acreage in high or very high disturbance	<44% of acreage with no or very low disturbance, and/or more than 2% of acreage in high or very high disturbance

4.1.4 Condition and Trend

There are few areas of high or very high impact within the analysis area (Figure 4.1.2), and these are primarily associated with local towns and main highways. The area remains relatively undeveloped, with 69% of the area experiencing little to no anthropogenic impact, and only 5% of the area in high or very high impact levels (Table 4.1.4). In contrast to the metropolitan areas along Interstate 25 and the oil and gas fields to the southeast and southwest of the San Luis Valley, areas of high to very high disturbance within the San Luis Valley are small and dispersed. The floor of the San Luis Valley is primarily affected by irrigated, tilled agriculture (moderate disturbance), with areas of expanding urban and exurban development. Nevertheless, over 40% of the valley has little to no impact, with only 11% of the area in the high to very high levels.

GRSA as a whole has 84% of its area in the very low to no impact range, with most disturbance occurring in the park portion (Table 4.1.4). Impacts within GRSA are for the most part very low to moderate-low and are due to the few local and primitive roads, occasional structures, and the degraded rangeland of the former ranch lands. The area immediately surrounding GRSA is also only modestly impacted. Lands within four miles (6.5 km) of GRSA are 56% unimpacted with 22% in the very low impact category, and 19% in the moderate-low category, leaving only 3% of the area in the higher impact categories. At distances greater than four miles (6.5 km) away, agricultural and housing development impacts begin to increase.

Table 4.1.4. Percent of each area in each impact classification.

Impact Level	Analysis Area	San Luis Valley	All GRSA	Park Only	Preserve Only
None	50%	19%	66%	55%	95%
Very Low	19%	22%	18%	24%	3%
Moderate-Low	20%	36%	14%	19%	2%
Moderate-High	6%	14%	2%	3%	0.002%
High	3%	7%	0.01%	0.02%	0%
Very High	2%	4%	0.001%	0.001%	0%

Grazing by large ungulates is the primary source of moderate-low disturbance on the west side of the dune field. Native grazers present prior to the 1840s included bison (*Bison bison*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn antelope (*Antilocapra americana*). These were then largely replaced in the analysis area by domestic livestock (cattle and sheep). Cattle grazing continued on the sandsheet area within GRSA until 2005, and bison ranching operations reintroduced this large grazer to the San Luis Valley in the 1980s (Schoenecker et al. 2006). The elk population has rebounded from near extirpation (Swift 1945) to about 5,000 individuals (CDOW 2010), and in recent decades the numbers of bison and elk utilizing sandsheet plant communities has been of particular concern to NPS and USFWS managers. An ungulate management plan for GRSA is currently under development. Due to the preliminary nature of the research at the time this assessment was completed, we were not able to include data explicitly addressing disturbance impacts due to ungulate grazing. However, the results of our LDI analysis (based on mapped land cover types) does agree with impacts observed by ungulate researchers, reinforcing the management importance of this resource.

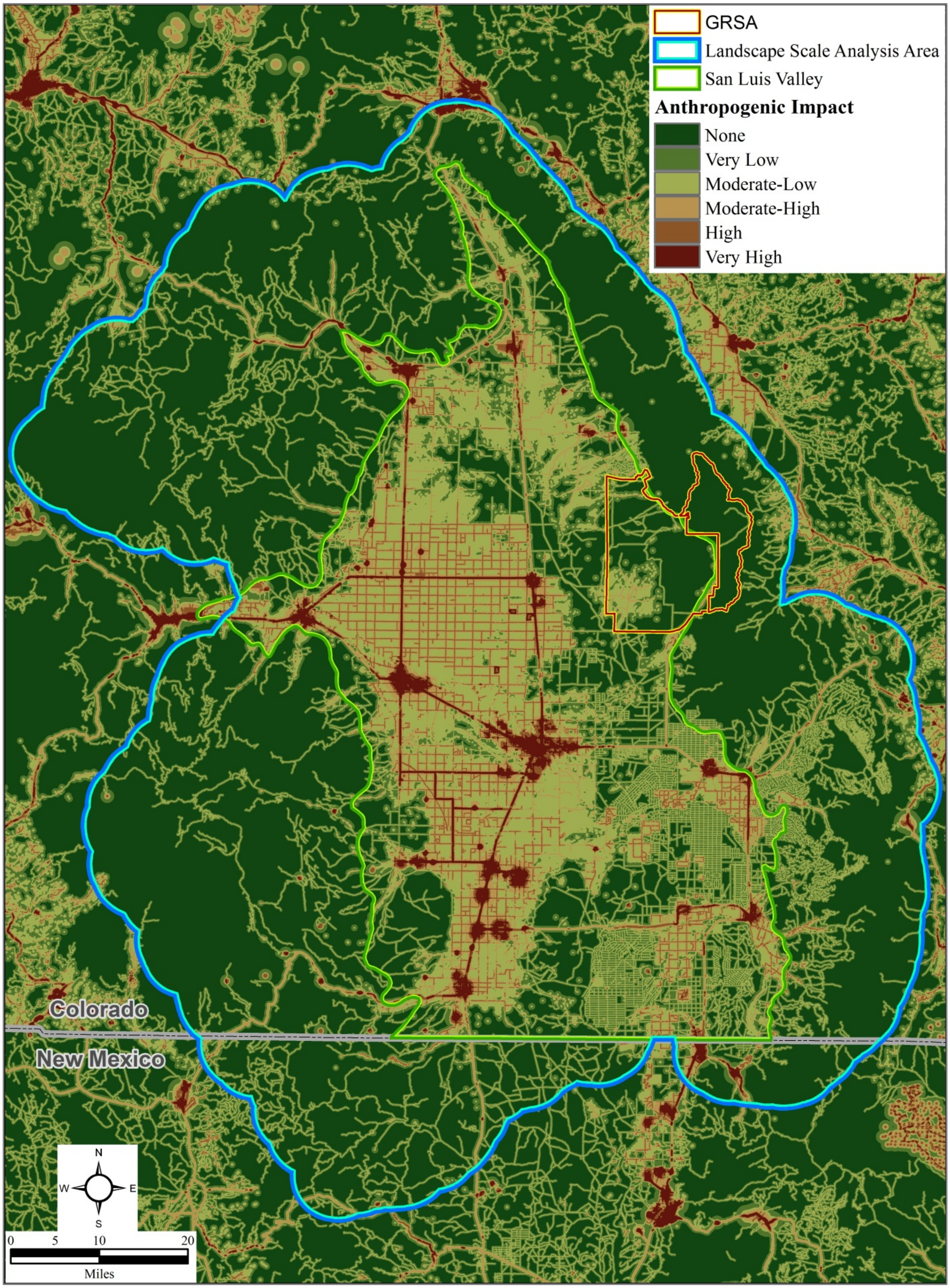


Figure 4.1.2. Landscape Disturbance Index model for the San Luis Valley.

Table 4.1.5. Summary of landscape disturbance condition.

Indicator	Interpretation	Condition Assessment
Landscape Disturbance Index	The larger landscape around GRSA has substantial acreage with little to moderate impact and is largely undeveloped. LDI scores within GRSA are better than in the surrounding area. 84% of GRSA has no or low impact, and acreage of high impact is much less than 1%.	Resource is in Good Condition

Current levels of anthropogenic disturbance within the larger analysis area and in GRSA indicate that the resource is in good condition (Table 4.1.5). Human-caused disturbance is expected to increase slightly in the future, but less so than in more populated areas. The population of Alamosa County has gained about 1,000 inhabitants per decade since 1960, reaching 15,445 in 2010, while the population of Saguache County has remained fairly constant between 4,000 and 6,000 throughout its history (US Census Bureau 2012). Future disturbance from development in the region is expected to remain essentially stable or have only a slight upward trend (Theobald 2005). The extent of cropped land in the San Luis Valley is closely tied to water availability, and has probably reached a more-or-less stable configuration under current water allocation procedures (see section 4.3). Some agricultural lands have been converted to solar energy production, and this trend is likely to increase if the difficulties surrounding the construction of a new large transmission line can be resolved. Oil and gas exploration continues in the San Luis Valley, and the potential for future increased development cannot be ruled out. Mining, although historically an important part of the regional economy, is expected to remain at the current low levels.

Increasing anthropogenic disturbance in the analysis area does not necessarily translate to increased disturbance within GRSA, and landscape disturbance within the park can reasonably be expected to remain at more-or-less current levels. Over time, however, park lands may become increasingly isolated from similar, low-to-no impact areas.

4.1.5 Sources of Expertise

The primary authors have developed landscape disturbance/integrity indices for a number of projects throughout Colorado and surrounding areas, and built upon this experience for the work presented herein. ROMN staff reviewed and commented on this section.

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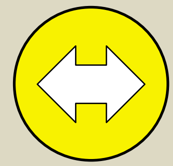
4.2 Landscape Composition and Connectivity

Indicators / Measures

- Ecosystem diversity
- Patch size distribution
- Connectivity

Condition - Trend



4.2.1 Background and Importance

A primary purpose for which GRSA was designated is to "Provide long-term protection of the geological, hydrological, ecological, scenic, scientific, cultural, wilderness, educational, wildlife, and recreational resources of the area. Preserve the remarkable biodiversity evident in the landscape from the valley floor to the mountain crest" (NPS 2007). The recognition that management issues and ecological processes extend across park boundaries to encompass the larger landscape highlights the importance of attention to the larger landscape patterns (Britten et al. 2007), and indicates that the composition and connectivity of the larger landscape within which GRSA is situated is an important natural resource.

Landscape composition and connectivity are important considerations in the evaluation of the regional context of many natural resources at GRSA. Landscape composition, i.e., the relative amount of each habitat type present in the landscape (Dunning et al. 1992) has a direct influence on what species are or may be present in the area. Although patch size and arrangement are scale dependent and closely tied to inherent characteristics of the landscape, there is general agreement that large patches are important for the conservation of many species. Furthermore, connectivity between patches of similar habitat types facilitates movement of species between the various patches (Taylor et al. 1993), and can increase the effective size of existing protected areas such as GRSA (Carroll et al. 2004, Goetz et al. 2009).

Although there is general agreement that conservationists should act to prevent fragmentation and preserve connectivity, methods of measuring fragmentation and connectivity are highly debated, and often lacking verification of their applicability in real-world situations (Li and Wu 2004, Kupfer 2012). Research on landscape connectivity is typically driven by a focus on dispersal, and therefore defined in a species-specific way. In this analysis, however, we focus on a more generalized concept of landscape connectivity, considering the operation of ecological processes (e.g., wildfire, disease spread, movement of large mammals). Our general analysis evaluates the connectivity of the GRSA landscape. This structural connectivity is "…derived from physical attributes of the landscape, such as size, shape, and location of habitat patches, but does not factor in dispersal ability" (Crooks and Sanjayan 2006). Over time, changes in composition and connectivity in the region could lead to changes in patterns of species movement and the operation of ecological processes, with a potential for directly impacting the condition of species populations at GRSA.

We address landscape composition through a descriptive analysis of the extent (patch size distribution) and diversity of ecosystem types presently documented in the study area. We investigated structural connectivity via a least-cost corridor analysis. Our goal is to characterize the landscape in the vicinity of GRSA in relation to the larger landscape of the upper Rio Grande basin.

4.2.2 Data and Methods

<u>Ecosystem Diversity and Patch Size</u>

We reviewed available land cover maps for Colorado and New Mexico, including SWReGAP (USGS 2004), LANDFIRE (USDA Forest Service 2008), CVCP (CDOW 2003), Colorado Vegetation Model 8 (CVM8; Theobald et al. 2004), and the National Landcover Dataset (Homer et al. 2007). The CVCP and CVM8 are limited to Colorado, and the NLCD was considered too coarse, so we concentrated our review between SWReGAP and LANDFIRE land covers. We concluded that LANDFIRE shows too much alpine area as simply "barren" and also contains some signature analysis artifacts that cause greasewood and sand shrubland ecosystems to be mapped in artificial bands in several areas of the San Luis Valley. Consequently, we selected the SWReGAP land cover for all ecosystem analyses. This dataset also has the advantage of using U.S. National Vegetation Classification ecological system names.

We used a focal majority analysis to produce a smoothed land cover that reduced the number of small inclusions of dissimilar ecosystem types, resulting in a more cohesive map of medium- to large-patch and matrix-forming ecosystems. We used a 0.25 mile (0.4 km) radius circle (area of 0.2 mile^2, 0.52 km^2) moving window in the focal majority to adequately retain representation of medium-patch ecosystems. Small-patch and linear ecosystems, such as wetlands and riparian are not well mapped within SWReGAP to begin with, and the smoothing process further reduces their presence. Therefore, wetland and riparian ecosystems are not analyzed at the landscape level, but are discussed in section 4.7 below. After smoothing, very similar ecosystems, such as "dry-mesic" versus "mesic" versions of the same ecosystem type, were lumped together and the contiguous patches of each (8-neighbor rule) were extracted and their area and elevation ranges calculated.

As a measure of natural ecosystems diversity at the landscape level, we used a focal variety analysis. This counts the number of naturally occurring ecosystems within a moving window across the analysis area. The smoothed ecosystem layer discussed above was used, and all non-natural land cover types removed so they would not contribute to ecosystem diversity. Because landscape metrics change with scale, we tested several window sizes, all of them circular in shape: 0.2 square miles (0.25 mile radius), 1 square miles (0.5 mile radius), 3 square miles (1 mile radius), and 20 square miles (2.5 mile radius). The maximum number of possible ecosystems increases with window size, showing only a slight leveling-off at the largest size tested. We selected a moving window size of 20 square miles (32 km^2) as being the most relevant to both the scale of the full analysis area and that of GRSA. This window is an order of magnitude smaller than GRSA, which is 234 square miles (606 km^2) in size.

Patch size distribution was evaluated by sampling a randomly placed rectangle (approximately centered on the large analysis area) with a grid of 132 squares of 234 square miles (606 km^2) each.

Four of these squares contained portions of GRSA (Figure 4.2.1). When this grid was superimposed on the smoothed ecosystem patch layer, each grid cell covered 672,400 raster cells, each cell attributed with either the total patch size of the patch to which it belongs, or as no data. For each of 14 matrix- or large patch-forming ecosystems, the mean of all patch cells within that grid square was obtained, resulting in an area-weighted sample of patches contributing to that square. Non-zero grid-square means were plotted as a cumulative distribution function, and the relative contribution of GRSA cells used to evaluate the condition of patch sizes in the vicinity of GRSA.

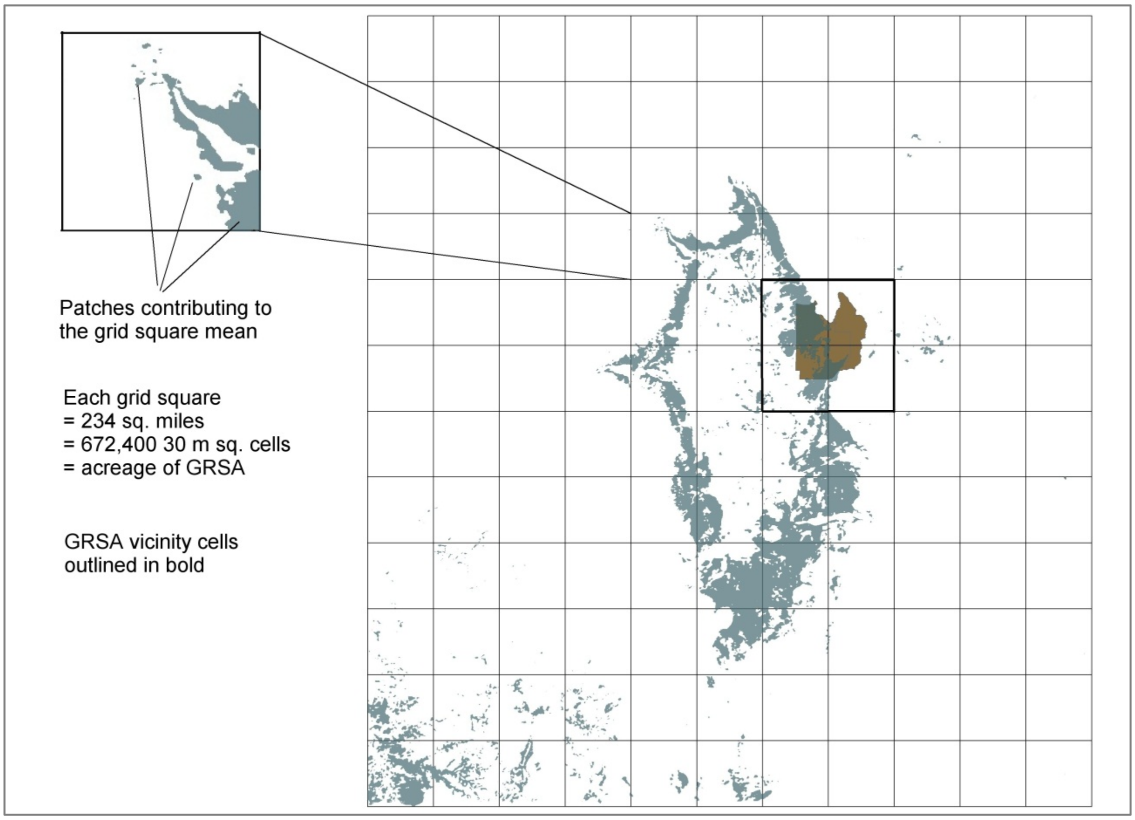


Figure 4.2.1. Example of evaluating the distribution of semi-desert shrub steppe patches in the large analysis area.

Core Areas and Connectivity Analysis

We defined core areas as contiguous areas at least 100 acres (40 ha) in size that have an impact score of zero as defined in the landscape disturbance model (see section 4.1), regardless of land cover type. The concept of a core area takes into account the effect over distance of the various anthropogenic disturbances modeled. By looking at only those areas with no impact, core areas should be high quality natural landscapes free from disturbance edge effects. The cut-off of 100 acres or more is arbitrary but meant to represent a minimum level of functional connectivity and quality at the scale of this analysis. Larger core areas are more effective in conserving the natural processes and species assemblages.

The landscape disturbance model was used as the basis of a generalized cost surface to determine the most likely connections between the larger core areas. Because the landscape disturbance model can be viewed as representing percent impacted and therefore conversely as degree of naturalness across the landscape of the analysis area, it can be used to estimate the permeability of the landscape to terrestrial species and natural processes in a general way, rather than needing to focus on specific species or processes.

Connectivity between large core areas was determined using a Least Cost Corridor methodology. This method looks at both the absolute distance between core areas as well as the degree of naturalness across the intervening distance to determine the least impacted swath of land between core areas that can serve as a corridor for species and natural processes. The landscape disturbance scores were truncated at 100 (e.g., scores > 100 were reclassified to 100), making the range of values 0 – 100 to represent percent impact. A function was then applied to these values to create an adaptive response weighted cost distance curve such that the permeability of minimally impacted areas is only slightly affected, but the effect increases exponentially as impact increases. The function was specifically tailored to this landscape disturbance model such that minor levels of anthropogenic impact (defined as having a landscape disturbance score of <25) add only trivially to the weighted cost distance and high impact levels (score >= 75) should be avoided if at all possible, and so should have approximately an order of magnitude greater cost weight than the trivial impacts. The resulting equation is:

$$w = e^{\frac{L}{e*10}}$$

where:

w = cost weight applied to distance

L = landscape disturbance model score (0 – 100)

The weighted cost distance to each core area >= 50,000 acres (20,235 ha) was then calculated using the ESRI PathDistance command. In addition to the adaptive cost surface, the true surface distance (as opposed to the planimetric distance) and the steepness of the slope were also accounted for. So, for each raster cell, which is planimetrically 30 m on a side, an elevation model was used to determine actual surface distance, which was then multiplied by the cost weight (w) and further modified to apply a modest increase in cost for slope inclines and a modest decrease in cost for slope declines (very steep inclines and declines are treated as movement barriers). The result is a cumulative cost distance to each large core area. These cost distances were then combined to determine the least cost corridor from each core area to all the others. Full details of methods used are available in the corridor analysis metadata.

4.2.3 Reference Conditions

This analysis is made at the landscape level, focusing on the position and contribution of GRSA within the regional array of connected native vegetation. Individual ecosystem groups are evaluated within the park and preserve in section 4.7 below. The patch sizes, diversity, and connectivity that would be observed in the complete absence of any anthropogenic alteration of the area is the best possible condition. Because it is not feasible to remove all such alterations, the current patch size distribution, composition and patterns of connectivity are regarded as the baseline reference condition. Data that could be used to estimate trends are not available, so we evaluate expected future changes in the regional landscape in narrative form.

We evaluated the landscape composition and connectivity of GRSA with regard to the surrounding landscape according to qualitative criteria (Table 4.2.1). We expect that GRSA should have diversity of native ecosystems higher or equal to the analysis area as a whole, which includes substantial acreage of other public land in native ecosystems. GRSA diversity should also be notably higher than that of the San Luis Valley as a whole, due to the extent of highly altered habitat (e.g., agriculture) on the valley floor. Current patch sizes distributions are presented as a baseline. Due to the steep and narrow character of the Sangre de Cristo Mountains, patch sizes of many montane ecosystems in the preserve are expected to be smaller than would be typical of the San Juan Mountains of the other side of the large analysis area. However, for ecosystems of the valley floor, it is expected that the vicinity of GRSA will support some of the largest examples in the analysis area. Finally, we expect that GRSA acts as a key connection along the eastern edge of the San Luis Valley and analysis area as a whole.

Table 4.2.1. Criteria for evaluating landscape composition and connectivity.

Condition Assessment	Ecosystem Diversity	Patch Size	Connectivity
Resource is in Good Condition	GRSA has ecosystem diversity greater than or equal to the surrounding landscape	The vicinity of GRSA includes patches in the upper quartile of size distribution for dune, shrub-steppe, and greasewood ecosystems, and in the upper half of size distribution for ecosystems most characteristic of the Sangre de Cristo Mountains	Natural habitats at GRSA are well connected to a surrounding natural landscape – GRSA is part of one or more core areas
Warrants Moderate Concern	Diversity of ecosystem types in GRSA is at least 85% of that of the surrounding landscape	The vicinity of GRSA includes patches in the upper quartile of size distribution for dune, shrub-steppe and greasewood ecosystems, but lacks large patches of 1-3 ecosystems most characteristic of the Sangre de Cristo Mountains	Natural habitats at GRSA remain connected to a surrounding natural landscape in most areas – GRSA is part of at least one core area
Warrants Significant Concern	Ecosystem diversity of is depauperate in comparison with surrounding landscape	The vicinity of GRSA includes patches in the upper half of size distribution for dune, shrub-steppe and greasewood ecosystems, but lacks large patches of most ecosystems characteristic of the Sangre de Cristo Mountains	GRSA appears to be isolated from natural habitats in the surrounding landscape, and is not part of a larger core area

4.2.4 Condition and Trend

Diversity of native ecosystems

The preserve portion of GRSA has high diversity of native ecosystems (Figure 4.2.2), averaging approximately 15 ecosystems per 20 square miles (32 km^2), in contrast to the analysis area as a whole (averaging 8 ecosystems / 20 square miles) and the San Luis Valley floor (averaging 5 ecosystems / 20 square miles). This is largely due to the steep elevational gradient present in the preserve and all along the Sangre de Cristo Mountains, allowing many ecosystems to exist in a relatively small area, but it is also a consequence of the largely undisturbed nature of the preserve and the quality of the high elevation ecosystems there. No other area along the Sangre de Cristo Mountains has as large of an area of high ecosystem diversity, with 17% of the area of the preserve (approximately 7,080 acres, or 2,865 ha) having a level of ecosystem diversity within the 90th percentile (Table 4.2.2), although the west slope of Blanca Peak comes close with approximately 6,500 acres (2,630 ha) within the 90th percentile (Figure 4.2.3).

In terms of the large core areas (discussed below), the Twin Sisters core area has the greatest average ecosystem diversity (averaging 14.1 ecosystems per 20 square miles) or 67% of maximum diversity) and the Poison core area has the lowest average diversity (8.8 ecosystems per 20 square miles or 42% of maximum diversity). The Sangre-Dunes and Blanca core areas, while containing the largest areas of highest ecosystem diversity, also contain areas of relatively low diversity, and so have average diversities of 58% and 62% of maximum, respectively.

Table 4.2.2. Number of ecosystems per 20 square miles.

Area of Concern	MIN	MAX	MEAN	STD	Percentile of Mean	Percent Area in 90th Percentile
Analysis boundary	1	21	8	4	39%	0.3%
San Luis Valley	1	20	5	3	24%	0.02%
GRSA	1	21	9	5	42%	6%
GRSA park only	1	20	6	4	30%	1%
GRSA preserve only	7	21	15	3	73%	17%

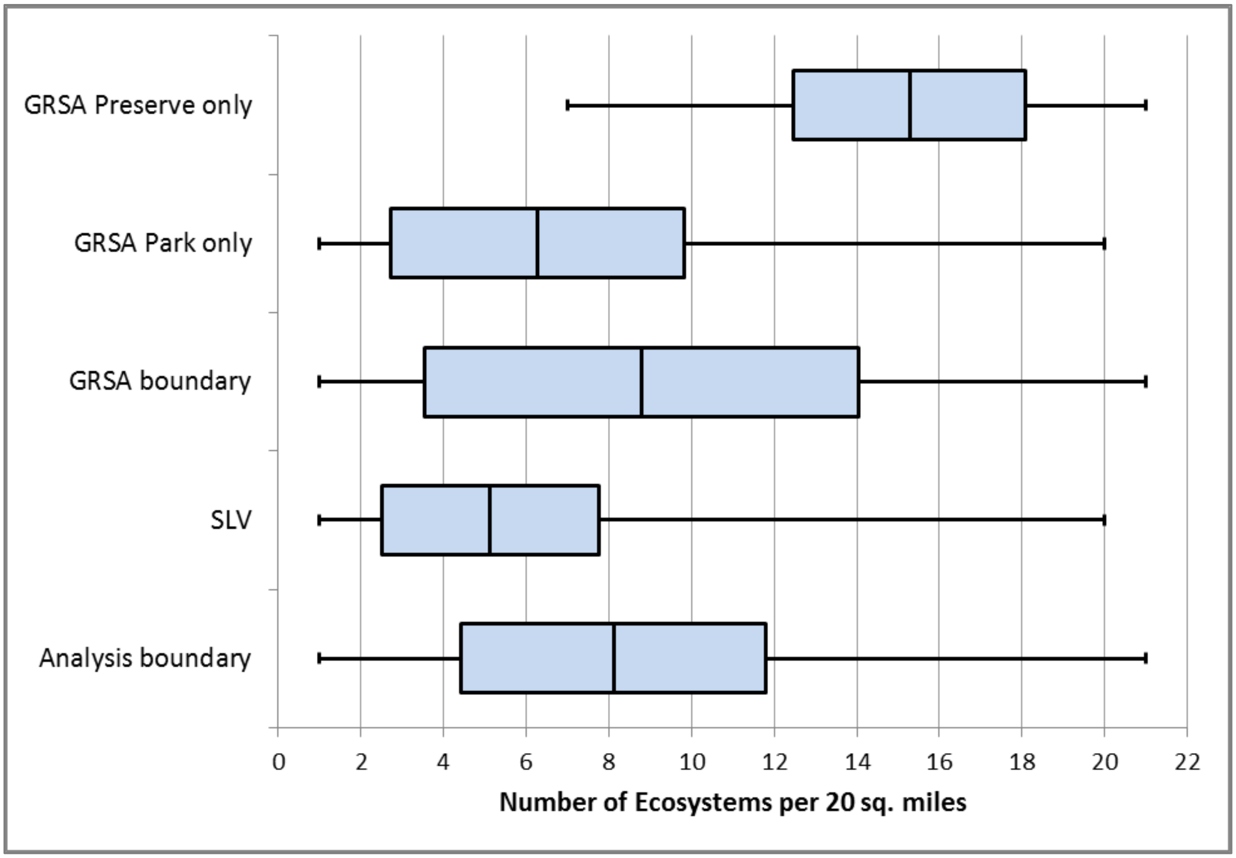


Figure 4.2.2. Comparison of ecosystem diversity using a 2.5 mile radius (~20 sq. mile) moving window. The center of each box is the mean, each half of the box is one standard deviation, and the whiskers represent the minimum and maximum values.

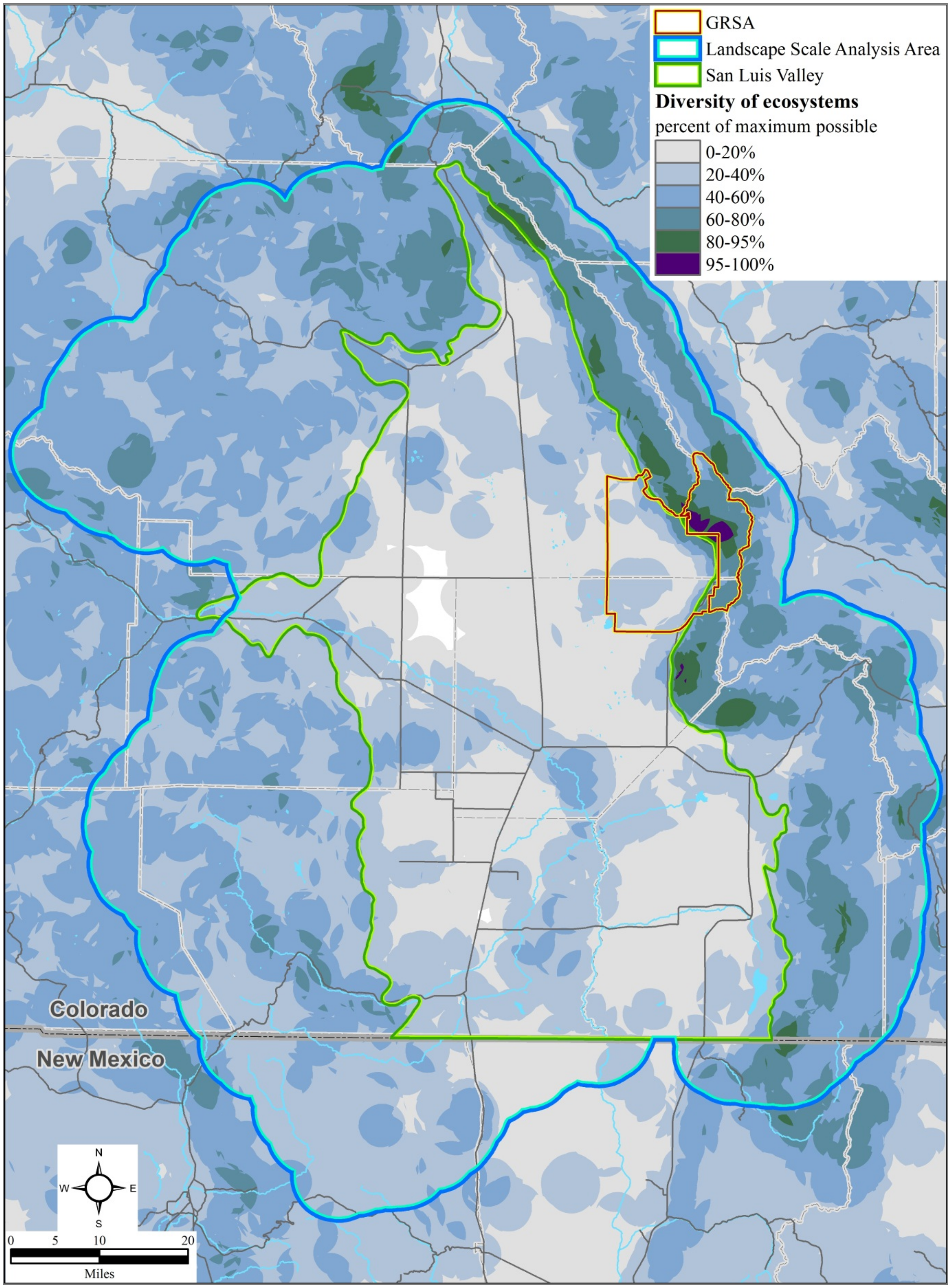


Figure 4.2.3. Diversity of ecosystems per 20 square miles. The percent of maximum assumes that the extant mapped diversity is the reference condition.

Patch size in native ecosystems

The final smoothed ecosystem patch map for the larger analysis area included 15 ecosystem types (Figure 4.2.4). Patch numbers given in Table 4.2.3 include those that only partially overlap the analysis area, however, the largest patch area reported is for those patches that have a substantial portion within the analysis area. Results for each ecosystem type are discussed below, and compared with the size distribution of patches in the grid square sampling area.

Table 4.2.3. Ecosystem patches within the analysis area.

		Number of Patches >=			
Ecosystem	**Largest Patch (ac)**	**100 ac**	**500 ac**	**1,000 ac**	**5,000 ac**
Rocky Mountain Alpine Bedrock and Scree	14,854	86	24	18	3
Rocky Mountain Alpine Fell-Field*	323	10	0	0	0
Rocky Mountain Alpine Turf	6,512	92	23	14	2
Rocky Mountain Aspen Forest and Woodland	42,037	286	130	85	22
Rocky Mountain Subalpine Spruce-Fir Forest and Woodland	602,488	227	87	62	23
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	2,598	49	4	2	0
Southern Rocky Mountain Montane Mixed Conifer Forest and Woodland	28,653	342	128	63	12
Southern Rocky Mountain Ponderosa Pine Woodland	11,816	222	65	34	11
Southern Rocky Mountain Pinyon-Juniper Woodland	111,272	90	39	30	13
Rocky Mountain Lower Montane-Foothill Shrubland	261	1	0	0	0
Inter-Mountain Basins Semi-Desert Shrub-Steppe	419,229	151	37	20	9
Inter-Mountain Basins Semi-Desert Grassland	4,081	48	19	10	0
Southern Rocky Mountain Montane-Subalpine Grassland	121,175	280	95	52	18
Inter-Mountain Basins Active and Stabilized Dune	25,058	4	1	1	1
Inter-Mountain Basins Greasewood Flat	217,762	91	28	15	6

*not included in frequency distribution analysis.

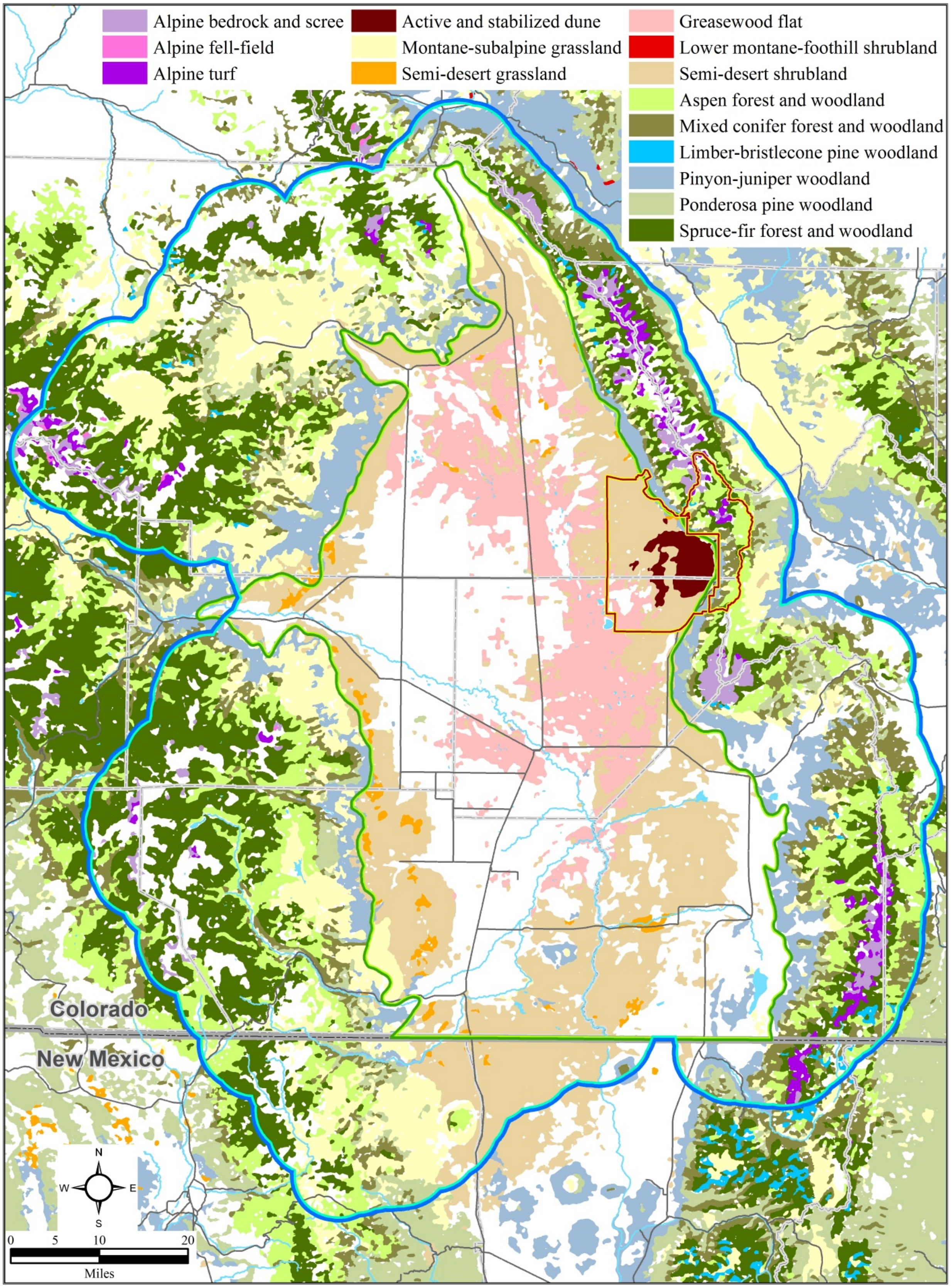


Figure 4.2.4. Ecosystem patches of 100 acres or greater within the analysis area.

The San Juan and Sangre de Cristo mountains support large alpine communities, although the largest patches of vegetated alpine in the Southern Rockies are not within the analysis area. A high-quality mosaic of primarily Rocky Mountain Alpine Bedrock and Scree and Rocky Mountain Alpine Turf, with a few small patches of Rocky Mountain Alpine Fell-Field, starts at the northern end of the Preserve and continues for nearly thirty miles north along the spine of the mountains. The largest contiguous patch of alpine is of Rocky Mountain Alpine Bedrock and Scree covering a large portion of Blanca Peak, to the south of GRSA. The vicinity of GRSA includes patches in the upper quartile of size distribution for Rocky Mountain Alpine Bedrock and Scree (Figure 4.2.5a), and in the upper half of size distribution for Rocky Mountain Alpine Turf (Figure 4.2.5b).

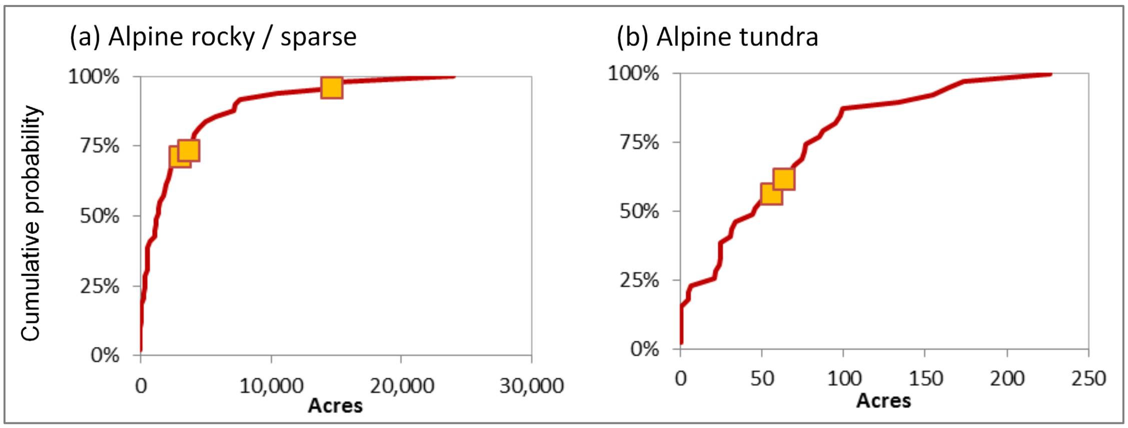


Figure 4.2.5. Cumulative patch size distribution of alpine ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

Spruce-fir (including both Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland and Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland) is abundant in both the steep, narrow Sangre de Cristo Mountains and the more expansive San Juan Mountains. The San Juan patches are some of the largest parches of spruce-fir in Colorado. Consequently, the vicinity of GRSA does not have patches within the upper half of size distribution for spruce fir (Figure 4.2.6a).

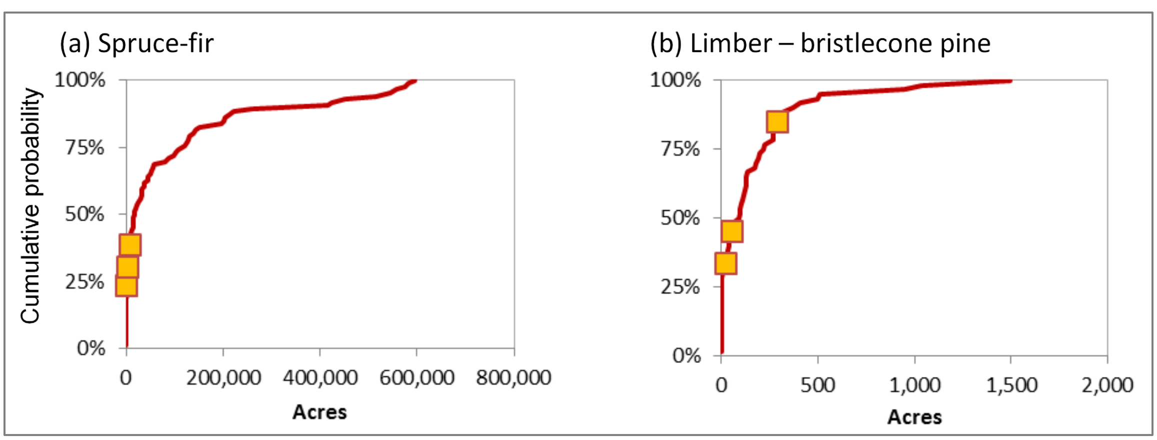


Figure 4.2.6. Cumulative patch size distribution of subalpine forest ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland occurs in generally smaller patches scattered throughout the mountains, the largest of which, between 800 and 2,600 acres, occur to the south of GRSA, within the Culebra Range of the Sangre de Cristo Mountains. However, the vicinity of GRSA does support one patch in the upper quartile of patch size distribution (Figure 4.2.6b).

The largest contiguous patches of aspen within the Southern Rockies are not in the analysis area. Aspen, which includes Rocky Mountain Aspen Forest and Woodland and Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland, occurs all along the valley-bordering mountain ranges in a clear elevation band spanning 2,400-3,600 m (7,900-11,800 ft), but is mostly within the 2,900-3,200 m (9,500 -10,500 ft) range. The largest aspen patches are along the east slope of the Culebra Range to the Spanish Peaks and along the western slope of the San Juan Mountains within the Rio Chama watershed. The vicinity of GRSA includes patches in the upper half of patch size distribution (Figure 4.2.7a).

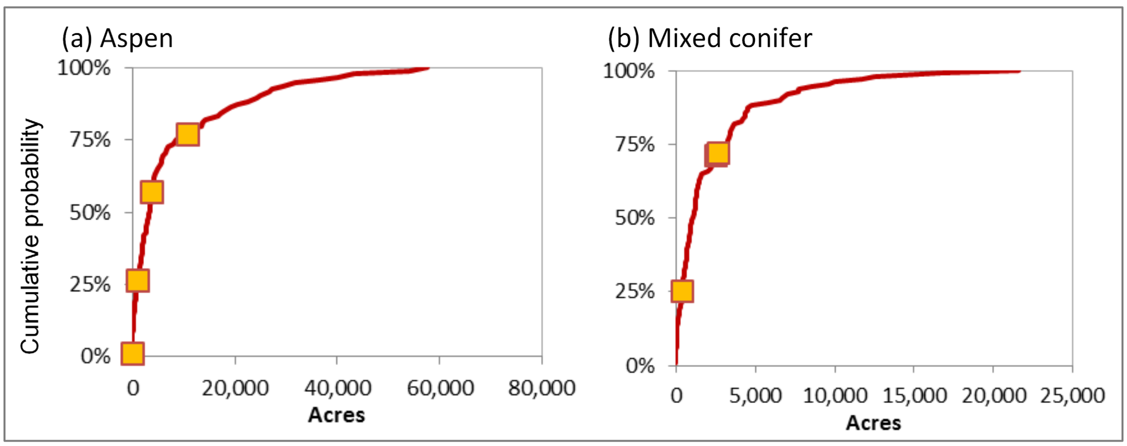


Figure 4.2.7. Cumulative patch size distribution of montane forest ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

Mixed conifer includes both Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland and Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland. This ecosystem occurs in scattered moderately sized patches that grade gradually into the aspen-mixed conifer type that we chose to lump with aspen. Mixed conifer occurs in all surrounding mountains, with the largest contiguous patch lying south of La Veta Pass, along the slopes surrounding McCarty Park. The vicinity of GRSA includes patches in the upper half of patch size distribution (Figure 4.2.7b).

Compared to the rest of the Southern Rockies, patches of Southern Rocky Mountain Ponderosa Pine Woodland within the analysis area are relatively small, although two large patches greater than 200,000 acres (80,940 ha) border the southern edges of the analysis area, within Carson National Forest and the Park Plateau west of Trinidad and Raton. Recent fires throughout Wyoming, Colorado and New Mexico have burned a number of the larger contiguous areas of ponderosa pine in the Southern Rockies. This, in addition to wide-spread pine beetle mortality, has likely impacted the patch dynamics of this ecosystem for years to come. Patches within the vicinity of GRSA are generally not within the upper half of patch size distribution (Figure 4.2.8a), as larger patches are more characteristic of the south flank of the San Juan Mountains.

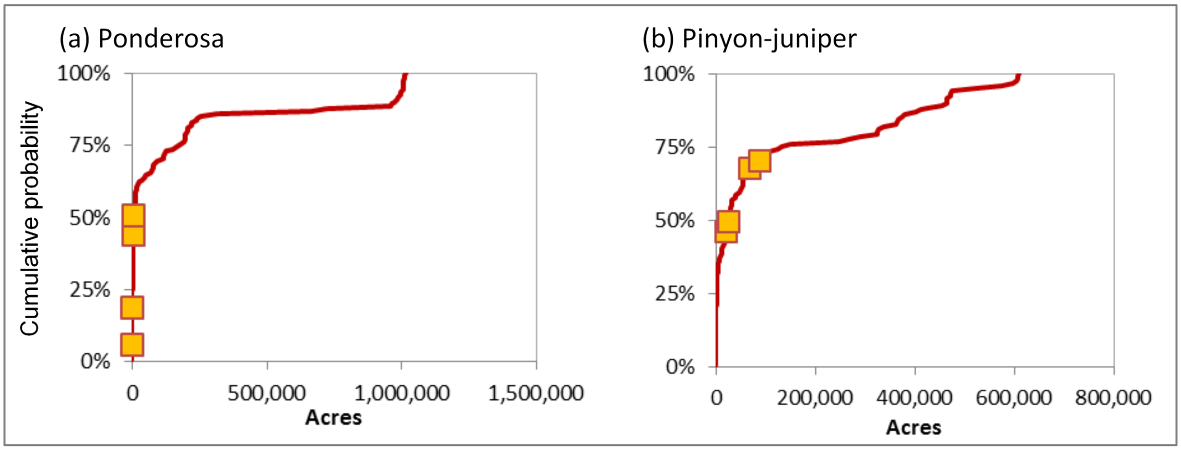


Figure 4.2.8. Cumulative patch size distribution of woodland ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

Most pinyon-juniper woodlands (we combined Southern Rocky Mountain and Colorado Plateau Pinyon-Juniper Woodlands) are found either to the east of the Sangre de Cristo Mountains, or to the south and west of the San Juan Mountains in New Mexico. Closer to the analysis area, there is a large, 475,000 acre (192, 225 ha) patch of pinyon-juniper between South Park and the San Luis Valley. The next largest patch in the area (111,000 acres, or 44,920 ha) is north of Blanca Peak, extending outside of the analysis area into Huerfano Park. Other than these two broad patches, pinyon-juniper grows in a narrow band along the edge of the San Luis Valley and at the bases of the volcanic cinder cones at the south end of the valley. The vicinity of GRSA contains patches in the upper half of patch size distribution (Figure 4.2.8b).

Rocky Mountain Lower Montane-Foothill Shrubland is better represented in north-central and north-western Colorado and only occurs in rather small patches within the analysis area. Consequently, the focal majority technique (which makes large patches larger and small patches smaller) subsumed most of these shrubland patches into larger patch types. A single patch greater than 100 acres (40 ha) occurs at the northern edge of the analysis area, along the Arkansas River just south of Salida, but patches within the vicinity of GRSA are not within the upper half of patch size distribution (Figure 4.2.9a).

Inter-Mountain Basins Semi-Desert Shrub-Steppe is well represented in large patches within the San Luis Valley, and serves as the transitional ecosystem between pinyon-juniper and the greasewood flats of the valley floor. The vicinity of GRSA includes patches in the upper quartile of patch size distribution (Figure 4.2.9b).

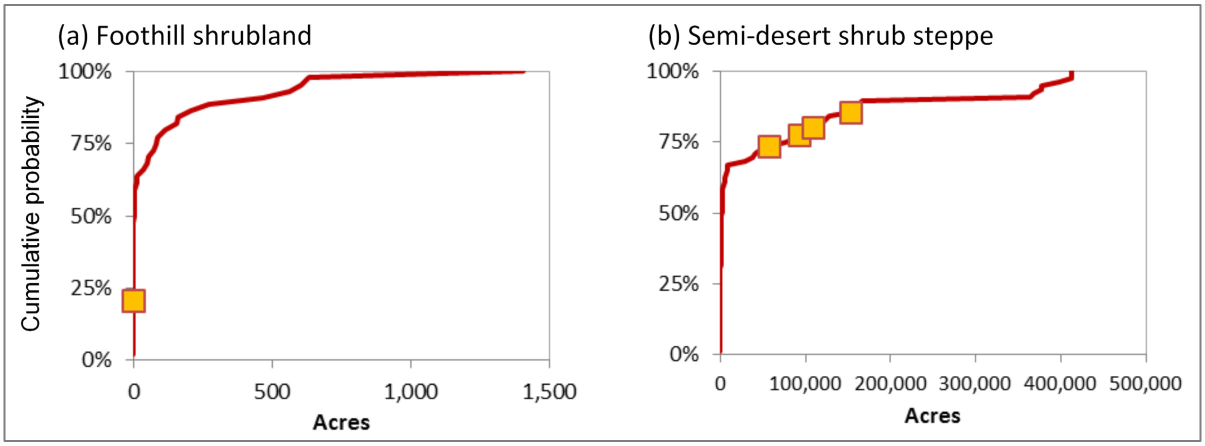


Figure 4.2.9. Cumulative patch size distribution of shrubland ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

The largest patch of montane-subalpine grassland in the Southern Rocky Mountains is found in South Park, to the north of the San Luis Valley. Within the larger analysis area, the largest patch of Southern Rocky Mountain Montane-Subalpine Grassland occurs in the Cochetopa Hills, in the Saguache Creek watershed. However, the vicinity of GRSA also includes part of the extensive montane grassland patch in the Wet Mountain Valley, in the upper quartile of patch size distribution (Figure 4.2.10a). In the San Luis Valley, Inter-Mountain Basins Semi-Desert Grassland occurs in small patches interspersed within the larger shrub-steppe ecosystem patches, and patches in the vicinity of GRSA are generally not within the upper half of patch size distribution (Figure 4.2.10b).

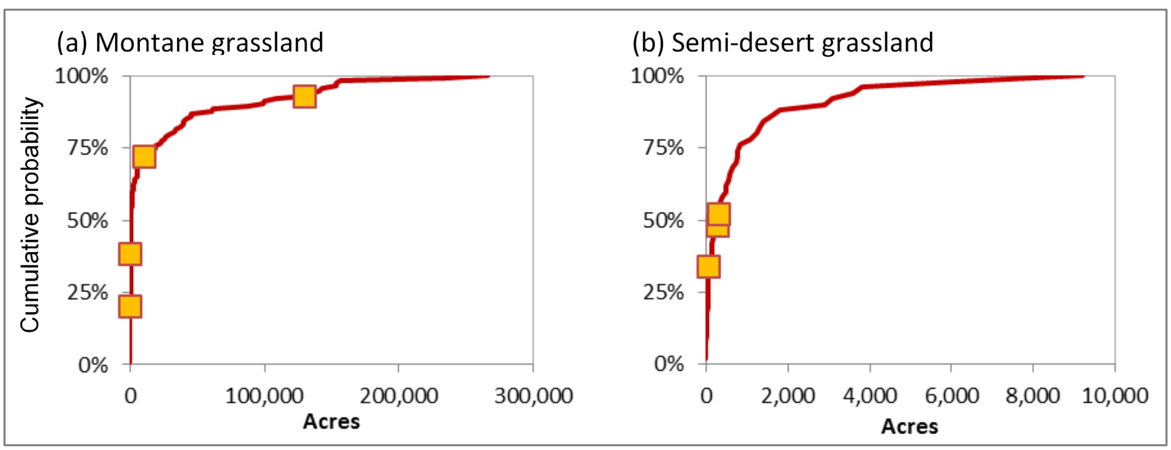


Figure 4.2.10. Cumulative patch size distribution of grassland ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

The valley floor, where it is not tilled agriculture, is primarily Inter-Mountain Basins Greasewood Flat, mostly in one large unbroken patch of over 200,000 acres (192, 225 ha). This is by far the largest patch of greasewood in the Southern Rocky Mountains, and puts the vicinity of GRSA within the upper quartile of the patch size distribution (Figure 4.2.11a). The Inter-Mountain Basins Active and Stabilized Dune ecosystem is best represented within GRSA; all patches within the vicinity of GRSA are in the upper quartile of the patch size distribution (Figure 4.2.11b).

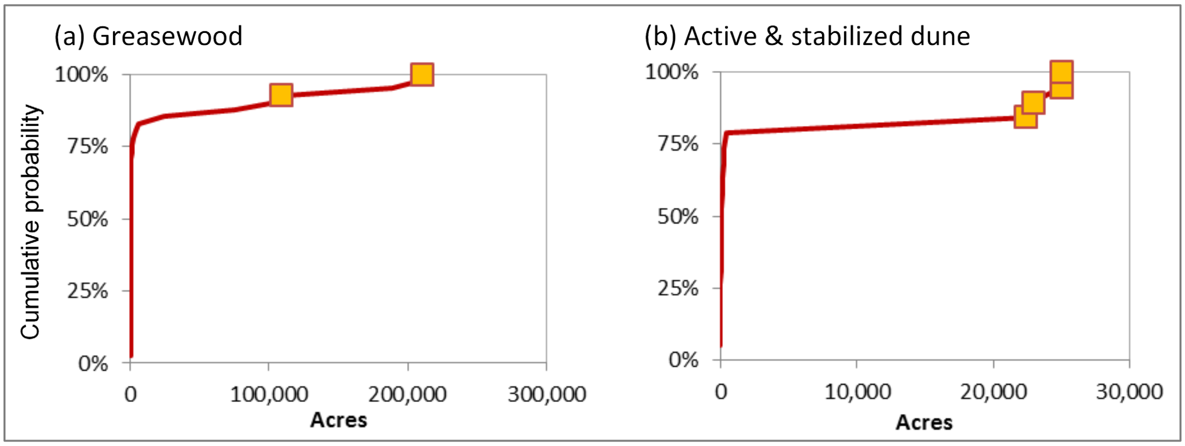


Figure 4.2.11. Cumulative patch size distribution of dune and greasewood ecosystem types in the analysis area. Grid square analysis - orange squares indicate cells in the vicinity of GRSA.

<u>Core Areas and Connectivity</u>
Within the landscape scale analysis area, there are thirteen core areas of 50,000 acres (20,235 ha) or larger. We focused on the vegetation composition of these large core areas and the level of functional connectivity between them.

The largest core areas in the analysis area are primarily in the mountains (Figure 4.2.12). There are nearly 40 core areas of at least 10,000 acres (4,047 ha) that are a part of the analysis area, 13 of which are at least 50,000 acres (20,235 ha); nine of those are greater than 100,000 acres (40,470 ha). There are only three core areas of at least 10,000 acres (4,047 ha) entirely within the valley floor, the largest being around 23,000 acres (9,308 ha). GRSA supports two core areas greater than 100,000 acres (40,470 ha), split only by the Medano Pass Road. Although this small 4WD road is not the same type of barrier as a large tract of developed land, the separation represents the edge effects caused by anthropogenic disturbance such as potential invasive weed propagation, erosion, noise, and impacts to air and water quality. This division would probably not be a barrier to many species or ecological processes, and for some purposes these two core areas could be considered as a single core area of approximately 300,000 acres (121,406 ha).

For the purposes of the connectivity analysis, we looked at core areas >= 50,000 acres (20,235 ha) only. To facilitate description and discussion of these large tracts of undeveloped land, we named each of them according to the prominent natural features that they contain (Figure 4.2.13).

The composition of these large core areas is largely forested (Figure 4.2.14). All but the Sangre-Dunes core area are at least 60% forested (Table 4.2.4). In addition to containing the sparsely vegetated dunes themselves, the Sangre-Dunes core area also includes shrublands within the San Luis Valley as well as extending into the grasslands of the Wet Mountain Valley on the east side of the mountains, making this the most structurally diverse unimpacted core area of the group. This is also the fourth largest core area.

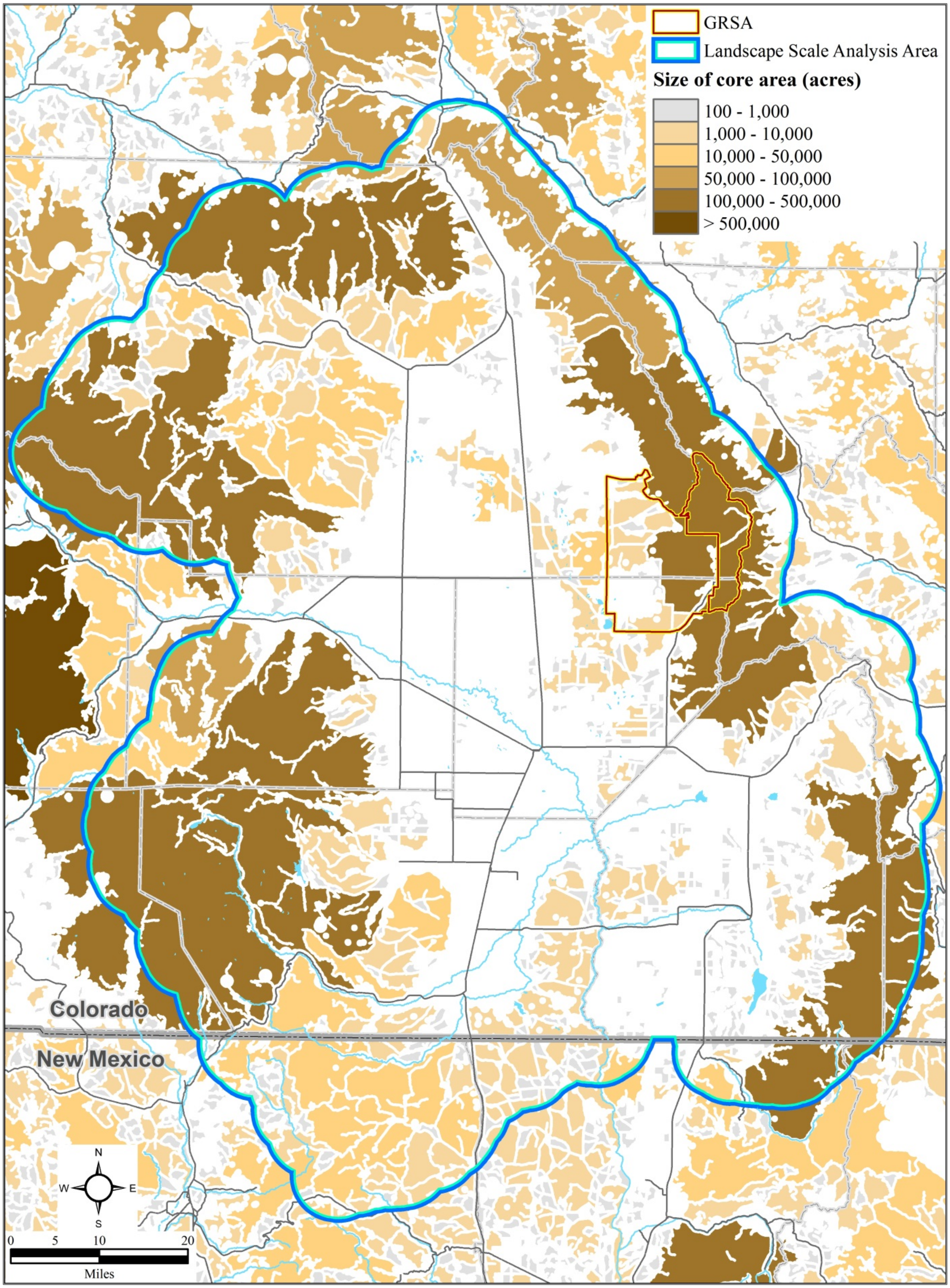


Figure 4.2.12. Core areas within the analysis area.

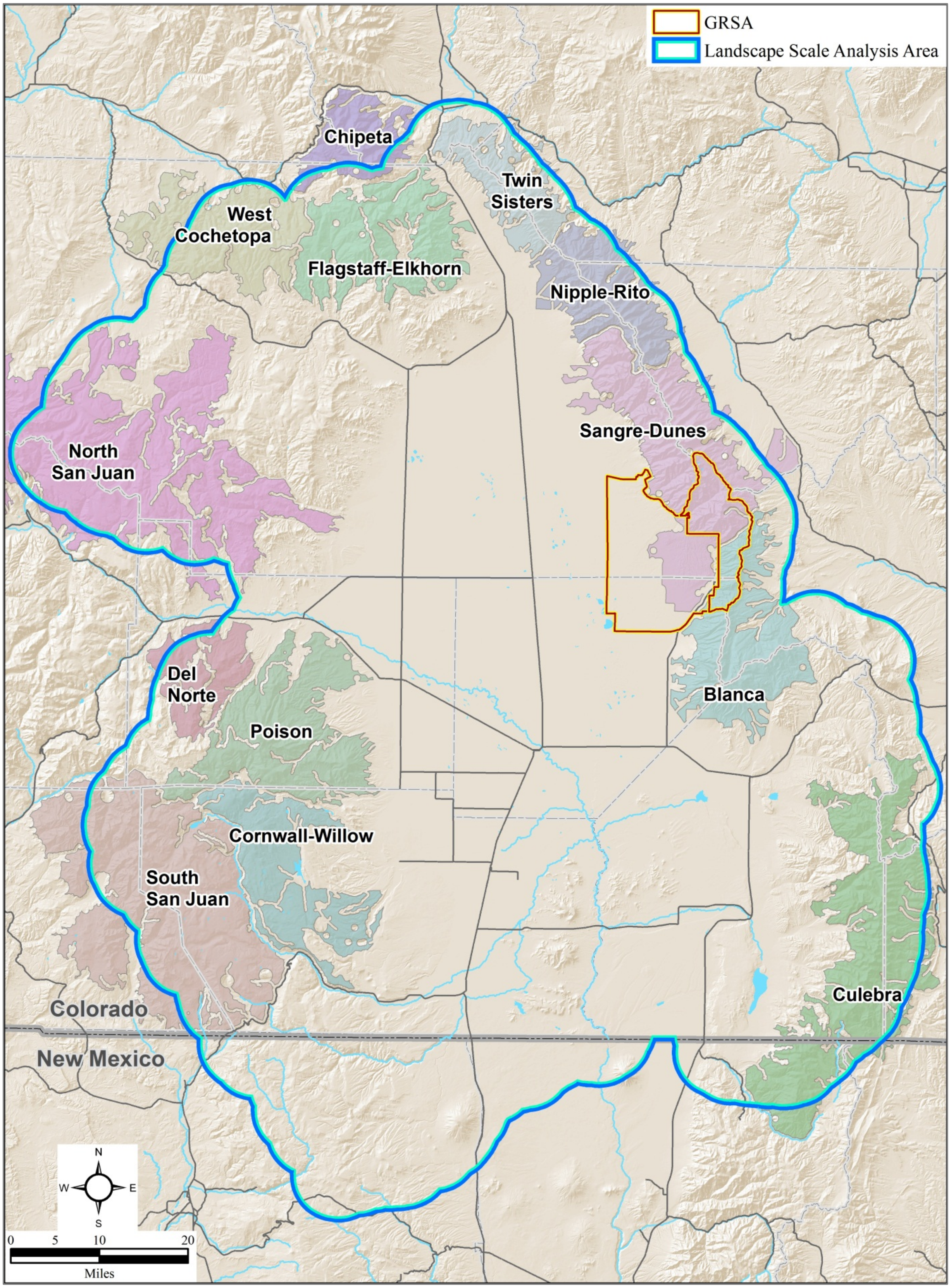


Figure 4.2.13. Core areas at least 50,000 acres (20,235 ha) in size.

Table 4.2.4. Large core areas (sorted by size) and their vegetation structural composition. GRSA is part of two (shaded) core areas.

Core Area	Acres	Forest	Grassland	Herbaceous	Shrubland	Sparsely Vegetated
North San Juan	432,001	60.9%	21.3%	6.8%	6.2%	4.7%
South San Juan	302,817	77.0%	0.8%	13.9%	5.1%	2.9%
Culebra	223,680	77.5%	12.9%	1.9%	2.3%	5.3%
Sangre-Dunes	176,326	48.6%	15.4%	3.1%	12.6%	20.2%
Poison	139,527	62.5%	23.7%	5.5%	6.6%	1.8%
Blanca	122,974	71.9%	11.3%	2.0%	3.0%	11.8%
Flagstaff-Elkhorn	112,280	81.9%	14.3%	0.7%	0.9%	2.2%
West Cochetopa	108,302	82.9%	9.3%	0.1%	7.3%	0.4%
Cornwall-Willow	101,177	70.3%	23.0%	3.9%	2.5%	0.2%
Nipple-Rito	84,692	63.3%	18.1%	0.6%	9.6%	8.3%
Twin Sisters	64,432	74.3%	5.3%	0.1%	8.6%	11.7%
Chipeta	51,542	83.5%	4.1%	1.2%	1.9%	9.4%
Del Norte	50,837	82.4%	10.3%	1.6%	5.2%	0.4%

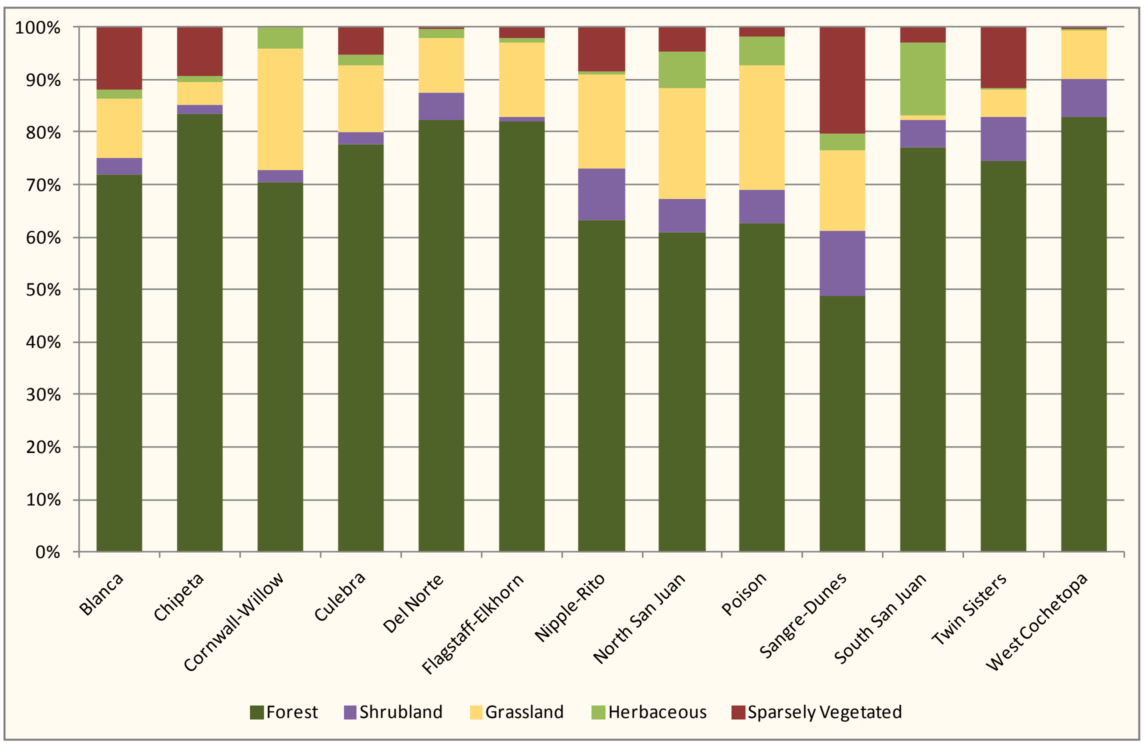


Figure 4.2.14. Vegetation composition of large core areas.

Corridors between large core areas (Figure 4.2.15) reflect the degree of "naturalness" of the landscape between the undisturbed areas. Although these corridors are general, and not tied to the behavior of a particular species, they represent the least disturbed and shortest path between core areas.

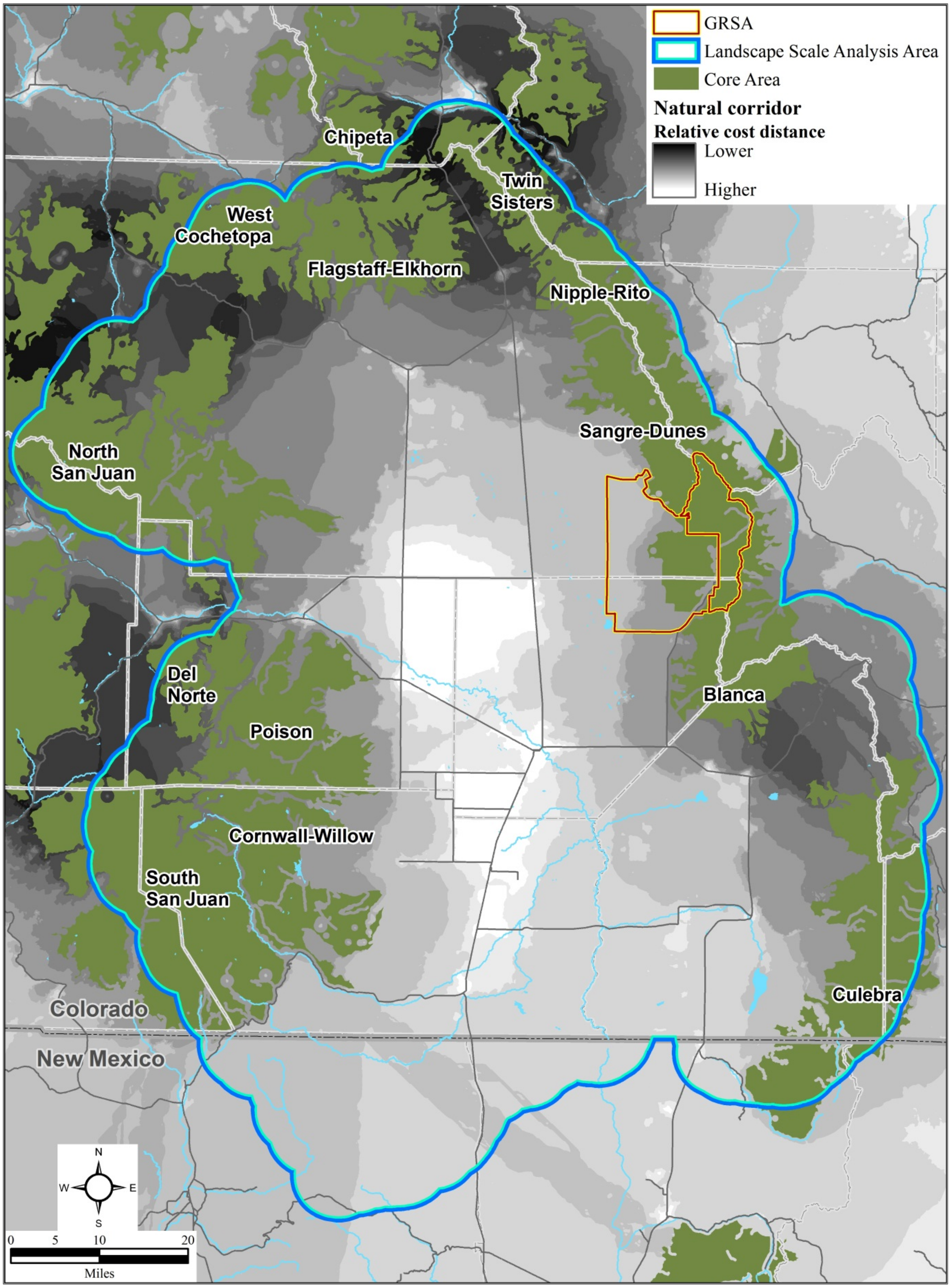


Figure 4.2.15. Least impacted corridors between large core areas in the analysis area. A darker shade of gray indicates a lower weighted cost distance.

There are several corridors of particular interest as they relate to GRSA. The corridor between the Poison and Sangre-Dunes core areas that crosses the valley floor between Monte Vista and Alamosa (Figure 4.2.16) runs between two of the most heavily developed agricultural parts of the valley and illustrates the importance of the undeveloped floodplain of the Rio Grande River as well as Rock Creek and the Monte Vista National Wildlife Refuge in facilitating cross-valley movement. The corridor constricts where it crosses Highway 285 between the Monte Vista Municipal Airport and County Rd 103 S. There is a secondary corridor that branches along Rock Creek to the south of Alamosa, crossing Highway 285 and skirting south of the Alamosa Municipal Airport. There are also multiple paths between the Blanca and Culebra core areas (Figure 4.2.17) that provide connectivity along the east side of the valley, south of GRSA. The least-cost part of this corridor is just east of Fort Garland before the confluence of Sangre de Cristo Creek with West Indian Creek, an area currently under exurban development. There are also several alternate pathways on either side of the primary one.

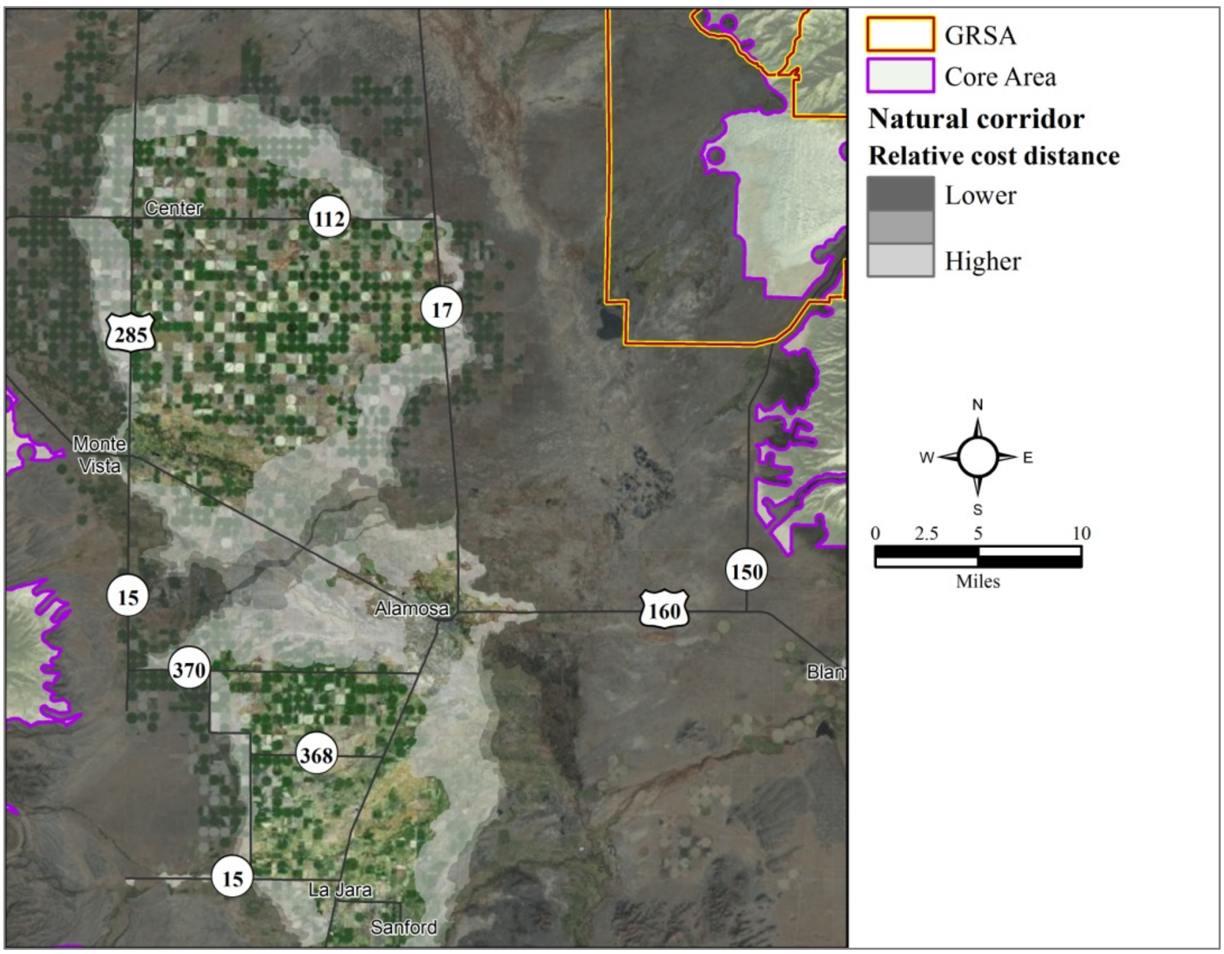


Figure 4.2.16. Detail of the corridor between Poison and Sangre-Dunes core areas. The weighted cost distance has been re-scaled to show finer detail.

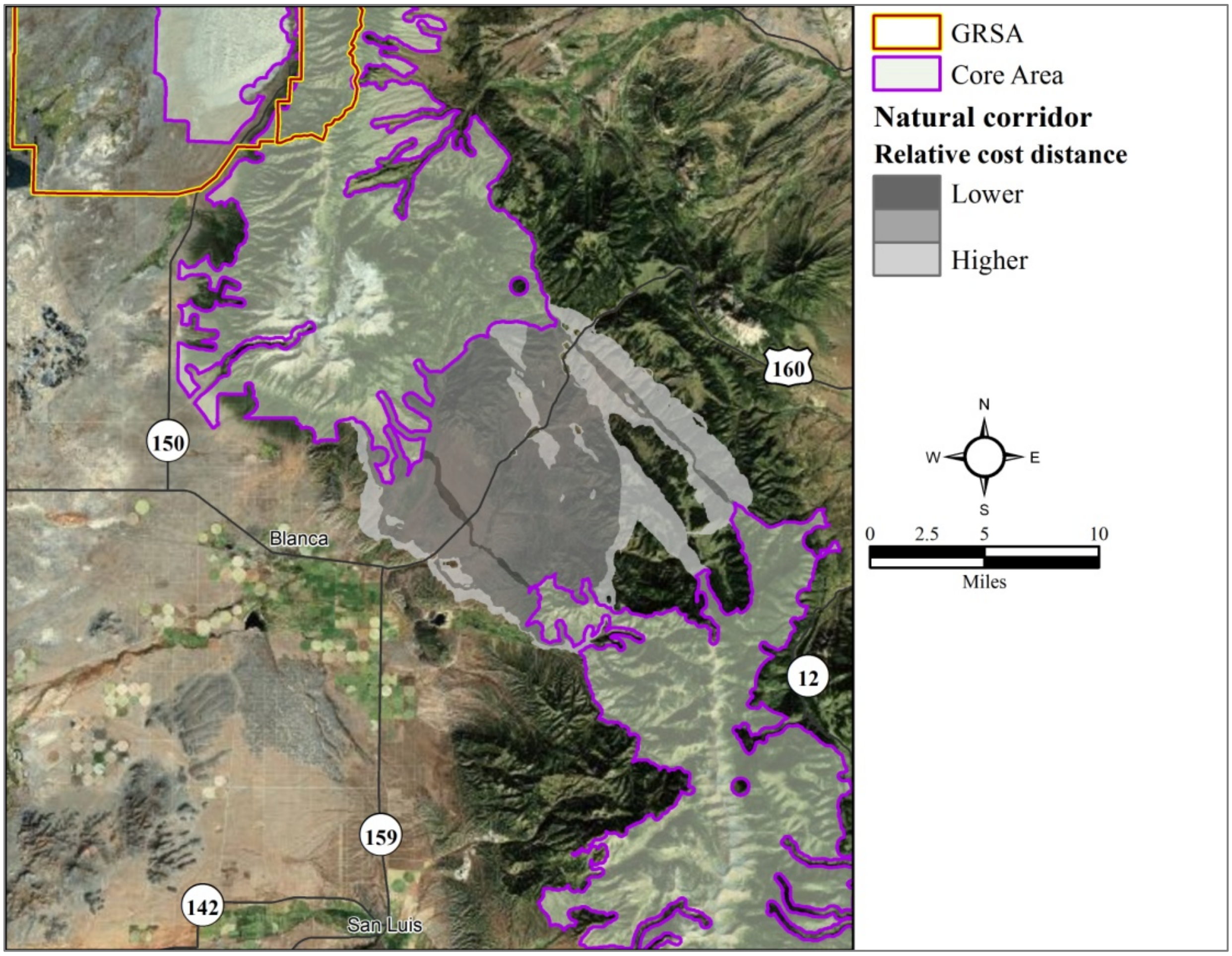


Figure 4.2.17. Detail of the corridors between Blanca and Culebra core areas. The weighted cost distance has been re-scaled to show finer detail.

Overall condition of landscape composition and connectivity

Two of the three indicators were ranked as in good condition, and the third is of moderate concern (Table 4.2.5). Following the rule of using the lowest score among multiple indicators, we assessed this resource as warranting moderate concern. The lack of trend information constitutes uncertainty in the assessment. Although connectivity, in particular, is not likely to be improving, the condition of the indicators is likely to be changing slowly, if at all. We chose to represent the trend as stable, until future data can be compared with baseline conditions reported herein.

Table 4.2.5. Summary of landscape composition and connectivity condition.

Indicator	Interpretation	Condition Assessment
Ecosystem diversity	Overall, GRSA has ecosystem diversity slightly greater than that of the analysis area.	Resource is in Good Condition
Patch size distribution	The three ecosystems characteristic of the park (Active and stabilized dune, Greasewood flats, and Semi-desert shrub-steppe) are all represented by patches in the upper quartile of patch size distribution in the vicinity of GRSA. Furthermore, the vicinity of GRSA also includes relatively large patches (in the upper half of the size distribution) of ecosystems characteristic of the Sangre de Cristo Mountains, with the exception of Spruce-fir. This ecosystem appears well developed in areas of the Sangre de Cristos to the north and south of GRSA. However, because there is no evidence that spruce-fir is lacking in the vicinity of GRSA due to anthropogenic impacts, we chose to regard this as a natural condition, not requiring a rank of warrants moderate concern. Therefore we consider that, in comparison with the larger landscape, patch size distributions of ecosystems characteristic of the preserve are in good condition.	Resource is in Good Condition
Core Areas and Connectivity	The connectivity analysis indicates that GRSA remains connected to native ecosystems in the larger landscape along the Sangre de Cristos, and is part of two large core areas. However, the reduced or absent connectivity across the floor of the San Luis Valley indicates moderate concern.	Warrants Moderate Concern

4.2.5 Sources of Expertise

Michelle Fink, CNHP Landscape Ecologist, has completed a variety of connectivity analyses for landscapes in Colorado and surrounding states. ROMN staff reviewed and commented on this section.

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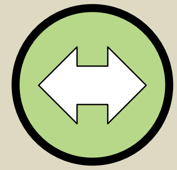
4.3 Hydrology

Indicators / Measures

- Surface water: timing and magnitude of runoff
- Groundwater: seasonal high and low elevations at boundary piezometers

Condition - Trend



4.3.1 Background and Importance

The significance of water in the western U.S. can hardly be over emphasized, and this holds true for the San Luis Valley and GRSA as well. Moreover, the formation and persistence of the dunes themselves is closely tied to local and regional hydrology, including both surface and groundwater (see section 4.4 below). Surface waters have historically been the first and primary source of supply for both public and private requirements (Topper et al. 2003). In the San Luis Valley, however, the use of groundwater for agriculture is also of great importance.

Surface water

The northern portion of the San Luis Valley where GRSA is located forms a closed basin with no natural external drainage, while the southern part of the valley is drained by the Rio Grande River. The Rio Grande and Conejos rivers are the primary perennial streams in the San Luis Valley. The Rio Grande and its tributaries, including the closed basin, drain approximately 7,500 square miles (19,500 km^2) in Colorado (Topper et al. 2003), and constitute the headwaters of one of the major North American river drainages. In addition to the larger perennial rivers and streams, many smaller creeks that are perennial in their upper reaches drain from the mountains on both sides of the valley, and disappear into the valley floor. Within GRSA, Medano and Sand creeks are the primary examples of this type. Finally, the valley contains numerous smaller drainages that are intermittent or ephemeral.

Although GRSA and its streams belong to the closed basin and are not naturally connected to surface flow patterns in the Rio Grande drainage, the overall landscape patterns of the San Luis Valley (and in the vicinity of GRSA) are closely influenced by patterns of water distribution. Surface water supplies in the San Luis Valley are highly variable from year to year. For example, during the period of record 1890 to 2011, annual streamflow on the Rio Grande at Del Norte has ranged from a high of over 1,073,000 acre-feet (af) in 1987 to a low of 160,000 af in 2002 (CDWR 2012).

The condition of surface water at GRSA is assessed by comparing seasonal streamflow characteristics (timing and magnitude of flow) of selected streams originating within GRSA to similar nearby streams (Figure 4.3.1).

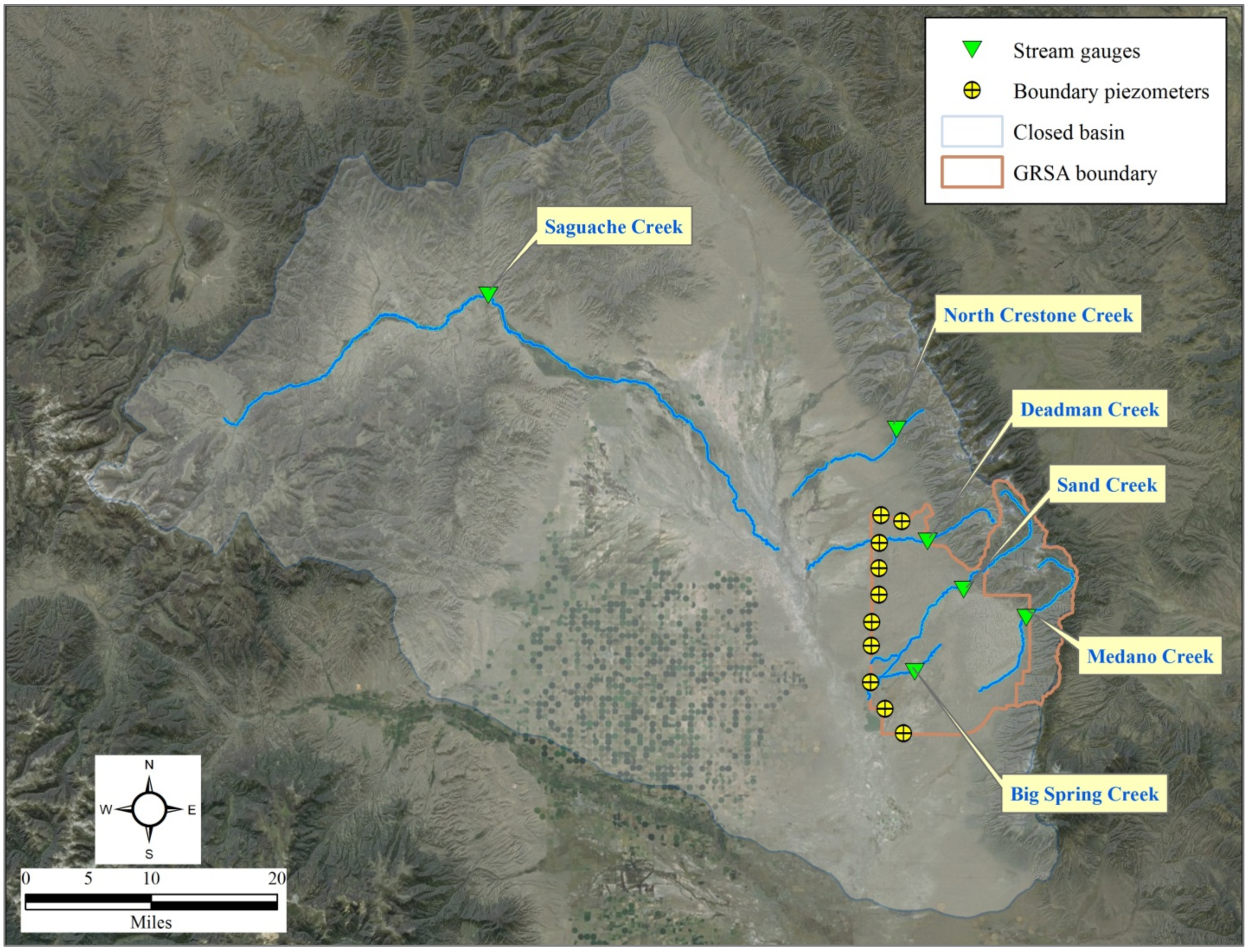


Figure 4.3.1. Stream gauge and boundary piezometer locations at GRSA.

<u>Groundwater</u>

The complex aquifer and groundwater situation of the area has been extensively studied, described, and modeled elsewhere (CDWR 2004). Beneath the valley surface, a series of geologic layers make up an interconnected system of aquifers. Pumping from the unconfined and confined aquifers depletes surface streamflow through several mechanisms. The unconfined aquifer discharges directly to surface streams through springs (e.g., Russell Springs and McIntyre Springs) or groundwater inflow. At GRSA, discharge from the unconfined aquifer to surface streams (Big and Little Spring creeks, interdunal ponds, and wetlands such as Twin Lakes) is much more important than discharge to the surface from the confined aquifer.

In much of the GRSA region the clay-dominated second layer acts as an aquitard between the two aquifers, although some water is able to move upward from the confined aquifer to the unconfined aquifer. The hydraulic connectivity between the two aquifers is greater on the eastern side of the dunes, near the Sangre de Cristo Mountains (HRS 2006). A reduction in artesian pressure in the confined aquifer also reduces the amount of upward leakage, reducing the amount of water entering the unconfined aquifer from the confined aquifer, and potentially decreasing the flow of surface streams and springs such as Big and Little Spring creeks within GRSA.

In order to define the upper limits of the water table in the unconfined aquifer, and to facilitate the administration of GRSA's *in situ* groundwater right under the prior appropriation system, a set of ten groundwater monitoring wells (termed Boundary Piezometers in the GRSA water right decree) have been installed (Figure 4.3.1). These wells are also intended to serve as long-term monitoring sites and generally increase knowledge and scientific understanding regarding the hydrogeology of the unconfined aquifer, and interactions between groundwater and surface water in the GRSA area (HRS 2006).

The condition of groundwater at GRSA is assessed by evaluating groundwater dynamics (overall patterns and seasonal high and low elevations) for selected monitoring wells. We compared average, maximum, and minimum annual water table elevations for the ten boundary piezometers to the elevations listed in the final water decree.

4.3.2 Data and Methods

Data used to evaluate surface water resources were obtained from the Colorado Division of Water Resources surface water database (CDWR 2012), and from Andrew Valdez at GRSA. A representative subset of stream gauging stations used in the GRSA groundwater model is presented.

GRSA boundary piezometer well data for three complete water years (October 2009 through September 2012) were obtained from Andrew Valdez at GRSA. This dataset represents an initial sample from what is intended to be a longer baseline period, and should be regarded as a preliminary result.

4.3.3 Reference Conditions

Reference criteria are summarized in Table 4.3.1. For surface water, the historical average annual hydrograph of discharge for area streams is the reference condition for timing and magnitude of seasonal flow patterns. We focused on providing a baseline of conditions for future comparison, and made a general qualitative assessment of condition and trend based on best professional judgment.

Table 4.3.1. Criteria for evaluating hydrology.

Condition Assessment	Surface Water	Groundwater
Resource is in Good Condition	Flows in Medano and Sand creeks appear stable over the period of record, and with patterns similar to nearby streams with longer period of record.	Boundary piezometer elevations are stable or increasing, and all wells meet decree levels.
Warrants Moderate Concern	Flows in Medano and Sand creeks may be declining, and this decline is not matched by nearby streams with longer period of record	Boundary piezometer elevations may be decreasing; not all wells meet decree levels
Warrants Significant Concern	There is strong evidence that flows in Medano and Sand creeks have declined over the period of record, and this decline is greater than or unmatched by nearby streams with longer period of record	There is a clear trend toward lower elevations, few or no wells meet decree levels

The reference condition for change in groundwater level is the base period interval (1 January 1999 to 31 December 2003) used in the GRSA groundwater model, which reflects conditions under which the dune system and other resources are able to persist.

4.3.4 Condition and Trend

Surface water

Hydrographs for GRSA area streams show two general patterns of seasonal discharge. The typical pattern of a perennially flowing stream coming off the Sangre de Cristo Mountains is shown by Medano and Sand creeks (Figure 4.3.2a and b). Measurable flow is generally very low between mid-November until about mid-March. Flow increases fairly rapidly until the normal peak runoff in late May or early June, then gradually decreases, with occasional dramatic increases due to local intense precipitation events. The other pattern is exhibited by Big Spring Creek, which shows a fairly uniform year-round discharge from its source (Figure 4.3.2b). Seasonal patterns for Medano and Sand creeks are comparable to those of North Crestone and Deadman creeks, two other nearby streams that originate in the Sangre de Cristos and run to the valley floor. There are no comparable data for a comparison of Big Spring Creek.

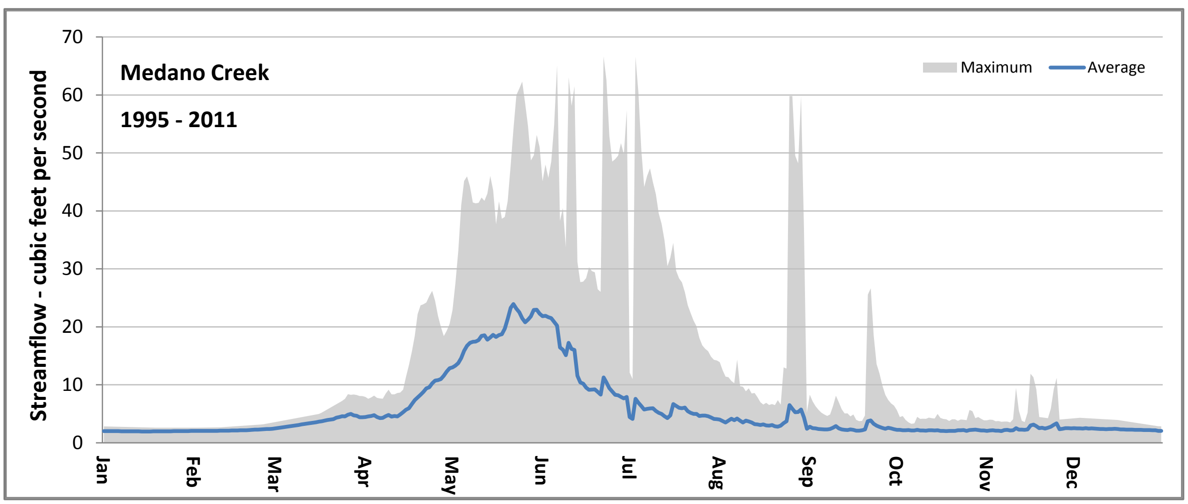


Figure 4.3.2.a. Period of record hydrograph for Medano Creek.

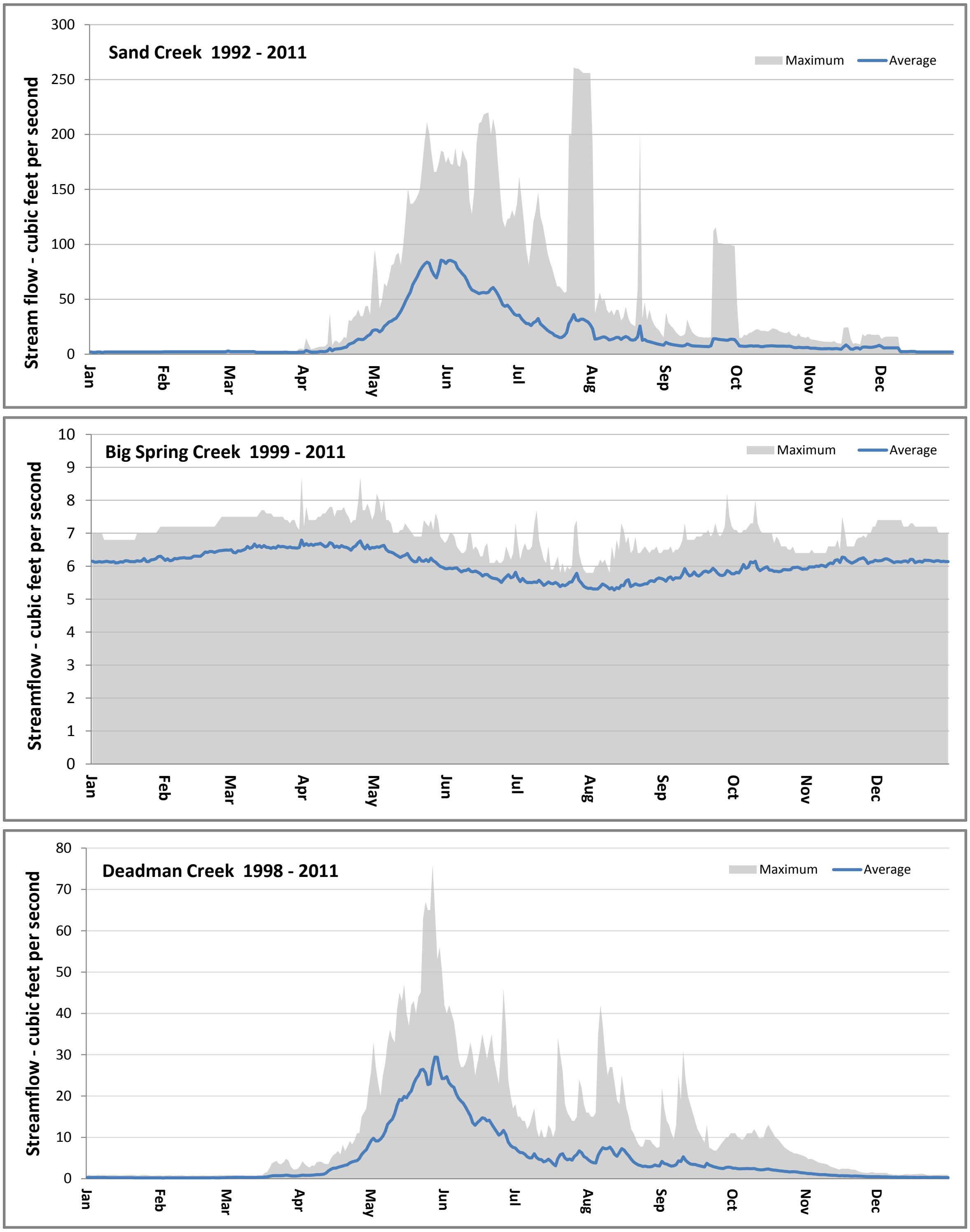


Figure 4.3.2.b. Period of record hydrographs for Sand Creek, Big Spring Creek, and Deadman Creek.

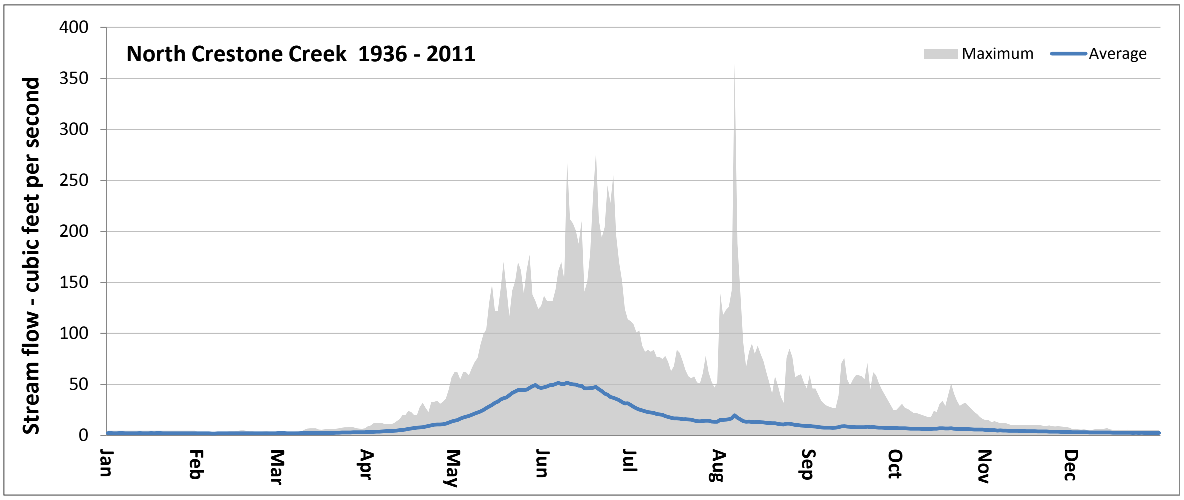


Figure 4.3.2.c. Period of record hydrograph for North Crestone Creek.

Of the three streams originating within GRSA that were evaluated, Sand Creek has the highest discharge (Table 4.3.2). Both Medano Creek and Sand Creek can be highly variable between years, while Big Spring Creek is much more constant.

Table 4.3.2. Discharge levels for selected streams originating within GRSA.

Stream	Period of Record for Hydrograph	Cumulative Discharge per Water Year (acre-feet) Average	Min	Max
Sand Creek*	1993-2011	11,544	5,250	19,857
Medano Creek	1995-2011	3,887	408	10,001
Big Spring Creek	2000-2011	4,388	4,102	4,600

*Data include many incomplete years

With the exception of Saguache and North Crestone creeks, streams included in the GRSA groundwater model have record periods encompassing 20 or fewer years of complete data. No real streamflow trends are discernable over this short time frame. Within the closed basin, Saguache Creek has the longest continuous period of record (1915-present). Discharge amounts in Saguache Creek have been lower than average during the first dozen years of the 21st century (Figure 4.3.3). In the highly manipulated hydrologic setting of the San Luis Valley it is difficult to determine if this is solely a response to reduced precipitation, or perhaps a decline aggravated by water withdrawals for agriculture use. These same years show a similar, if less severe, declining trend for other area streams (Figure 4.3.3). The 18-year period of record for Medano Creek shows a similar pattern to the corresponding period of the North Crestone Creek record.

Although there is a suggestion of a regional decline in streamflows during the past few decades, there is insufficient evidence to support a decline due to water withdrawal under the contemporary configuration of surface and groundwater use. Surface hydrology is considered in a stable, but altered condition, until such time as additional data are available. The lack of threshold standards for this indicator constitute a primary source of uncertainty in the assessment.

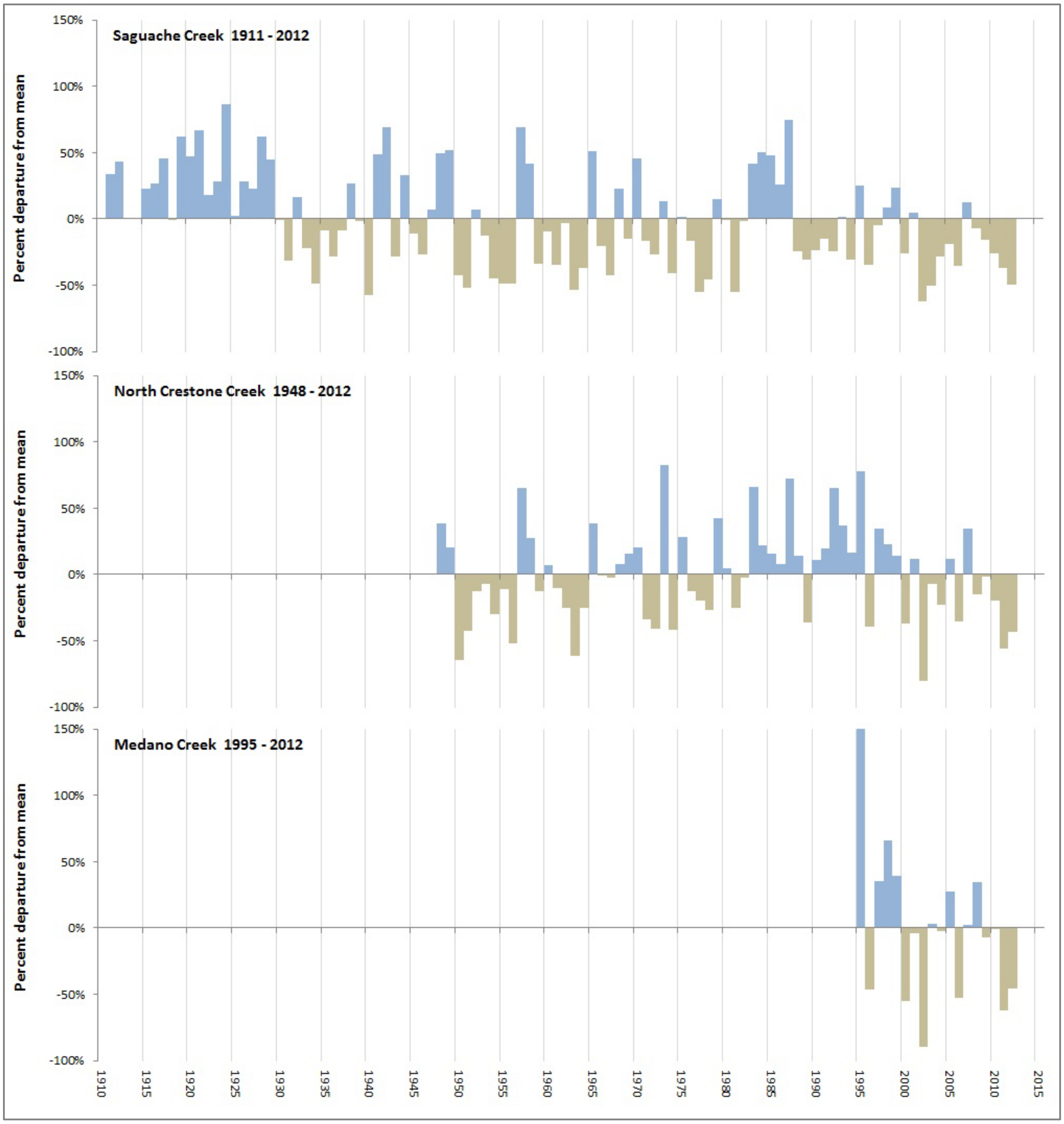


Figure 4.3.3. Comparison of Medano Creek streamflow trends with other area creeks.

<u>Groundwater</u>

The final GRSA groundwater right decree lists maximum historically observed water table elevations for the approximate locations of the ten boundary piezometers prior to June 11, 2007. Whenever the water table elevation at the Park boundary is at or above the elevation shown for the locations in the decree, the water right is satisfied at that location. Three-year averages for six of the ten monitoring wells indicate that the water table is meeting the decreed level (Table 4.3.3) at those locations.

Table 4.3.3. Comparison of boundary piezometer levels with decreed water table elevations.

Well	Maximum Water Table Elevation in Decree	2010 Average	2011 Average	2012 Average	2010-2012 Average
BP-1	7552	7538.19	7537.86	7537.69	7537.91
BP-2	7527	7528.06*	7527.08*	7526.65	7527.26*
BP-3	7534	7531.34	7531.13	7531.23	7531.23
BP-4	7569	7569.15*	7569.05*	7569.03*	7569.08*
BP-5	7590	7591.96*	7591.87*	7591.74*	7591.86*
BP-6	7601	7615.64*	7615.51*	7615.37*	7615.51*
BP-7	7603	7622.82*	7622.55*	7622.38*	7622.58*
BP-8	7609	7630.67*	7630.40*	7630.20*	7630.43*
BP-9	7647	7642.64	7642.27	7642.10	7642.34
BP-10	7726	7682.00	7681.39	7680.76	7681.38

*Values are equal to or above decree elevations.

Groundwater elevations from the ten boundary piezometers (Figure 4.3.4a-b) show several patterns during the three year span. Wells 1 and 10 show little evidence of the seasonal variation in elevation that is characteristic of the other wells. Wells 4 through 9 have a regular seasonal pattern from year to year, while 2 and 3 are less regular. In addition, all wells show a slight decline in groundwater elevation over the period of measurement, corresponding to a period of lower local and regional precipitation. Because this represents only a portion of the intended baseline period, we hesitate to conclude that there is evidence for a decline in groundwater levels over the longer term. Furthermore, the regional history of groundwater pumping and the practice of storing water in the aquifer increase uncertainty about the significance of this trend in the longer term. Clearly groundwater pumping can and has affected aquifers in the past, and will continue to do so in the future.

Because there is some slight evidence for a decline in surface flows and groundwater levels in the short term, this resource warrants moderate concern. The importance of both surface water and groundwater at GRSA, combined with the uncertainties of this limited assessment led us to characterize this resource as stable, but of moderate concern, with low confidence (Table 4.3.4).

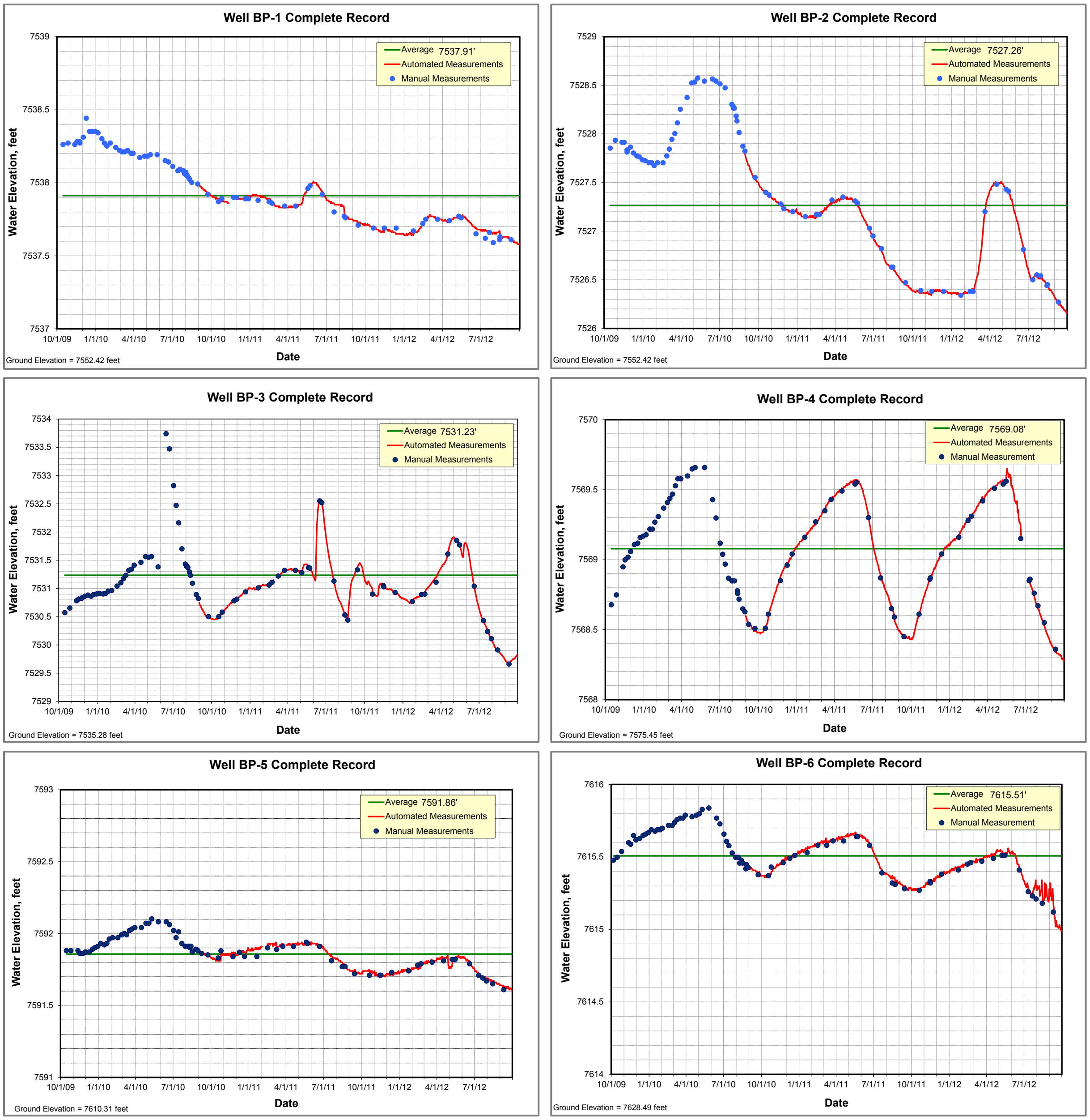


Figure 4.3.4.a. Boundary piezometer records (courtesy A. Valdez).

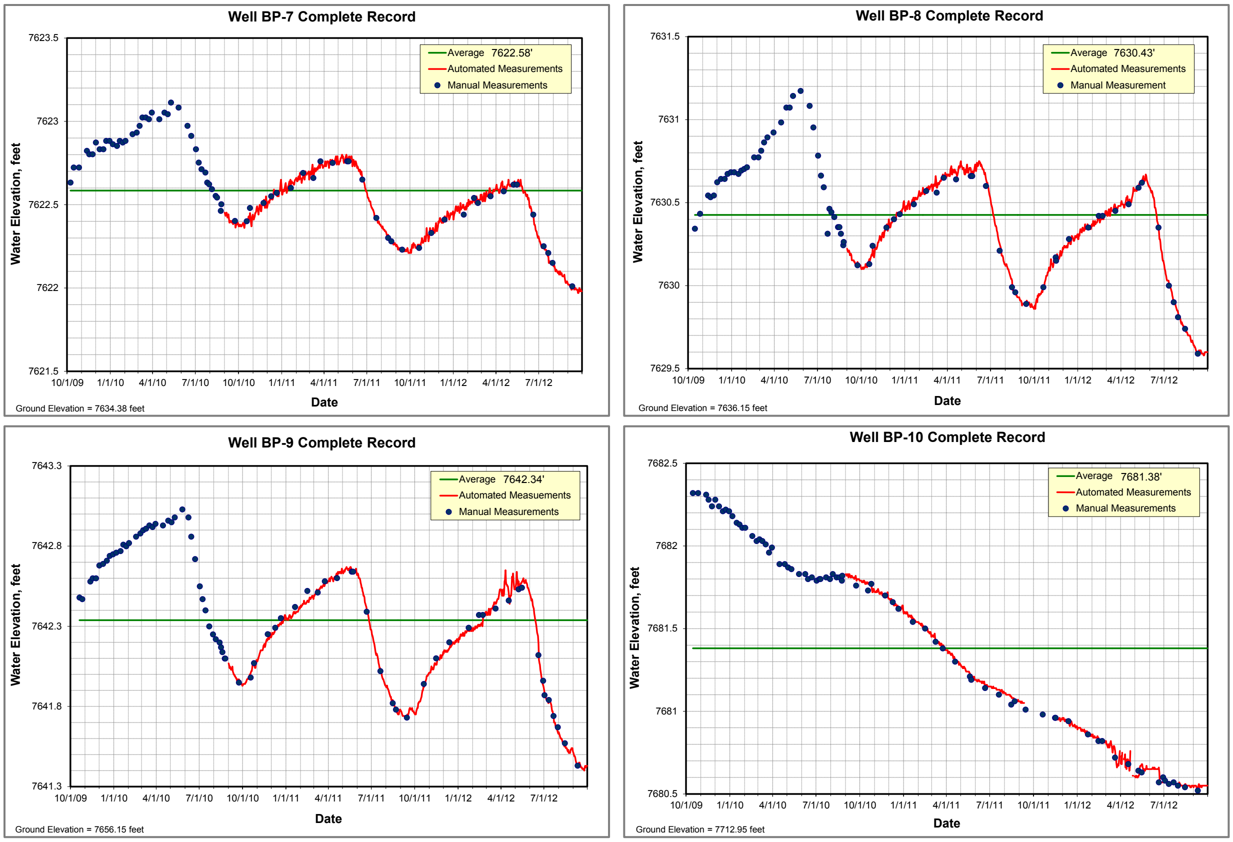


Figure 4.3.4.b. Boundary piezometer records (courtesy A. Valdez).

Table 4.3.4. Summary of hydrology condition.

Indicator	Interpretation	Condition Assessment
Surface Water	Although there may be a regional decline in streamflows during the past few decades, flows in Medano and Sand creeks appear stable over the period of record, and with patterns similar to nearby streams with longer period of record.	Resource is in good condition
Groundwater	All wells show a slight decline in groundwater elevation over the period of measurement, corresponding to a period of lower local and regional precipitation. Not all wells meet decree levels.	Resource warrants moderate concern

4.3.5 Sources of Expertise

Data and review were provided by Andrew Valdez, geologist at GRSA. James Harte, hydrologist with the NPS Water Resources Division, Natural Resource Program Center, Fort Collins, Colorado, also reviewed this chapter and provided suggestions for interpreting data.

4.3.6 Literature Cited

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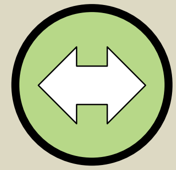
4.4 Dune System

Indicators / Measures

- Wind direction and intensity
- Precipitation amounts and seasonality
- Size and distribution of dune system components

Condition – Trend



4.4.1 Background and Importance

The dune system consists of the unvegetated dunefield, the extensive sandsheet stabilized by vegetation, and the sabkha of carbonate-cemented sand that forms in places where sand is seasonally saturated by rising groundwater. The dynamics of this system are affected by several factors, including precipitation, sand supply, wind patterns, the topography of the Sangre de Cristo Mountains, and surface flow in Medano and Sand Creeks at the dunefield perimeter. Important considerations for the dune system natural resource at GRSA include the size and stability of the dunefield, dune dynamics and stabilizing vegetation on the sandsheet, the sand transporting action of Medano and Sand Creeks, and the maintenance of near-surface water tables in the sabkha.

<u>Size and stability of the dunefield</u>

Madole et al. (2008) summarized published estimates of the height and area occupied by the Great Sand Dunes, noting that variation in estimates of height is largely due to improved measurement techniques over time, while variation in estimates of area arises from the way the dunefield is defined. Moreover, the ongoing action of wind erosion and deposition is constantly altering the dunefield. Madole et al. (2008) defined the dunefield (Great Sand Dunes) as:

> *…those dunes having the following characteristics: they are >10 m high, contiguous, presently active, have identifiable slip faces, and contain bedding that dips >20°. Dunes at the edge of the active sand mass that barely meet these criteria are included in the area of the Great Sand Dunes if they are contiguous with them … but outlying areas of well-defined active dunes that may be higher than 10 m are not considered to be part of the Great Sand Dunes."*

The dunefield as so defined is part of a larger area of eolian sands and low dunes referred to as the sandsheet (Fryberger et al. 1979) that extends along the east side of the San Luis Valley over a north–south distance of ~40 miles (~65 km)(Madole et al. 2008). Within this area, eolian sand covers about 240 square miles (625 km^2), of which, approximately 28 square miles (72 km^2) represents the dunefield, while the remaining 212 square miles (553 km^2) is low-relief dunes and sheet sand (Madole et al. 2008). The lack of precise information about both the lower boundary and the upper surface of the sand dunes limits the accuracy with which the volume of sand present can be estimated. Madole et al. (2008) estimated the total sand volume of the dunefield to be between ∼10 and 13 billion m^3 ±430 million m^3, with 10 billion m^3 being more likely, and the remaining eolian sand area to contain between ∼2 and 5 billon m^3 of sand. Although the period over which the dunefield formed is much longer than the typical management planning time-frame, the stability of the dunefield and sandsheet in their present configuration is of interest for monitoring the potential effects of changing climate on this resource.

Changes in the height and position of dunes, as well as smaller aeolian forms at GRSA have been documented by a variety of studies (e.g., Weigand 1977, Janke 2002, Lorenz and Valdez 2011). Such changes are an ongoing and frequent event in the system. Weigand (1977) investigated dune movement over the period from 1936 to 1975 in several areas around the dunefield by comparing three sets of low-level aerial photographs. Weigand found that dunes on the western edge of the dunefield near Sand Creek had moved toward the northeast at a rate of 9-11 ft (2.7-3.3 m) per year, while along the eastern edge of the dunefield, movement was about 7.5-9 ft (2.3-2.8 m) per year. In spite of ongoing dune movement, the action of Medano Creek maintained the eastern edge of the dunefield in essentially the same location. Janke (2002) used remote sensing techniques to compare imagery of the dunefield dated 1984 and 1998, focusing primarily on the center dunefield and peripheral sandsheet within the (then) monument. The orientation of the dunes did not change during the 14-year study interval, but the area covered by semidesert scrub increased (Janke 2002), suggesting that active dune area decreased during this period.

Sandsheet dune dynamics and stabilization by vegetation

Parabolic dunes may form on the sandsheet in "blowout" areas of erosion. The arms of these dunes are anchored by vegetation but the center arc migrates toward the main dunefield (NPS 2012). Marín et al. (2005) compared remote sensing images for the period 1936 to 1999 to investigate dune migration and changes in vegetation cover. Dune movement is episodic, and increases during droughts when reduced vegetation cover and surface water are common (Marín et al. 2005). Movement of smaller aeolian landforms is also episodic. Lorenz and Valdez (2011) detected ripple movement on a large parabolic dune on the sandsheet on only 12 days during an approximate ten week observation period. Stratigraphic analysis and luminescence dating of quartz grains (Forman et al. 2006), has documented at least five periods of eolian depositional events, suggesting that eolian sand transport in the San Luis Valley has been episodic since at least the 8th century. The sand-anchoring properties of vegetation were quantified by Valdez (1999), who found that 10% ground cover was sufficient to prevent most sand movement, and that shrubby vegetation cover of 50% or more completely halted sand movement.

Sand transport by Medano and Sand Creeks

The dunefield is bounded by Medano Creek on its east and southeastern edge, and by Sand Creek on the northwestern side. These creeks originate high in the Sangre de Cristo Mountains and terminate in the sand, where the water they carry percolates into the shallow unconfined aquifer. During high runoff periods, the creeks erode sand from along the mountain front and deposit it on the valley floor. When flows decrease and the wide braided channels of the streams dry up, prevailing winds blow the sand back into the dunefield (Valdez 1992). The cyclical erosion and deposition action of these streams has contributed to the overall asymmetrical crescent shape of the dunes; the larger southern arm of the crescent is associated with Medano Creek, and the smaller northern lobe is associated with Sand Creek (Valdez 1992).

Key factors in the formation and maintenance of the dune system are wind and water. Wind speed and direction are evaluated by a narrative comparison of recent patterns with those reported in earlier work. Recent and historical precipitation patterns (amount and seasonality) are compared and summarized in relation to flow distance of dunefield bounding creeks. Finally, the size and distribution of dune system components (dunefield, sandsheet, sabkha) are summarized as a baseline for future comparison.

4.4.2 Data and Methods

We addressed the wind factor by obtaining data on wind speed and direction for both day and night periods, and for various seasonal periods. Precipitation seasonality, quantity, form, and temporal variation (Palmer Drought Severity Index) are summarized for the period of record at GRSA. Wind and precipitation records were obtained from WRCC (2012). GPS coordinates of the terminal points for Sand and Medano Creeks in 1997, 1999, 2000, and 2002 were provided by park staff. Mapped acreage for dunefield, sandsheet, and sabkha was estimated from the GRSA vegetation map (Salas et al. 2011) to provide a baseline for future comparison. Map units were assigned to each component as indicated below:

Dunefield

- Barren Sand Dune

Sandsheet

- Greasewood Sand Deposit Shrubland and Steppe Alliances
- Herbaceous Stabilized Dune and Sandsheet Alliances
- Sandsheet Rabbitbrush Shrubland and Steppe Alliances
- Wash
- Narrowleaf Cottonwood Sand Dune Woodland Association

Sabkha

- San Luis Valley Mesic Meadow Alliances
- Alluvial Flat Herbaceous Alliances
- Greasewood Flat Shrubland and Steppe Alliances

4.4.3 Reference Conditions

The Great Sand Dunes are a dynamic system, so it makes sense to define a reference condition of a range of sustainability rather than a static baseline. Historic conditions have obviously been suitable for the formation and maintenance of the dune system. The dune system should be considered stable if the relative proportions and landscape locations of active dunefield, sandsheet, and sabkha remain more-or-less as they have been through the history of the park and preserve, and if the climatic drivers remain in a similar pattern to that which has been historically documented. Ongoing changes in the size, shape and position of these components can be monitored by repeated ground, aerial, or satellite surveys. Period of record data for key climatic drivers of the system are presented. We evaluated this resource qualitatively according to criteria shown in Table 4.4.1.

Table 4.4.1. Criteria for evaluating the condition of the dune system.

Condition Assessment	Wind	Precipitation	Dune System Components
Resource is in Good Condition	Wind speed and direction patterns appear to be stable, within documented range of variation	Precipitation patterns vary within historic norms	Relative percent contribution of each dune system component has remained fairly stable, and tracks drought cycles
Warrants Moderate Concern	Wind speed and direction patterns may be changing, continued change could have adverse effects on persistence of the dune system	Precipitation patterns appear to be changing, and continued change could have adverse effects on persistence of the dune system	Relative percent contribution of each dune system component appears to be shifting (e.g., increased vegetation-stabilized areas)
Warrants Significant Concern	There is strong evidence that wind speed and direction patterns are shifting in a way that will have adverse effects on persistence of the dune system	There is strong evidence that precipitation patterns are changing in a way that will have adverse effects on persistence of the dune system	There is strong evidence that the percent contribution of each dune system component is moving to a new state in which dunes will not persist

4.4.4 Condition and Trend

Wind speed and direction

Weigand (1977) presented wind data from Great Sand Dunes during the period of June 1975 through February 1976, and for the period of record at the time at Alamosa, Colorado that showed wind direction predominantly from the southwest. Period of record (June 2004-present) at GRSA (Figure 4.4.1) shows a similar pattern for the strongest (daytime) winds, although night hours have a noticeable southeasterly component of lighter winds that was not explicitly identified in the "sand rose" provided by Weigand. Wind intensity and direction continues to be sufficient for maintenance of the dune system.

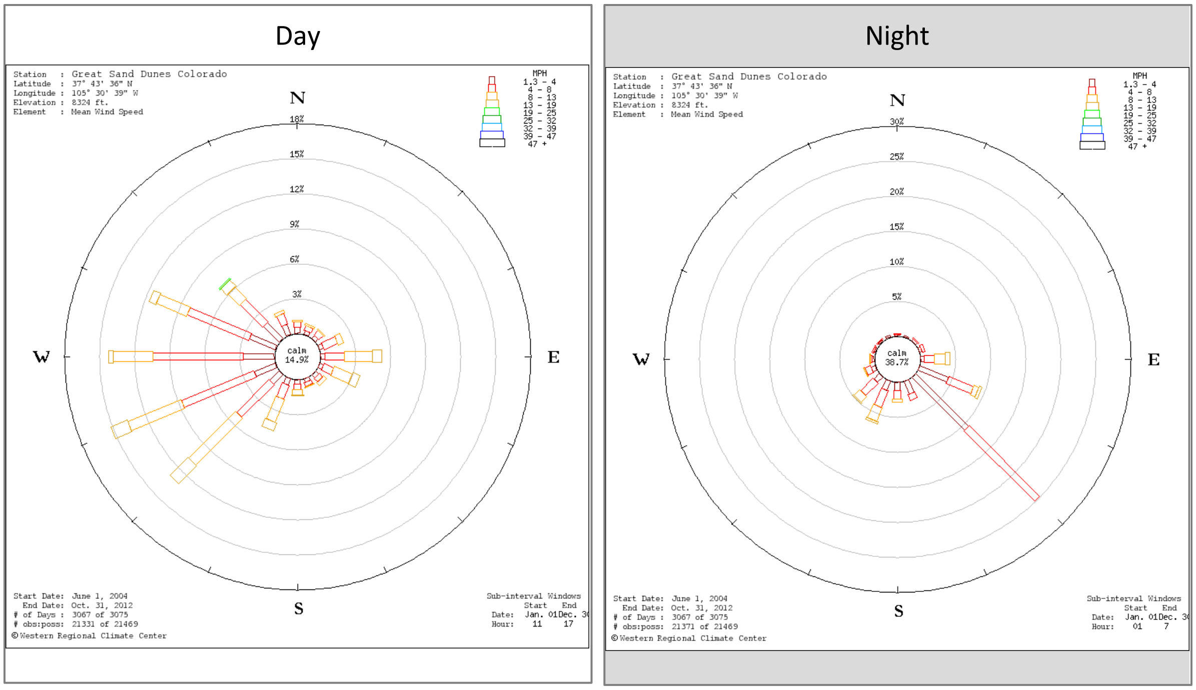


Figure 4.4.1. Wind speed and direction as measured at GRSA.

<u>Amount and seasonality of precipitation</u>

Annual precipitation at GRSA has averaged 11.12 in (28.25 cm) during the period from 1951 to 2012, with a historic annual minimum of 5.85 in (14.86 cm) in 1951, and a maximum of 20.14 in (51.16 cm) in 1997. Precipitation increases in spring from March to May as warm, moist air from the south moves into Colorado. Precipitation amounts are greatest during July and August (Figure 4.4.2), when the area receives “monsoon” moisture originating over the Mexican Plateau. A portion of the early spring precipitation typically falls as snow, and snowfall is a significant component of precipitation from November through February (WRCC 2012).

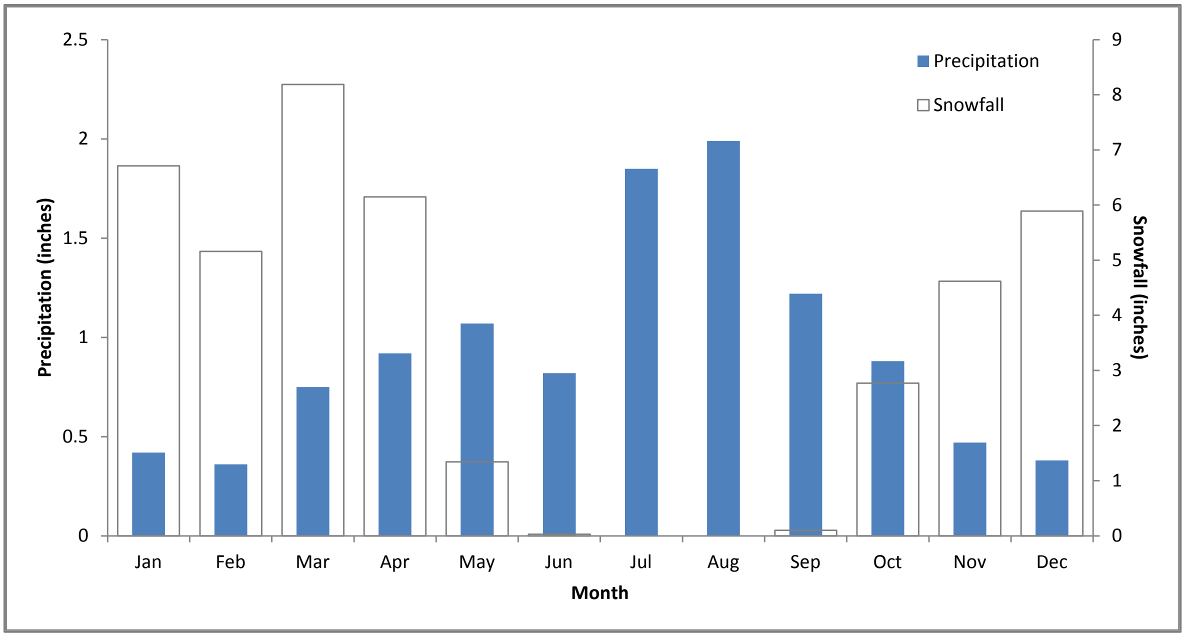


Figure 4.4.2. Annual average precipitation and snowfall at GRSA.

Flow in Sand Creek and Medano Creek is clearly tied to precipitation (Figure 4.4.3). In years with above normal precipitation, the creeks extend well past the main dunefield. In a year of severe drought such as 2002, Sand Creek's furthest extent was more than 5 miles upstream than that observed in wetter years.

Dune movement is also generally greater in periods of drought (Figure 4.4.4). Weigand's (1977) observation period included two periods of severe drought accompanied by significant dune migration, while Janke's (2002) study period was a much wetter period, during which dune stabilization increased.

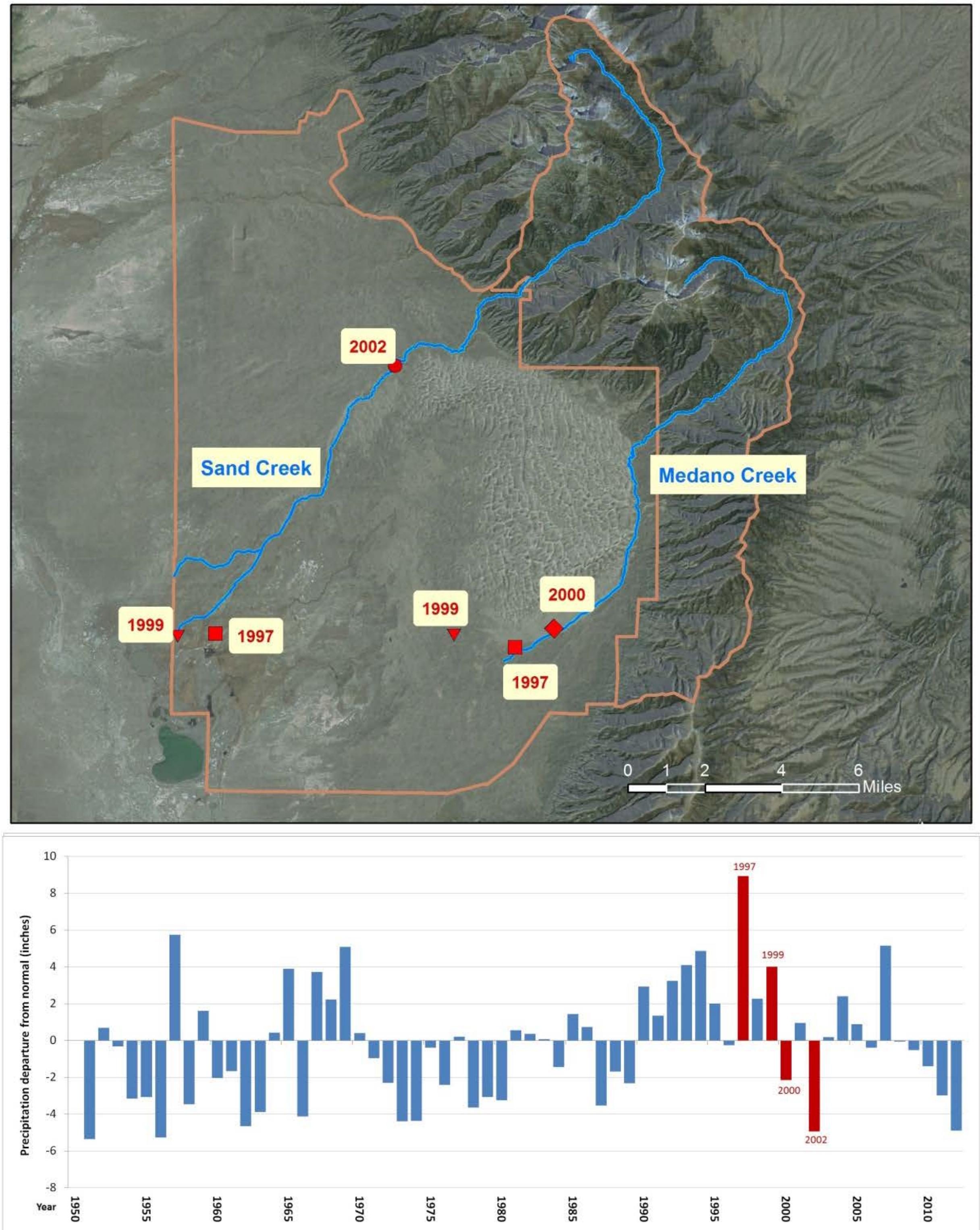


Figure 4.4.3. Precipitation and boundary stream flow.

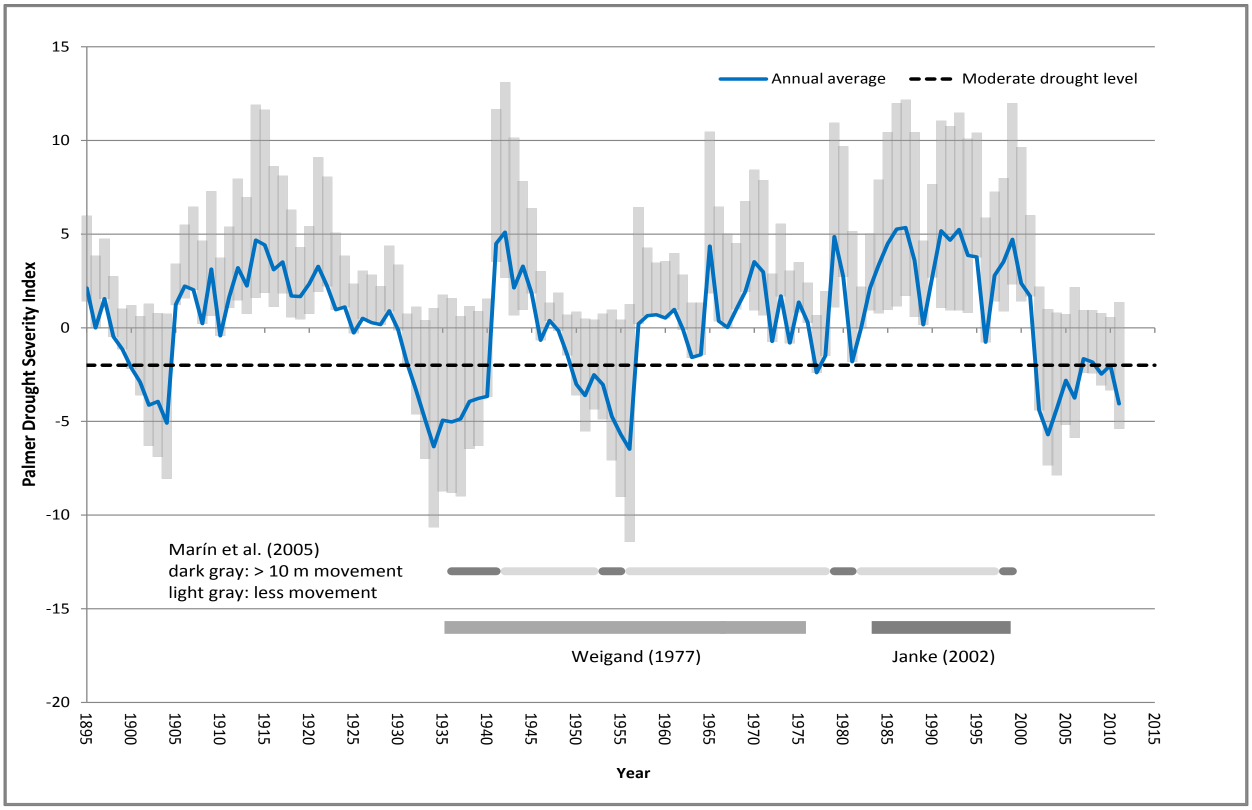


Figure 4.4.4. Palmer Drought Severity Index for the Rio Grande Region, and periods of dune movement. Light gray "error" bars indicate annual range of PDSI.

Size and distribution of dune system components

As mapped in Salas et al. (2011), the dune system components account for 63% of the total vegetation mapping area (Table 4.4.2). Dunefield covers about 7% of the dune system area, sandsheet accounts for the largest portion at about 60%, and the remaining 34% is sabkha. The vegetation mapping was completed during a period of moderate drought. Observed proportions may change under changing climate condition, but until the area is remapped this represents a presumed stable baseline.

Table 4.4.2. Area of dune system components within 2005 GRSA vegetation mapping boundary.

Component	Acres (ha)
Dunefield	17,391 (7,038)
Sandsheet	155,866 (63,077)
Sabkha	88,322 (35,743)
Total dune system	261,579 (105,858)
Total vegetation mapping area	**413,514 (167,343)**

Until additional information is available, the patterns and trends documented during the period of record for indicators evaluated for the dune system resource (Table 4.4.1) suggest that the resource can be considered stable and in good condition.

4.4.5 Sources of Expertise

Andrew Valdez, geologist at Great Sand Dunes National Park and Preserve provided data and review for this assessment.

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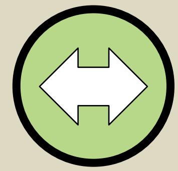
4.5 Fire

Indicators / Measures

- Fire extent and frequency – regional and local
- Proportion of each ecosystem group in fire condition classes

Condition - Trend



4.5.1 Background and Importance

Fire, whether due to natural or human causes, has the potential to exert a landscape level influence on the ecosystems of the San Luis Valley and Sangre de Cristo Mountains (Figure 4.5.1). Throughout the western U.S., management activities including fire suppression, have altered fire regimes, and changed the composition of habitats upon which native species depend (Neely et al. 2001). The National Park Service manages wildland fire to protect the public, communities and infrastructure, conserve natural and cultural resources, and restore and maintain ecological health (NPS 2008). Individual park units, including GRSA, are directed to fully integrate wildland fire management into land management planning.

Figure 4.5.1. Aftermath of the 2010 Medano Creek Fire at GRSA. Photo credit: NPS.

<u>Fire-affected ecosystems at GRSA</u>

Alpine ecosystems are not generally influenced by fire, due to the lack of fuel (low-growing vegetation and rock), and the typically cool, mesic conditions. It is thought that fire may occasionally burn into the alpine zone from adjacent spruce-fir forests, but that fire return intervals are normally similar to or longer than those of the forest type (USFS 1996, Anderson et al. 2008).

Spruce-fir forests are typically characterized by moderately long to very long fire return intervals (100-400 years) with a combination of mixed severity fires and stand-replacing fires (USFS 1996, Alington 1998, Arno 2000). Bristlecone pine is believed to regenerate well in a post-fire environment (Baker 1992), although fire does not appear to be a frequent disturbance in the upper subalpine. Historically, bristlecone pine subalpine forests in the vicinity of GRSA have experienced stand-replacement fires at intervals on the order of >300 years (Fryer 2004). Quaking aspen is characteristic of recently burned sites, where it is often found as a seral species for many decades after a disturbance, gradually diminishing in frequency as conifers become reestablished. Aspen is normally top killed by fire, however, it regenerates quickly by sprouting from its root system and can form an even-aged stand within a decade (Howard 1996).

Because the component species in mixed conifer forests (primarily Douglas-fir, white fir, Colorado blue spruce, and ponderosa pine) respond differently to fire, the fire history influences the structure and composition of a given stand (Rondeau 2001). Pure stands of ponderosa pine are relatively rare within GRSA, and fire return intervals for the relatively rare pure stands of ponderosa pine areas also appear to be quite different from those observed elsewhere in the southwest (NPS et al. 2005). Although fire was historically important in pinyon-juniper woodlands at the lower elevations within GRSA, this type is thought to have been greatly altered by historical wood harvesting of mature juniper trees for fence posts and firewood (NPS et al. 2005).

Fire is a naturally occurring process in lower-montane foothill shrublands and grasslands, but not always a driving factor, as these ecosystems often occupy rocky sites where fuels are likely to be sparse (NatureServe 2009). The different responses to fire among the component species may gradually change the composition of a shrubland. Fire regimes in this type are probably naturally variable, depending on local site factors (Knight 1994, Paysen et al. 2000). Although fire may occasionally burn into montane grasslands from adjacent forests, it is a minor factor interacting with climatic variation, grazing, and edaphic factors in the maintenance of these grassland patches (Zier and Baker 2006).

Due to the lack of vegetation, fire is not an important process in the dunefield. In some instances it is believed that grassy areas on the sandsheet occupy sites where shrubs have been eliminated by fire. The natural fire regime of the sandsheet and sabkha is poorly understood, particularly in light of the fact that these areas have probably been greatly altered by a combination of fire suppression, overgrazing, and climatic change (NPS et al. 2005). Many of the component species in these ecosystems are relatively fire-tolerant, and documented fires have almost always been very small and quickly extinguished or burnt out (NPS et al. 2005). Although fire is not a primary factor in the dynamics of these areas, it may make a contribution to the composition of the vegetation.

Although little is known about the fire dynamic of wet meadows and intermittently flooded areas on the valley floor, they are assumed to naturally burn infrequently, depending on a multitude of factors including aspects of the weather (e.g., temperature, wind speed, and relative humidity) and the condition of the vegetation (e.g., species composition, density, fuel load, and moisture content) at the time of the burn (NPS et al. 2005). Wetlands and riparian areas of the foothills to alpine zones are also thought to have infrequent natural fire, again depending on weather conditions, fuel loads, and the condition of the surrounding upland vegetation.

Our evaluation of the condition of fire-affected ecosystems in relation to natural fire regimes used two indicators: 1) fire extent and frequency within the GRSA analysis boundary, in comparison to the surrounding landscape, and 2) fire condition class of native ecosystems within the GRSA analysis boundary. The Environmental Assessment for the Greater Sand Dunes Fire Management Plan (NPS et al. 2005) incorporated a thorough review of the fire dynamics expected at GRSA and concluded that "the majority of ecological systems within the Greater Sand Dunes landscape are thought to be within or close to their natural range of variability for fire (i.e., fire suppression and other past land management activities have not severely altered the characteristics of fire across this landscape)." We evaluated this conclusion by summarizing the vegetation condition class for each ecosystem type in the vegetation mapping area.

4.5.2 Data and Methods

Recent (1980-2011) fire history of the area was evaluated with data obtained from the National Interagency Fire Center Fire and Aviation Management FAMWEB data warehouse. Although the available data cover a small interval in terms of many natural fire regimes, they are presented as a baseline against which to measure future conditions.

LANDFIRE (also known as Landscape Fire and Resource Management Planning Tools) is an interagency vegetation, fire, and fuel characteristics mapping program, sponsored by the United States Department of the Interior (DOI) and the United States Department of Agriculture, Forest Service. LANDFIRE 2010 Vegetation Condition Class (VCC; SEM 2010) categorizes the departure of current vegetation conditions against reference conditions using methods outlined in Hann et al. (2004), with the exception that fire regime departure was not included in the analysis. Reference conditions were derived from the LANDFIRE Vegetation and Disturbance Dynamics model. The LANDFIRE Succession Class layer was used to represent current conditions. The departure index ranges from 0 (no departure) to 100 (maximum departure). The index was then classified into three broad condition classes; (I) Low Departure (index values 0-33), (II) Moderate Departure (index values 34-66), and (III) High Departure (index values 67-100). Only those areas currently in a valid Succession Class were evaluated. Although fire regime departure is not explicitly included in this model, we assumed that a portion of the departure from historical conditions was attributable to fire suppression, and that this dataset could give a generalized picture of the operation of natural fire regimes in the GRSA landscape.

4.5.3 Reference Conditions

Recent fire history was evaluated both within and outside the GRSA vegetation mapping boundary. We considered a baseline reference condition to be no difference between the two areas in relative frequency and extent of fire. Although this reference condition does not address the potential region-wide departure from a natural range of variation, we assumed that historical fire suppression regionwide has suppressed natural fire regimes. Therefore, a higher fire frequency within the GRSA analysis area is likely to indicate conditions closer to those that would be expected in the absence of fire suppression.

The ideal reference condition for vegetation condition class would be “no departure” or a score of zero. Because the vegetation condition class mapping uses a fairly coarse scale, and is not explicitly modeling fire regimes, we considered a current baseline as conditions under which most vegetation within GRSA is in low or moderate departure from natural conditions (Table 4.5.1).

Table 4.5.1. Criteria for evaluating fire regime condition.

Condition Assessment	Fire Extent & Frequency	Fire Condition Class
Resource is in Good Condition	Patterns of fire size and frequency are similar within GRSA compared to the surrounding landscape.	Acreage of vegetation types affected by fire within GRSA is predominantly in a condition of low or moderate departure from natural conditions, with relatively small area in high departure.
Warrants Moderate Concern	Patterns of fire size and frequency within GRSA appear to be different from those in the larger landscape.	Acreage of vegetation types affected by fire within GRSA is predominantly in a condition of low to moderate departure from natural conditions, but there is substantial acreage in high departure condition.
Warrants Significant Concern	Patterns of fire size and frequency are dramatically different than are those in the surrounding landscape.	Acreage of vegetation types affected by fire within GRSA is predominantly in a condition of moderate and high departure from natural conditions.

Reference conditions were defined in detail for models of pinyon-juniper woodland, mixed conifer forests, and spruce-fir forests in the GRSA Fire Management Plan (NPS et al. 2005).

Models developed for pinyon-juniper woodlands within GRSA incorporate a stand-replacing fire-return interval of 425 years and an interval of 170 years for mixed-severity fire return. Mixed conifer forest models incorporate a stand-replacing fire-return intervals of 550 years and a mixed severity fire return interval of about 90 years, which is less frequent than expected for similar forests in other areas of the Southern Rocky Mountains. Spruce-fir forests were modeled with a stand-replacing fire return interval of about 330 years and non-replacement (mixed severity) fire return intervals of approximately 235 years. Generalized reference condition fire intervals for vegetation types (where available) developed as part of the LANDFIRE vegetation models are given in Table 4.5.2.

Table 4.5.2. Average fire intervals for ecosystems within GRSA vegetation mapping area.

	Fire Intervals (years)			
Ecosystem	**Replacement**	**Mixed**	**Surface**	**All**
Alpine				
Rocky Mountain Alpine Turf	208			208
Rocky Mountain Alpine Fell-Field	525			524
Forest & Woodland				
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland*	205	435		139
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	500	200		143
Rocky Mountain Aspen Forest and Woodland	150	2000	850	120
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	75	75	125	29
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland*	275	107	26	19
Southern Rocky Mountain Pinyon-Juniper Woodland*	435	200	2000	128
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	200	150	150	55
Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	205	435		139
Southern Rocky Mountain Ponderosa Pine Woodland	460	160	160	68
Shrubland				
Rocky Mountain Lower Montane-Foothill Shrubland	75	200		50
Grassland				
Southern Rocky Mountain Montane-Subalpine Grassland	18		22	10
Dunefield-Sandsheet-Sabkha				
Inter-Mountain Basins Greasewood Flat	217			217
Inter-Mountain Basins Semi-Desert Shrub-Steppe	92	714		81
Inter-Mountain Basins Semi-Desert Grassland	75	37		25
Wetland/Riparian (Foothill to Montane)				
Rocky Mountain Subalpine-Montane Riparian Shrubland	270		81	62
Rocky Mountain Subalpine-Montane Riparian Woodland	270		81	62
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	270		81	62

*Indicates inclusion in FMP

4.5.4 Condition and Trend

<u>Recent fire history: frequency and extent</u>

Consistent, comprehensive fire records are not available for more than a few decades. Records from 1980 to the present indicate that fires occur frequently in the regional landscape; at least 818 fires were reported in the larger study area during that time, and 49 within the GRSA fire boundary. Fires are generally small (about 75% are an acre (0.4 ha) or less), but larger fires (>100 acres or 40 ha) occur once or twice a decade (Figure 4.5.2). Litschert et al. (2012), in their summary of fire history for the Southern Rocky Mountain ecoregion for the period 1930-2006 noted that 96% of recorded fires were class A or B (< 10 acres), and that the largest size classes (D-G) accounted for 96% of acres burned. Patterns are similar between GRSA and the larger landscape, with many small fires, and a few larger fires.

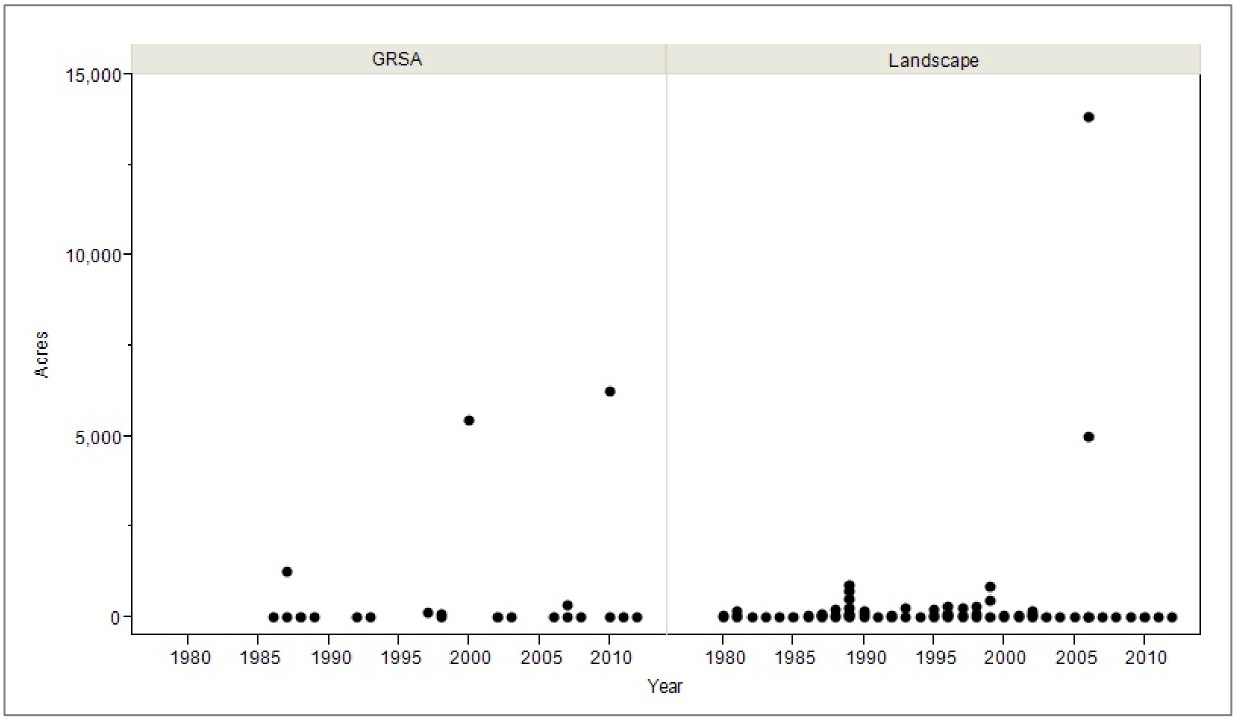


Figure 4.5.2. Size and year of recorded fires during the period 1980-2012.

In the ecoregion as a whole, the annual average number of recorded fires increased from 47 per year during the period 1930–1950 to 417 per year for the period 1991–2006 (Litschert et al. 2012). The increasing trend of number of recorded fires per year is also present for the period 1980-2012 in the San Luis Valley / Upper Rio Grande landscape, but is negligible in the GRSA management area (Figure 4.5.3).

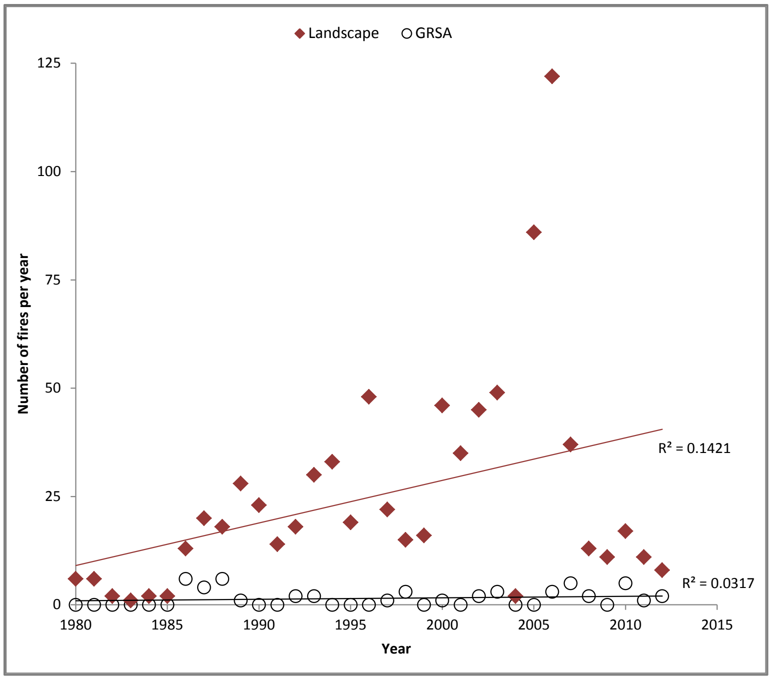


Figure 4.5.3. Number of recorded fires per year during the period 1980-2011.

Although the largest fires recorded have been in the past 12 years, there is not a detectable trend toward increasing fire size or area burned over time. During the 32 year period of record, however, the lands within the GRSA vegetation mapping/fire management boundary have experienced proportionally more area burned (3.3%) in comparison with the landscape (0.5%). Models of expected future burned area under a variety of climate change scenarios (Litschert et al. 2012) predict an increase over the entire Southern Rocky Mountain ecoregion, including GRSA.

Vegetation types affected by recorded fires since 1980 (Table 4.5.3) are primarily those of lower elevations within the park. Although fire location data are not precise enough to identify acreage of each type burned, it is clear that most fires have occurred in either sandsheet shrublands or lower elevation forests and woodlands.

Table 4.5.3. Vegetation types within GRSA mapping area affected by recorded fires since 1980.

Vegetation Type	# Fires
Forests	
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	3
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	1
Rocky Mountain Aspen Forest and Woodland	2
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	4
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	3
Southern Rocky Mountain Pinyon-Juniper Woodland	10
Total Forests	**23**
Shrublands	
Rocky Mountain Lower Montane-Foothill Shrubland	4
Grasslands	
Inter-Mountain Basins Semi-Desert Grassland	3
Dunefield-Sandsheet-Sabkha	
Inter-Mountain Basins Active and Stabilized Dune	11
Barren Sand Dune*	(1)
Greasewood Sand Deposit Shrubland and Steppe Alliances*	(1)
Herbaceous Stabilized Dune and Sandsheet Alliances*	(1)
Sandsheet Rabbitbrush Shrubland and Steppe Alliances*	(8)
Inter-Mountain Basins Greasewood Flat	5
Total Dunefield-Sandsheet-Sabkha	**16**
Wetland - Riparian (Foothill To Alpine)	
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	1
WETLAND - RIPARIAN (Valley Floor)	
Inter-Mountain Basins Alkaline Closed Depression	2

*Breakdowns ot the more general ecosystem type they follow.

Fire condition class of native ecosystems

A summary of vegetation condition class for the GRSA vegetation mapping area (Figure 4.5.4) indicates that overall, vegetation condition shows low to moderate divergence from model reference conditions. Within the forest and woodland group, lower elevation types (pinyon-juniper, ponderosa pine, and mixed conifer), which make up nearly 60% of the woodland and forest acreage within GRSA, have 24-34% of their acreage in the high departure from reference conditions class (Figure 4.5.5), and from 46 to 66% acreage in moderate departure condition. High departure condition is concentrated in the lower and middle reaches of canyons on the east side of the vegetation mapping area, and in the northern portion of the area in sandsheet shrubland and herbaceous communities (Figure 4.5.6). Vegetation of the GRSA vegetation mapping area also appears to be generally closer to modeled reference conditions than that of the landscape of the upper Rio Grande and San Luis Valley as a whole.

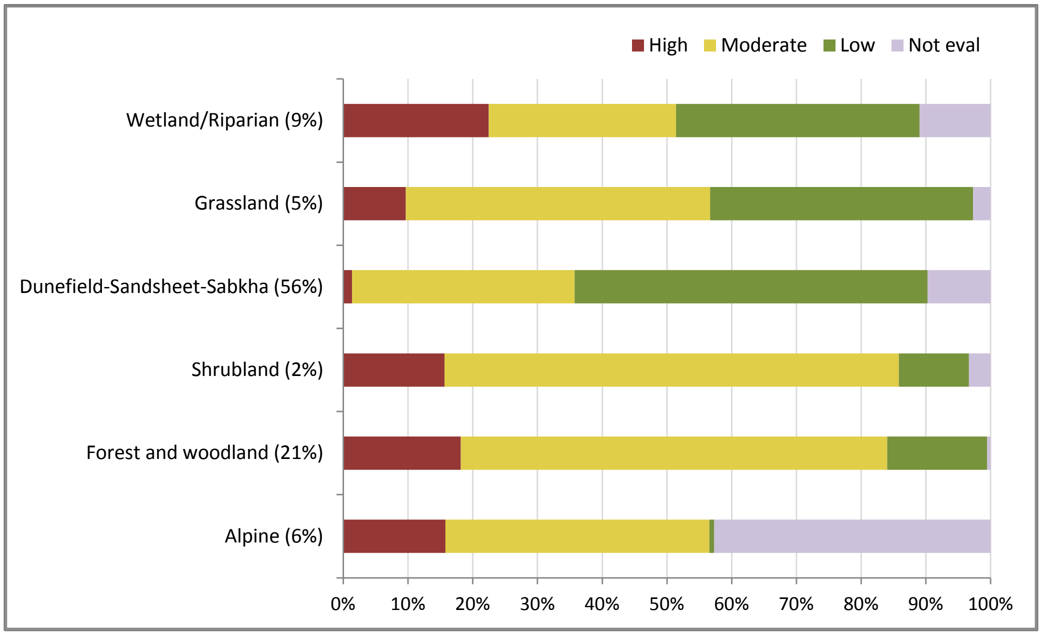


Figure 4.5.4. Vegetation departure from reference conditions, by ecosystem group. Numbers in parentheses indicate the proportion of the total mapped area represented by each group (the other 1% was not included in an ecosystem type).

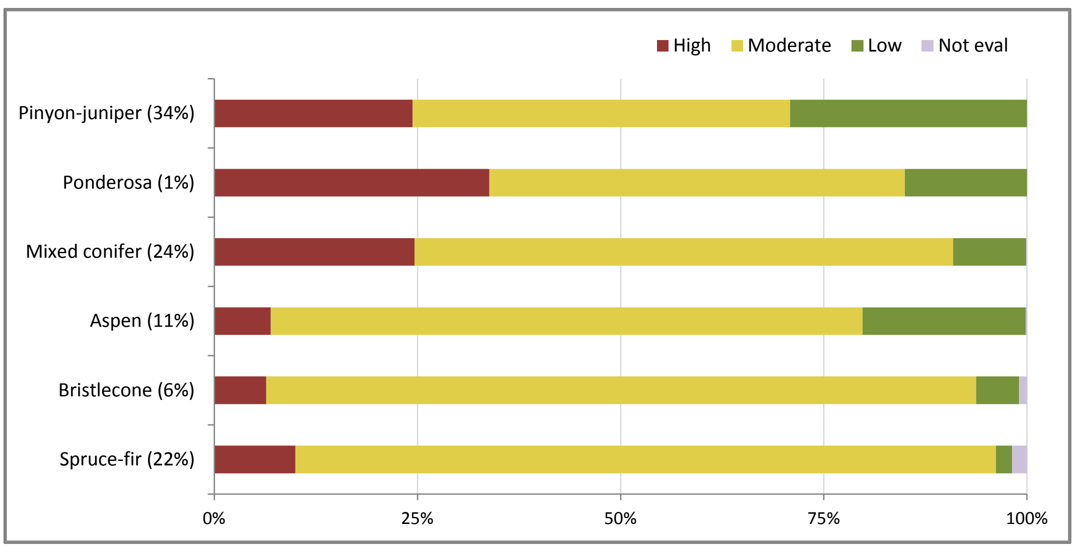


Figure 4.5.5. Vegetation departure from reference conditions, by forest and woodland types. Numbers in parentheses indicate the proportion of the total mapped area represented by each type.

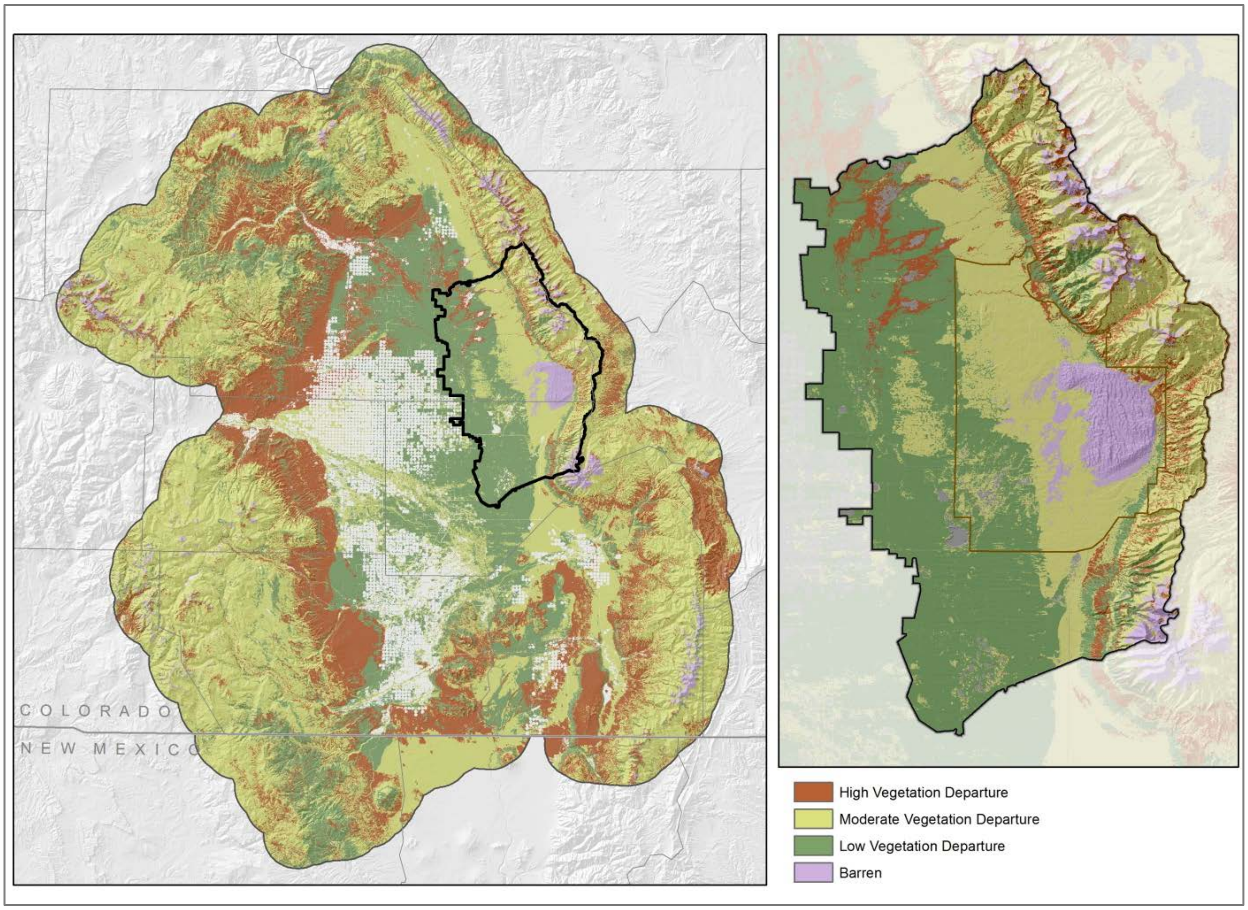


Figure 4.5.6. Spatial representation of vegetation condition classes for the Rio Grande area (left), and the GRSA vegetation mapping area (right).

A summary of the indicators evaluated for the condition of fire-affected ecosystems (Table 4.5.4) indicates that with regard to vegetation departure from expected fire regime conditions the resource is in good condition. Some lower elevation woodlands have substantial acreage in a high departure condition class, however, the overall proportion of forest and woodland types within GRSA is in either moderate or low departure. The overall assessment for the resource is stable and in good condition as far as is known. The lack of good trend information for the indicators led us to represent the confidence level as low.

Table 4.5.4. Summary of fire condition assessment.

Indicator	Interpretation	Condition Assessment
Fire frequency and extent	The area within the GRSA fire management boundary has experienced similar patterns of fire extent and frequency in comparison with the surrounding landscape. Relative proportions of burned area are slightly higher within GRSA than in the surrounding landscape, but fire frequency in the recent past has not increased within the fire management boundary.	The resource is in good condition, and may have a slight trend of improving toward a natural fire regime. Trend confidence is low.
Fire condition class for park and preserve ecosystems	Ecosystems of the valley floor within GRSA are mostly in conditions indicating low or moderate departure from natural fire regimes. Some lower elevation forest and woodland types have substantial acreage in the high and moderate departure condition classes, but these do not represent substantial acreage within GRSA.	The resource is in good condition, but because the fire condition class of some woodland types does not agree with the more detailed evaluation in the fire management plan, confidence is lower. Trends are unknown.

4.5.5 Sources of Expertise

This section was prepared by CNHP and reviewed by ROMN and GRSA staff.

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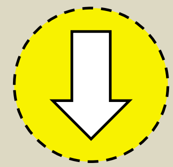
4.6 Forest Pests and Pathogens

Indicators / Measures

- Native forest-damage causing agents: natural patterns within a historic range of variation.
- Presence of WPBR, and levels of infection

Condition - Trend



4.6.1 Background and Importance

Causes of forest damage in southern Colorado in the vicinity of GRSA include both native and introduced species as well as natural processes. Damage may be caused by insects such as bark beetles that tunnel into the tree, causing direct injury and introducing harmful fungi. Diseases induced by rust-causing fungi may also spread to tree species without the aid of insect dispersal. Other forest insects such as budworms and tent caterpillars cause damage through defoliation of the tree. Finally, damage may be caused by a combination of factors, including natural processes such as fire, drought, and wind, or have an unidentified cause or causes; these effects are generally lumped under a summary complex term as a “decline” or “mortality” of particular tree species. Although natural, damage may result in shifts in species dominance and forest types.

White pine blister rust (WPBR) infection of limber pine caused by the fungus *Cronartium ribicola*, was initially reported in Colorado in 1998, and confirmed to be present in northern Larimer County in a 1999 survey (Johnson and Jacobi, 2000). The disease appears to have slowly spread southward throughout the range of five-needle pines, although its exact path in Colorado is unknown. In 2003, an infected Rocky Mountain bristlecone pine was discovered in the vicinity of infected limber pines along the Mosca Creek Trail in GRSA (Blodget and Sullivan 2004). This discovery revealed the southern extent of *C. ribicola* in Colorado, and was the first time that it had been discovered on Rocky Mountain bristlecone pine within the tree’s native range. Because infections of WPBR seriously threaten these slow-growing and long-lived tree species, the disease has the potential to permanently alter the composition of forest ecosystems in the area (Schoettle 2004).

We evaluated the condition of forests with respect to the presence and damage patterns of two indicators: 1) native forest-damage causing agents (pests), and 2) the introduced pathogen *Cronartium ribicola*.

4.6.2 Data and Methods

The U.S. Forest Service Aerial Survey maps forest damage on a more-or-less annual basis, identifying both the damage causal agent and the tree species and forest types affected. GIS shapefiles of mapped forest damage polygons for the years 1995 through 2011 were acquired from the USFS, and intersected with the GRSA vegetation mapping boundary. Mapped acreages were summarized by causal agent for each year. This procedure is intended to present an overall picture of forest damage in the vicinity of GRSA. Damage levels are also compared with precipitation and regional drought patterns.

Research on WPBR in the vicinity of GRSA is ongoing. Long-term monitoring plots (belt transects) have been installed in the Sangre de Cristo Mountains both within GRSA and to the south and east of the park boundary. Transect locations and presence/absence of rust recorded in 2004 were provided by USFS plant pathologist Kelly Burns. Transects were read again in 2012, although this recent sample data had not been processed at the time of this assessment.

Because *Ribes* species are known to be an intermediate host of WPBR (Kearns et al. 2008), we also identified plot locations where *Ribes* were documented during the vegetation mapping project.

4.6.3 Reference Conditions

Damage levels due to native forest pests were evaluated qualitatively in relation to regionally documented ranges of historic variation (Table 4.6.1). A number of dendrochronology studies have investigated historical patterns of western spruce budworm outbreaks in the southwestern United States. Research on mixed conifer forests of the Sangre de Cristo Mountains in northern New Mexico (115-175 miles or 185-188 km south of GRSA) documented a series of western spruce budworm outbreaks during the period 1690 to 1989 (Swetnam and Lynch 1989, 1993). Return intervals in this study were on the order of 20 to 33 years, and had a duration within stands of approximately 11 years. Swetnam and Lynch (1993) also identified a tendency for regional outbreaks in the 20th century to occur during years of increased spring precipitation, and for budworm activity to decrease with decreased precipitation. Similar research in the San Juan Mountains (50-75 miles or 80-120 km west of GRSA) documented a regionally synchronous pattern of at least 14 outbreaks during the past 350 years (Ryerson et al. 2003). Within stands outbreak intervals were highly variable, but regional intervals were more consistent, with periodicities of 25, 37, and 83 years. Baker and Veblen (1990) used historic photographs and tree-ring analysis to document spruce budworm outbreaks in subalpine forests on Colorado's west slope. Their analysis indicates that spruce beetle activity was widespread between the 1850s and the 1880s, affecting forests from central New Mexico to north-central Colorado. Historic photographs showed spatial variation in spruce beetle attack intensity; outbreaks were accompanied in some cases by fires and blowdowns (Baker and Veblen 1990).

Mountain pine beetle (MPB) primarily attacks ponderosa and lodgepole pine in the southern Rocky Mountains (Veblen and Donnegan 2005). Information about the natural patterns of this damage-causing insect is not available for the GRSA region, but bark beetle activity levels in the southwest have been generally low (Dahms and Geils 1997), and low levels of MPB activity in ponderosa pine stands in the vicinity of GRSA have been documented (Table 4.6.2). Schmid and Amman (1992) summarized known MPB outbreaks throughout the Rocky Mountains (although not in the Sangre de Cristos), and concluded that outbreaks could recur within a stand in as little as 20 years if few trees were killed, or within longer periods (50-200 years), with longer periods associated with higher initial stand mortality. Ranges of natural variation for other forest damage agents are essentially unknown at this time.

Because white pine blister rust is not a native pathogen, the reference condition is the absence of the disease. Since this condition may not be attainable, the infection levels presented here could serve as a minimally disturbed baseline for future control efforts.

Table 4.6.1. Criteria used to evaluate forest pest and pathogen condition assessment.

Condition Assessment	Native Forest-Damage Causing Agents	White Pine Blister Rust
Resource is in Good Condition	Damage levels appear to be within the range of documented variation for the region	WPBR is not present
Warrants Moderate Concern	Damage levels appear to be higher than the range of documented variation for the region, or may be increasing	WPBR is present at low levels, and may be spreading
Warrants Significant Concern	Damage levels are well known to be much higher than the range of documented variation for the region	WPBR is present and spreading rapidly

4.6.4 Condition and Trend

Native forest pests

The primary damage-causing agent in the vicinity of GRSA is the western spruce budworm, which has affected up to 10,587 acres in a single year, reaching a recent peak in 2009-2010 (Figure 4.6.1). During the recent outbreak, there is some evidence of budworm activity correlation with increased spring precipitation (Figure 4.6.1). Data are not of sufficient duration to identify multiple outbreaks at GRSA, but known trends are within what is thought to be the natural range of variation.

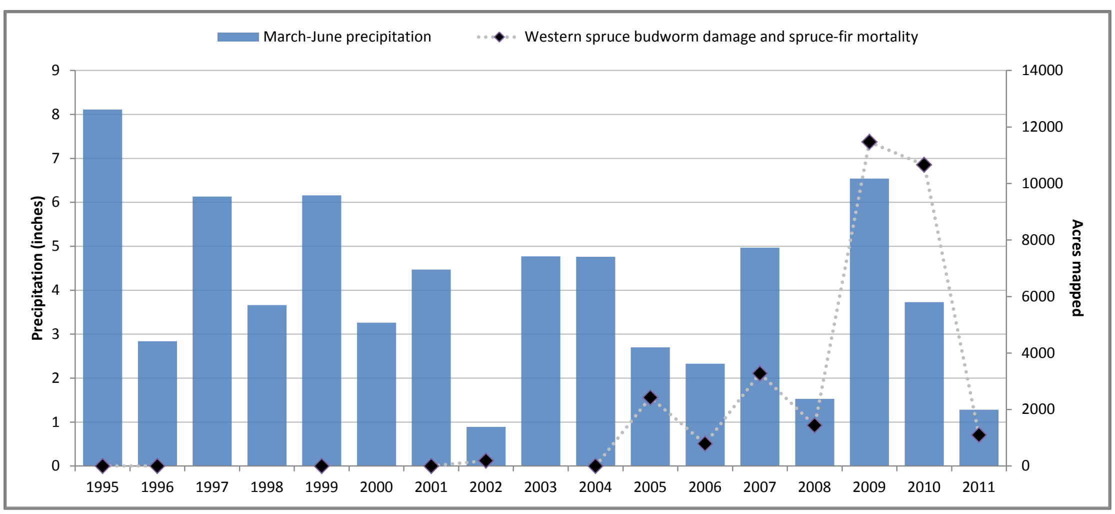


Figure 4.6.1. Western spruce budworm activity in relation to spring precipitation. No forest damage assessment was made in the area in the years 1997, 1998, 2000, and 2003.

Table 4.6.2. Mapped acreage within GRSA vegetation mapping boundary of forest damage causing agents by year.

Damage Causing Agent	Host Species	Forest Type	Acres Mapped per Year*													Total
			1995	1996	1999	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	
Insects and Similar																
Mountain pine beetle	*Pinus ponderosa* & *P. contorta*	Mixed conifers	0.5		4	21	127	51	18	4						226
Douglas-fir beetle	*Pseudotsuga menziesii*	Mixed conifers	8		2		6	14		10	1	11		6	8	65
Ips beetle	*Pinus contorta*	Mixed conifers				0.2	11									11
Fir engraver	*Abies concolor*	Mixed conifers							243		87					330
Western spruce budworm	*Pseudotsuga menziesii* & *Abies concolor*	Mixed conifers					189		1,185	210	1945	1,027	10,374	10,587	339	25,856
Tent caterpillars (*Malacosoma* spp.)	*Populus tremuloides*	Aspen								1,281	5239	735				7,255
Unknown defoliator	*Populus tremuloides*	Aspen											168	457	86	710
Diseases																
Sudden aspen decline	*Populus tremuloides*	Aspen											261	78	20	359
Aspen defoliation	*Populus tremuloides*	Aspen			252	910			500	10	49					1,720
Subalpine fir mortality	*Abies lasiocarpa*	Western fir-spruce		0.1			2		1,241	578	1,332	409	1,093	72	754	5,481
Five-needle pine decline	*Pinus flexilis* var. *reflexa*	Mixed conifers								2						2
Pinyon pine mortality	*Pinus edulis*	Pinyon-Juniper	31													31

*In 1994, 1997, 1998, 2000 and 2003, no damage assessment was made within the GRSA vegetation mapping boundary.

Aspen defoliation and decline are the next most prevalent forest damage type within GRSA. During the most recent outbreak of defoliation/decline, there is no evidence that damages levels (primarily identified as defoliation) are tied to warmer, drier conditions (Figure 4.6.2). In fact, damage levels appear to be higher in years of reduced or absent drought. Because the natural range of variation for these agents is not known, it is assumed that this relatively low level of damage is within a natural range of variation.

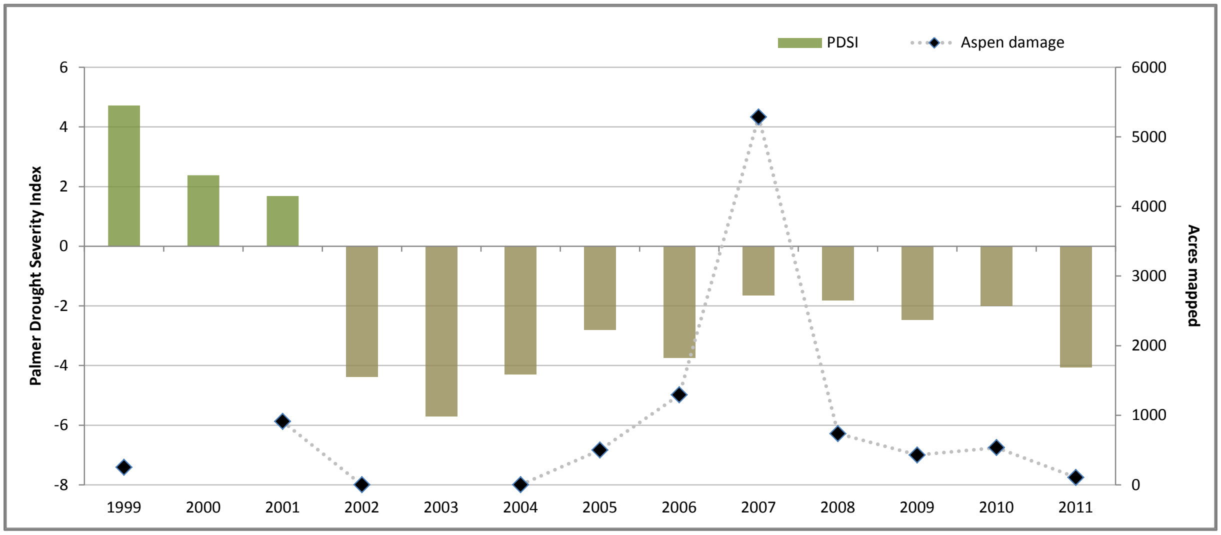


Figure 4.6.2. Aspen damage levels in relation to drought severity. No forest damage assessment was made in the area in the years 2000, and 2003.

<u>White pine blister rust</u>

Results of the field surveys made in 2004 indicate that white pine blister rust is currently impacting limber pine more extensively than bristlecone pine. Of the more than 1,500 trees inspected, about 70% were limber pine. WPBR was the second most common damaging agent after twig beetles and was found on 8 percent of all trees. In the Sangre de Cristo Mountains the distribution and intensity of WPBR in the vicinity of GRSA was centered around Mosca Pass in the Mosca Creek (west side) and May Creek (east side) drainages. Lower levels of WPBR were also observed in areas approximately 7 miles north (Medano Creek drainage) and about 5 miles south of the pass. No infected trees were found in the survey areas north of Medano Pass. Although WPBR infected trees were observed on both sides of the Sangres, the proportion of infected trees per plot was greatest on the west side, within GRSA (Burns 2006).

Permanent monitoring plots (Figure 4.6.3) were established in the Sangre de Cristo Mountains, including the Mosca Pass and Medano Pass areas. Nearly all plots (16 of 17) in the Mosca Pass area had rust-infected trees, with a mean of 14% infected trees per plot, and a maximum of 56%. In the Medano Pass area two of eight plots had rust-infected trees, with a mean of 1% infected trees per plot (Burns 2006). *Ribes* species (*R. cereum*, *R. inerme* and *R. montigenum*) occurred in 69% of plots, and were present in all drainages visited (Burns 2006). Vegetation mapping plots also confirm the widespread presence of *Ribes* species in mountainous areas in the vicinity of GRSA (Figure 4.6.3).

Although the incidence of WPBR is currently low in the Sangre de Cristo Mountains, it is expected to continue to increase and spread over time, especially in lower elevation sites (Burns 2006).

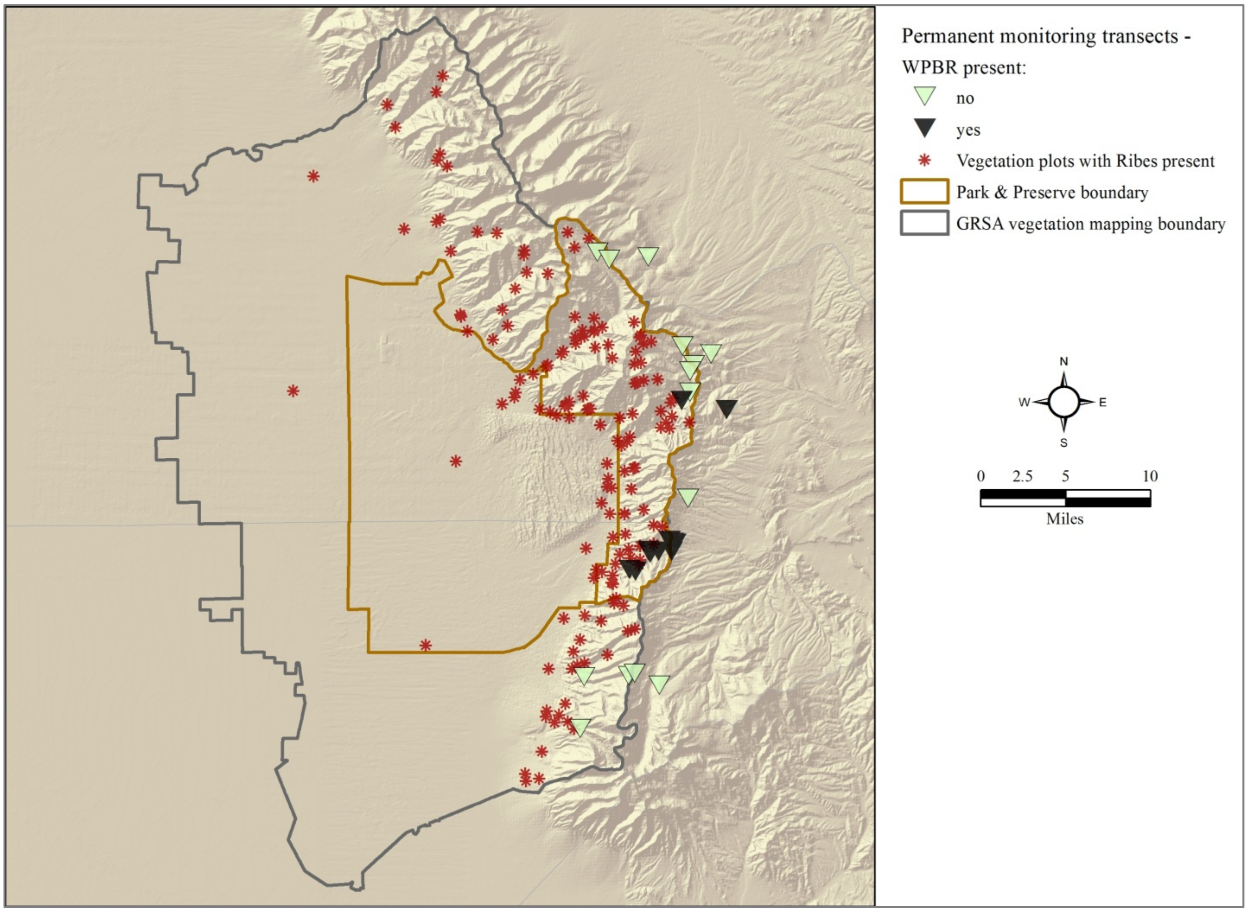


Figure 4.6.3. Locations of WPBR monitoring transects.

A summary of the indicators evaluated for the condition of forests with respect to native pests and pathogens (Table 4.6.3) shows that the resource is in good condition with respect to native forest damage-causing agents. However, the incidence of white pine blister rust, and the expected increase of this pathogen, led us to rank the overall condition of the resource as of moderate concern, with a decreasing trend. Because pest damage is reasonably low, and WPBR is being monitored, our confidence level is medium.

Table 4.6.3. Summary of condition indicators for forest pests and pathogens.

Indicator	Interpretation	Condition Assessment
Native forest damage-causing agents	Forest damage (including tree mortality) at GRSA is primarily due to western spruce budworm. Aspen defoliation and decline are also important causes of forest damage. Although historic damage levels for GRSA are essentially unknown, current damage levels appear to be within the range of historic variation documented in the region.	Resource is stable and in good condition.
White pine blister rust	WPBR is currently present in low levels, but is expected to spread and may increase over time.	Resource warrants moderate concern, and is likely to decline.

4.6.5 Sources of Expertise

Kelly Burns, US Forest Service plant pathologist provided data and review for this section. Phyllis Pineda Bovin, NPS biologist at GRSA, provided review and summarized related research at GRSA.

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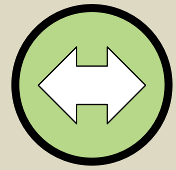
4.7 Native Ecosystems

Indicators / Measures

- Representation and extent of regional native ecosystem types
- Condition of native ecosystem types
- Landscape context of native ecosystem types

Condition - Trend



4.7.1 Background and Importance

Due to its combination of landforms and wide elevational scope, GRSA supports an impressive variety of native ecosytems within a relatively small area. The massif of the San Juan Mountains on the west side of the San Luis Valley intercepts much of the precipitation that would otherwise fall in the valley, resulting in one of the driest climates in the region. Vegetation of the park on the valley floor is characteristic of a high, cold desert, while the preserve exhibits most of the foothills to alpine vegetation types characteristic of the Southern Rocky Mountains. Native ecosystems of GRSA are described in detail in chapter 2, section 2.2.

The ecosystem is a practical working level for both land managers and conservation professionals. As used herein, the term native ecosystem corresponds to the ecological system concept as defined by Comer et al. (2003). The use of native ecosystems in this resource condition assessment is intended to identify major native vegetation types that if conserved and managed at appropriate scales would protect the majority of the plants and animals associated with them. A key assumption of this approach is that most native species can be maintained in viable numbers in native landscapes.

The assessment of native ecosystems at GRSA is based on the concept of viability specifications used for ranking occurrences of all types of elements of biodiversity under Natural Heritage methodology (NatureServe 2002). For ecosystems, the term "viability" is used loosely, since ecosystems are made up of many separate communities and species, each with its own viability. The viability of a native ecosystem group is considered to be the sum of the viability or persistence of the component communities and their ecological processes. More directly, the viability specifications usually reflect the degree of negative anthropogenic impact to a native ecosystem (i.e., the degree to which people have directly or indirectly adversely impacted community composition, structure, and/or function, including alteration of natural disturbance processes).

Under Natural Heritage ranking methodology, specifications summarize three factors: 1) size, 2) condition, and 3) landscape context, that contribute to the overall estimated viability of an ecosystem occurrence. We evaluated these three factors as indicators of resource condition for native ecosystems within the vegetation mapping area.

4.7.2 Data and Methods

As part of the National Park Service national inventory and monitoring program, the vegetation mapping and classification effort at GRSA (Salas et al. 2011) encompassed 413,031 acres (167,148 ha) within the San Luis Valley, west of the crest of the Sangre de Cristo Mountains. The mapping boundary included management units from a variety of government and private agencies (and a small amount of private property). These include the National Park Service (Great Sand Dunes National Park and Preserve-149,137 acres or 60,354 ha), U.S. Fish & Wildlife Service (Baca National Wildlife Refuge-92,623 acres or 37,483 ha), U.S. Forest Service, Bureau of Land Management (Blanca Wetlands), and the Nature Conservancy (Medano-Zapata Ranch-32,725 acres or 13,243 ha). The mapped area covers portions of Saguache and Alamosa counties. The actual mapping boundary reflects the U.S. Forest Service fire management plan area in an effort by the NPS-USGS mapping program to encompass not only lands within the NPS but also those that are in proximity and that have some type of ecological or management cohesiveness.

Vegetation plots and observation points were sampled during the summers of 2005 and 2006 over the entire mapping area. Analysis of the plot data using ordination and clustering techniques produced 198 distinct plant associations belonging to 29 ecological systems as defined by Comer et al. (2003). The PLOTS database and the digital vegetation map produced by the vegetation mapping and classification project were used as the basis for the analysis of native ecosystems. The documented native ecosystems in the GRSA vegetation mapping area are grouped into seven categories, based on physiological characteristics (Table 4.7.1).

Individual mapped polygons were combined according to ecosystem groups for the analysis of extent and diversity. Vegetation plot data (individual species recorded at each point) were used to generate floristic quality index scores at each point.

<u>Size</u>

Size was assessed by determining the contiguous patch sizes of each ecosystem as well as that of the respective ecosystem group. The vegetation map was converted to 10 m resolution rasters of the ecosystems and groups, and the ArcInfo RegionGroup command (using 8-neighbor rule) was used to create contiguous patches of each type. Note that patches at the edge of the vegetation map boundary are likely larger (in some cases, much larger) in extent than can be represented with an analysis that stops at the vegetation map boundary. The results can, however, be useful for future comparisons of the same spatial extent.

<u>Condition</u>

Condition of native ecosystems was investigated by using the plot data collected during vegetation mapping for the park. A floristic quality assessment index score (Mean C, Rocchio 2007) was used to evaluate the species composition of each ecosystem group. The Mean C score is the average "conservatism" of all native species documented growing at points within in the group. Conservatism is a measure of the degree to which a plant species displays fidelity to a specific habitat or set of environmental conditions (Wilhelm and Ladd 1988). Conservative species are those that have evolved with and are closely adapted to a specific set of biotic and abiotic factors, interactions, and natural disturbances (Wilhelm and Ladd 1988; Wilhelm and Masters 1996). Although generally indicative of habitat stability, conservative species are not completely restricted to relatively stable habitats but can also occur in periodically disturbed habitats. However, their narrower tolerance means they are sensitive to disturbance, and they will gradually decline or disappear under conditions that exceed the natural range of variation under which they evolved (Wilhelm and Masters 1995). Non-conservative or generalist species are those which have a broader ecological niche and don't show fidelity to a specific set of environmental parameters.

The floristic quality assessment methods uses the proportion of conservative plants in a plant community to assess the degree of "naturalness" of an area, recognizing that all plant species, not just the dominant or rare species, contribute useful information about a site's quality due to each species' ability to adapt to a unique set of biotic and abiotic conditions (Herman et al. 1997). Each species is assigned a C value as follows:

- 0-3 Species very prevalent in non-natural areas. They have a wide ecological tolerance and do not show any fidelity to high-quality natural areas.
- 4-6 Species that show weak affinity to natural areas but provide no indication of quality. Many matrix-forming or dominant species fall into this category.
- 7-9 Species that are obligate to natural areas but can sustain some habitat degradation.
- 10 Species which are obligate to high-quality natural areas and cannot tolerate any habitat degradation.

Species names from the PLOTS database associated with the GRSA vegetation mapping effort were cross-walked with species names in the Colorado Floristic Quality Index (FQI) database (Lemly and Roccio 2009). The Mean C score is calculated by summing the C values for each plot, and dividing by the total number of native species.

Additionally, the amount of both non-native plant species in general, and species with invasive qualities in particular, were summarized for each ecosystem and group. The Colorado FQI database contains information on whether a species is native or non-native to Colorado, and an invasiveness score for all non-native species. The score ranges from 1 (less invasive) to 4 (highly invasive), as described in Rocchio (2007). For the purposes of this assessment, a species was considered an invasive if it had an invasiveness score of 3 or 4. For an analysis and summary of individual invasive species, see Section 4.11.

Landscape context

The landscape context factor was addressed by using the Landscape Disturbance Index (LDI) dataset described in section 4.1 to produce an estimate of the overall level of disturbance from anthropogenic factors for each ecosystem group. The LDI dataset was re-classified as an integrity index into low, medium, and high categories of anthropogenic impact, using the value cut-offs of 0-25, > 25-75, and > 75, respectively. The proportion of each ecosystem and generalized ecosystem group in the medium and high categories was then calculated. A score, ranging from 0 (very poor) to 10 (excellent) was calculated for the ecosystem groups only, using the formula: (100-((2 * (P_h * 100)) +

(P_m * 100))) / 10, where P_h is the proportion in high impact and P_m is the proportion in medium impact. In this way, the area in high impact is given twice the weight of medium. This scoring method was used by Rondeau et al. (2011) to evaluate common and widespread ecosystem types in Colorado. Although it would be helpful to have a park-level LDI dataset that incorporated all forms of disturbance known to park staff (e.g., ungulate grazing, back-country recreation), this was beyond the scope of this assessment. The use of the regional dataset is intended to present the condition of GRSA ecosystems within a landscape-wide context rather than only within park boundaries.

4.7.3 Reference Conditions

Size

Because no element occurrences as defined under Natural Heritage methodology have been delineated, we used the ecosystem group patches as a surrogate for the formal element occurrence. Patch size of native communities is expected to vary naturally depending on both natural and anthropogenic factors. In general, larger patches are presumed to be more viable, less influenced by edge effects, and less susceptible to degradation (NatureServe 2002). We used size specifications developed for individual ecosystem types to estimate a minimum acceptable patch size for each ecosystem group. Because ecosystem groups include several to many ecosystems, we used the smallest minimum size criteria in the group, and calculated the proportion of group acreage in patches of at least minimum size (Table 4.7.1). In general, when a significant proportion of acreages is in larger patches we assume that this represents situations where native ecosystem patches include areas large enough and with sufficient diversity for natural processes to operate.

Table 4.7.1. Ecosystem group minimum patch sizes.

Group	Minimum Patch Size (acres)	Source(s)
Alpine	3,000	Rondeau 2001
Forests	30,000	CNHP 2005
Shrublands	100-250	CNHP 2013
Grasslands	500	CNHP 2005, 2007
Dunefield-Sandsheet-Sabkha	10,000	Rondeau 2001, CNHP 2005
Wetland/Riparian (foothill to alpine)	5	CNHP 2013
Wetland/Riparian (valley floor)	10	CNHP 2013

Condition

Because we can only indirectly address the condition of each ecosystem within the GRSA mapping area, we used metrics that could be derived from the vegetation mapping data to address native ecosystem group condition. Our primary indicators are the Mean C index and the presence of species with an Invasiveness Score of 3 or 4 in the Colorado FQI database. Mean C is obviously related to condition, but also to the intrinsic expected Mean C of the ecosystem in question (Rooney and Rogers 2002, Milburn et al. 2007). Although this metric has not been rigorously quantified, some ecosystems can be expected to have naturally lower Mean C values than others. Rather than assign an expected Mean C to each system group, we have relied on results from previous work (Wilhelm and

Masters 1996, Herman et al. 2001) showing that sites with a Mean C of 3.0 or less are unlikely to achieve higher C values. This value can be considered a threshold below which restoration efforts are unlikely to succeed. We use a slightly higher value of 3.5 to represent the minimum integrity threshold reference condition. This is assumed to represent conditions under which few to no invasive species are present, and other non-native species, or native species that increase with disturbance are present only with very low frequency.

Landscape context
Landscape disturbance model scores were converted into an integrity scale from 0 to 10, with higher scores indicating the most natural, least disturbed condition. Following the work of Rondeau et al. (2012), we assigned a qualitative description to disturbance ranges: very good (7.5-10), good (5-7.4), fair-poor (<5.0), and considered that the minimally disturbed condition would be in the range of 7.5 to 10.

Metrics derived from the vegetation mapping data were used to produce summary statistics for patch sizes, floristic quality index scores, and landscape integrity scores. Each ecosystem group was scored according to criteria shown in Table 4.7.2, and results summarized across all groups.

Table 4.7.2. Resource condition indicator scoring for ecosystem groups.

Condition Asssessment	Size	Condition Scoring	Landscape Context
Resource is in Good Condition	>50% of acreage is in patches that are greater than or equal to minimum size	Range of Mean C > 3.5 AND Invasives <=1% relative cover	Landscape integrity score >=7.5
Warrants Moderate Concern	25-50% of acreage is in patches that are greater than or equal to minimum size	Range of mean C includes 3.5 OR Invasives >1% relative cover	Landscape integrity score 5.0-7.4
Warrants Significant Concern	<25% of acreage is in patches that are greater than or equal to minimum size	Range of mean C includes 3.5 AND Invasives >3% relative cover	Landscape integrity score < 5.0

4.7.4 Condition and Trend
The vegetation mapping area represents 34 ecosystems as mapped in SWReGAP (Table 4.7.3). Note that these were represented as 29 map units in Salas et al. (2011). A few of the regionally common ecosystems such as lodgepole pine forest and Gambel oak – mixed mountain shrubland are not represented in GRSA. Also absent are examples of sagebrush shrubland and steppe. Fens, a fairly characteristic wetland type of the San Juan Mountains across the San Luis Valley, are not found within GRSA. In contrast, GRSA has significant representation of native ecosystems of the dune system and San Luis Valley floor.

Table 4.7.3. Ecosystem groups, with component ecosystem and/or alliance names.

Ecosystem Groups		Vegetation Map Acres	Total GRSA Acres	Park Acres	Preserve Acres
Alpine					
Rocky Mountain Alpine Turf		7,163	2,290	0	2,290
Rocky Mountain Alpine Fell-Field		4,344	1,178	0	1,178
Rocky Mountain Alpine Bedrock and Scree		12,599	2,301	0	2,301
North American Glacier and Ice Field (unvegetated)		478	93	0	93
	Total:	**24,584**	**5,862**	**0**	**5,862**
Forests					
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland		8,775	3,860	40	3,820
Rocky Mountain Aspen Forest and Woodland		9,877	4,113	18	4,095
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland		18,713	10,015	0	10,015
Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland		547	390	0	390
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland		5,583	2,983	0	2,983
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland		11,305	4,613	428	4,185
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland		615	296	10	286
Southern Rocky Mountain Ponderosa Pine Woodland		906	794	330	465
Southern Rocky Mountain Pinyon-Juniper Woodland		29,590	7,804	3,685	4,119
	Total:	**85,911**	**34,867**	**4,511**	**30,357**
Shrublands					
Rocky Mountain Lower Montane-Foothill Shrubland		3,906	2,316	375	1,941
Rocky Mountain Cliff, Canyon and Massive Bedrock		1,715	732	7	725
Inter-Mountain Basins Semi-Desert Shrub-Steppe		880	690	656	34
	Total:	6,501	3,738	1,038	2,700
Grasslands					
Inter-Mountain Basins Semi-Desert Grassland		16,272	3,681	3,677	4
Southern Rocky Mountain Montane-Subalpine Grassland		3,251	1,552	149	1,403
	Total:	**19,523**	**5,234**	**3,826**	**1,407**
Dunefield-Sandsheet-Sabkha					
Inter-Mountain Basins Active and Stabilized Dune		172,995	85,742	85,533	209
Barren Sand Dune*		17,391	17,365	17,319	46
Greasewood Sand Deposit Shrubland and Steppe Alliances*		21,185	1,832	1,832	0
Herbaceous Stabilized Dune and Sandsheet Alliances*		13,047	9,164	9,130	34
Narrowleaf Cottonwood Sand Dune Woodland Association*		238	120	120	0
Ponderosa Pine Sand Ramp Woodland*		618	512	429	83
Sandsheet Rabbitbrush Shrubland and Steppe Alliances*		120,517	56,749	56,704	45
Inter-Mountain Basins Greasewood Flat		59,920	5,689	5,689	0
	Total:	**232,915**	**91,430**	**91,222**	**209**
Wetland - Riparian (High Elevation)					
Rocky Mountain Alpine-Montane Wet Meadow		1,085	275	0	275
Rocky Mountain Subalpine-Montane Riparian Shrubland		1,453	359	2	357

*Are breakdowns ot the more general ecosystem type they follow.

Table 4.7.3 (continued). Ecosystem groups, with component ecosystem and/or alliance names.

Ecosystem Groups	Vegetation Map Acres	Total GRSA Acres	Park Acres	Preserve Acres
Wetland - Riparian (High Elevation—continued)				
Rocky Mountain Subalpine-Montane Riparian Woodland	572	235	0	235
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	2,874	1,046	910	136
Total:	**5,984**	**1,915**	**912**	**1,003**
Wetland - Riparian (Lower Elevation)				
Inter-Mountain Basins Alkaline Closed Depression	18,112	4,091	4,091	0
Inter-Mountain Basins Interdunal Swale Wetland	73	46	46	0
Inter-Mountain Basins Playa	10,188	371	371	0
Inter-Mountain Basins Wash	934	670	667	3
North American Arid West Emergent Marsh	2,290	1,013	1,013	0
Total:	**31,597**	**6,191**	**6,188**	**3**

*Are breakdowns ot the more general ecosystem type they follow.

Size

Higher elevation ecosystem groups meet the criteria for minimum patch size, and probably have larger effective patch sizes when adjacent, unmapped areas are considered (Table 4.7.4). Extensive patches of shrubland and grassland are generally less well represented within the vegetation mapping area. Semi-desert shrub steppe patches in the mapped area are small and not contiguous with the much larger occurrences that are characteristic of the San Luis Valley. Montane-foothill shrublands are also generally smaller than is characteristic of the rest of the Southern Rocky Mountain ecoregion. Dune-sandsheet-sabkha, and the two wetland/riparian groups are very well represented, with many exceptionally large patches (or reaches).

Table 4.7.4. Summary condition assessment scores for size of native ecosystems at GRSA.

Parameter	Alpine	Forests	Shrublands	Grasslands	Dunefield-Sandsheet-Sabkha	Wetland/ Riparian (foothill to alpine)	Wetland/ Riparian (valley floor)
Total Acres Mapped	24,581	85,913	6,500	19,523	232,903	5,981	31,600
Largest patch (ac)	15,874	81,594	299	1,533	223,770	315	6,643
% acreage in patches of minimum size	82[1]	95[1]	22[3]	25[2]	96[1]	92[1]	93[1]

[1]Resource is in Good Condition

[2]Warrants Moderate Concern

[3]Warrants Significant Concern

Condition

Mean C values for the seven ecosystem groups range from a low of 4.2 for the valley floor Wetlands/Riparian systems to a high of 7.1 for Alpine ecosystems (Table 4.7.5). The distribution of Mean C values for each group shows, however, that not all sample areas are above the 3.5 threshold value (Figure 4.7.1). All sample plots taken within Alpine, Forest, and Shrubland ecosystems are above the threshold. Grassland, Dune/Sandsheet, and Wetland/Riparian ecosystems have some plots with poor floristic quality. Although the valley floor Wetland/Riparian group has the widest range of values, its distribution is left-skewed to lower values overall. Results from the sandsheet and valley wetlands may reflect disturbance from heavy use by bison. In addition, some of these ecosystem types (e.g., saline areas, or areas more subject to natural disturbance) may have intrinsically lower Mean C values.

Table 4.7.5. Summary condition assessment scores for native ecosystems at GRSA.

Parameter	Alpine	Forests	Shrublands	Grasslands	Dunefield-Sandsheet-Sabkha	Wetland/ Riparian (foothill to alpine)	Wetland/ Riparian (valley floor)
# Plots	68	196	31	42	101	78	83
Avg Mean C	7.1	5.7	5	4.8	4.3	6.1	4.2
Range Mean C	6-8[1]	3.7-7.5[1]	4.1-6.6[1]	3.2-6.6[2]	2.4-6.0[2]	2.2-7.8[2]	2.4-10[2]
Avg Spp Richness	24.4	22.2	18.7	17.8	9.0	22.2	8.6
% Plots w/ Invasives	9%	16%	19%	40%	23%	36%	30%
Rel Cover of Invasives	0.1%[1]	0.4%[1]	1.0%[1]	1.9%[2]	1.7%[2]	1.3%[2]	1.9%[2]

[1]Resource is in Good Condition

[2]Warrants Moderate Concern

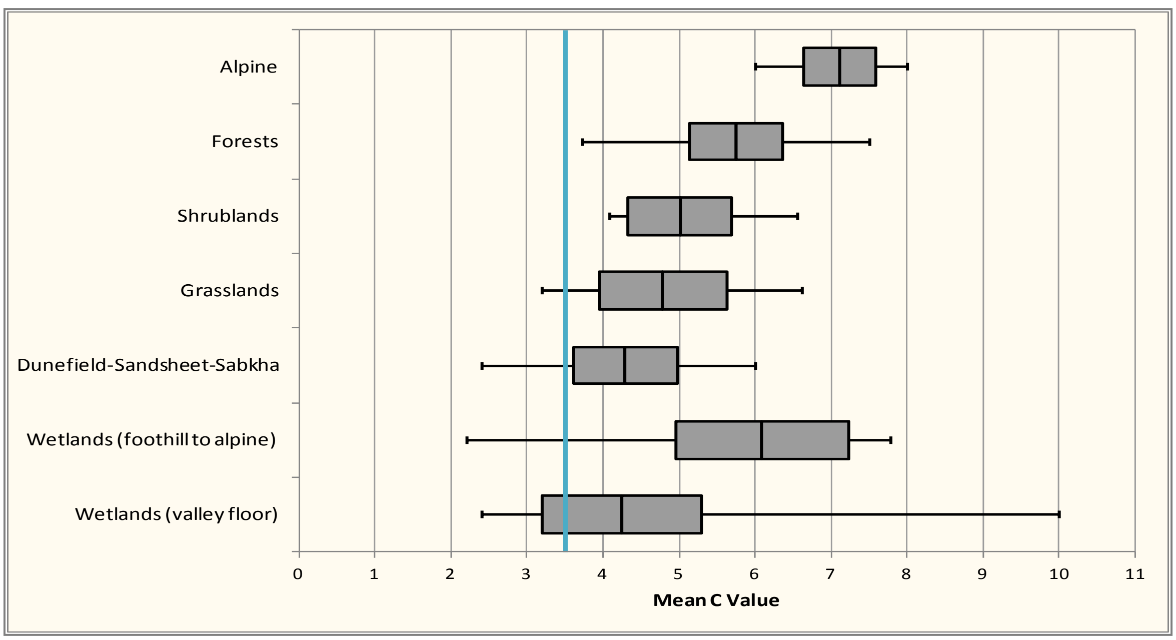


Figure 4.7.1. Distribution of Mean C values within system groups. Blue line = Mean C "recovery" threshold. Whiskers = min and max, center line = mean, box = +- standard deviation.

All of the ecosystem groups have some presence of non-native species, including species with higher invasive scores (Table 4.7.5). Alpine ecosystems have the highest overall species richness, and the lowest occurrence of non-natives; forests are second in species richness and low presence of invasives. The valley floor wetland/riparian ecosystems have the lowest species richness and the highest occurrence of non-natives. The dune-sandsheet-sabkha ecosystems have the next lowest species richness, but the grassland and foothill to alpine Wetland/Riparian ecosystems have more non-native species. Grassland and valley floor wetland/riparian ecosystems have the greatest average relative cover of invasive species, at 1.9%, with grasslands also having the greatest frequency of occurrence, with 40% of all plots containing an invasive plant. Alpine ecosystems have both the lowest relative cover (0.1%) and lowest frequency of occurrence (9% of plots) of invasives.

Landscape context

Four of the eight ecosystem groups score in the very good category of landscape integrity, with little anthropogenic disturbance (Table 4.7.6). Wetland and riparian areas are of moderate concern (foothill to alpine) or significant concern (valley floor), due to the concentration of anthropogenic activity in drainage bottoms, and on the valley floor. Grasslands warrant significant concern, however, this rank is primarily due to the landscape context of these plant communities on the valley floor, and less so for those in montane to subalpine areas.

Table 4.7.6. Summary condition assessment scores for landscape context of native ecosystems at GRSA.

Parameter	Alpine	Forests	Shrublands	Grasslands	Dunefield-Sandsheet-Sabkha	Wetland/ Riparian (foothill to alpine)	Wetland/ Riparian (valley floor)
Integrity score	10.0[1]	9.0[1]	9.4[1]	4.5[3]	7.5[1]	7.2[2]	2.8[3]

[1]Resource is in Good Condition

[2]Warrants Moderate Concern

[3]Warrants Significant Concern

Overall Condition and Trend

The three main indicators are averaged to produce an overall ecosystem group condition. Each indicator in the *Warrants Significant Concern* category is assigned one point, each indicator in the *Warrants Moderate Concern* category is assigned five points, and each indicator in the *Resource is in Good Condition* category is assigned nine points. The points for size, condition, and landscape context, are averaged, and the resulting value is compared to the scale below to determine condition for that ecosystem group. Finally, the average across all group summary scores is used to determine the overall condition score for native ecosystems at GRSA.

Overall Ecosystem Condition		
Score > 6 to 9	**Score > 3 to ≤ 6**	**Score 1 to ≤ 3**
Resource in Good Condition	Warrants Moderate Concern	Warrants Significant Concern

All ecosystem groups score as either *Resource is in Good Condition* or as *Warrants Moderate Concern* (Table 4.7.7). GRSA receives an overall condition score of 6.7, in the *Resource is in Good Condition* category. Because trends information is not available for this resource, this constitutes uncertainty in the assessment. However, the overall condition of ecosystem groups is expected to change slowly, and we chose to represent the current trend as stable.

Table 4.7.7. Summary of condition assessment for native ecosystems.

Native Ecosystem	Size	Condition	Landscape Context	Ecosystem Rank Score
Alpine	Good Condition	Good Condition	Good Condition	9.0
Forests	Good Condition	Good Condition	Good Condition	9.0
Shrublands	Significant Concern	Good Condition	Good Condition	6.3
Grasslands	Moderate Concern	Moderate Concern	Significant Concern	3.7
Dunefield-Sandsheet-Sabkha	Good Condition	Moderate Concern	Good Condition	7.7
Wetland/Riparian (foothill to alpine)	Good Condition	Moderate Concern	Moderate Concern	6.3
Wetland/Riparian (valley floor)	Good Condition	Moderate Concern	Significant Concern	5.0
			Overall Score	**6.7**

4.7.5 Sources of Expertise

CNHP Ecologist and Conservation Planning Team leader Renée Rondeau provided background information and expertise for native ecosystems in the San Luis Valley, and helpful discussion about evaluation criteria.

CHNP Wetland Ecologist Joanna Lemley provided helpful discussion and suggestions for the floristic quality analysis.

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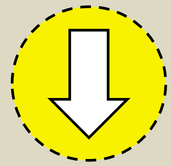
4.8 Endemic Insects

Indicators / Measures

- Presence/absence of individuals
- Presence/extent of sparsely vegetated sandy habitat

Condition - Trend



4.8.1 Background and Importance

The extensive and regionally unusual sandsheet and dune habitats in and around GRSA provide habitat for a large number of invertebrate species. Weissmann (1995) provided a species list of more than 850 species of arthropods recorded from the former monument prior to the expansion. Work by Pineda (2002) and Zuellig et al. (2006) increased this list to just over 1,000 species. Although the dune and sandsheet habitats appear largely barren, with only sparse vegetation, Weissmann (1995) estimated that perhaps a quarter of all of the recorded insect species occur on the sand and interdunal habitats. Among the hundreds of more common insects, there are five beetle species and one fly believed to be endemic to the vicinity of GRSA, a species of moth that is known from only one other locale, and a camel cricket that is a regional endemic (Table 4.8.1). These species are described briefly in chapter 2, section 2.2.2 above.

The local and regional endemic insect species have strong habitat associations and are largely found on active dunes, sandy blowouts, or shifting sands with sparse vegetation. Although the population levels and activity of similar taxa are known to be affected by factors such as climate, temperature, moisture, wind, available light, and available food (Britten et al. 2007), little is known about the GRSA endemic species. Because the protection and preservation of these species is an important management objective for GRSA, the study of their life-history characteristics and distribution is a high-priority.

Table 4.8.1. Endemic and special-interest species documented in the vicinity of GRSA.

Order	Family	Scientific Name	Common Name
Coleoptera	Cicindelidae	*Cicindela theatina*	Great Sand Dunes tiger beetle
	Histeridae	*Hypocaccus* (undescribed species)	clown beetle
	Tenebrionidae	*Eleodes hirtipennis*	circus beetle
	Anthicidae	*Amblyderus werneri*	Werner's ant-like flower beetle
	Anthicidae	*Amblyderus triplehorni*	Triplehorn's ant-like flower beetle
Lepidoptera	Noctuidae	*Copablepharon pictum**	a noctuid moth
Diptera	Asilidae	*Proctacanthus* (undescribed species)	a robber fly
Orthoptera	Rhaphidiophoridae	*Daihinibaenetes giganteus***	giant sand treader camel cricket

* also reported from Dinosaur NM.

**also occurs in New Mexico and Utah.

Two primary indicators were used to assess the condition of endemic insects at GRSA: presence/absence of individuals, and presence/extent of sparsely vegetated sandy habitat over time.

4.8.2 Data and Methods

The presence/absence of the endemic insect species was assessed using survey results and personal communication with subject matter experts. Survey and monitoring data on the endemic insect species at GRSA is sparse, with the exception of Pineda (2002) and Latchininsky and Gilchriest (2008). A monitoring protocol is currently under development (Britten et al. 2007).

Sandy habitat extent over time was estimated from vector digital data produced by NPS Intermountain Region GIS Support Office from a series of mosaicked historical aerial photos (NPS 1998a-d, NPS 2000), and from the most recent vegetation map (Salas et al. 2011). Datasets from 1936, 1953, 1966, 1979, and 1988 were clipped to the smallest common dimension, and acres for sandy upland habitat types (escape dunes, main dunefield, mobile dunes, and sandsheet) were calculated. Although the recent vegetation map was not produced with comparable methods, we estimated the extent of sandy habitat in 2006 by visually comparing the map unit types of Salas et al. (2011) with the land cover types from the historic data. The Barren Sand Dune and the Herbaceous Stabilized Dune and Sandsheet Alliances map units corresponded most closely with the historic land cover types, and were used to calculate sandy habitat acreage in the same area.

4.8.3 Reference Conditions

The population dynamics of the endemic insect species are not well known. It is difficult to assess abundance for insects, because they have short life cycles and insect populations respond quickly to changes in their environment. Furthermore, each species is likely to require somewhat different techniques for reliable detection. Until reliable methods for assessing the insect population dynamics can be developed, the only possible reference condition is that they are present, and that suitable habitat exists with extent sufficient to support them. These reference conditions were evaluated qualitatively (Table 4.8.2).

Table 4.8.2. Criteria for evaluating condition of endemic insect species at GRSA.

Condition Assessment	Presence/Absence of a Species	Presence and Extent of Suitable Habitat
Resource in good condition	Species presence well documented	Suitable habitat extensive
Warrants moderate concern	Species present but poorly documented, or with only a single occurrence, or well documented nearby, but not within GRSA	Suitable habitat present, but of lesser extent, or unknown
Warrants significant concern	Species not found	Suitable habitat very limited

4.8.4 Condition and Trend

Survey work during the summer of 2007 (Latchininsky and Gilchriest 2008) focused on collecting and observing the GRSA endemic insect species in five general locations (Figure 4.8.1). Four 2-day collection trips were made: early and late May, mid-June, and late-August (Table 4.8.3). Five of the seven species of interest were confirmed as present; no individuals of Werner's ant-like flower beetle were observed, and a single observation of the robber fly was deemed possible, but not confirmed by collection.

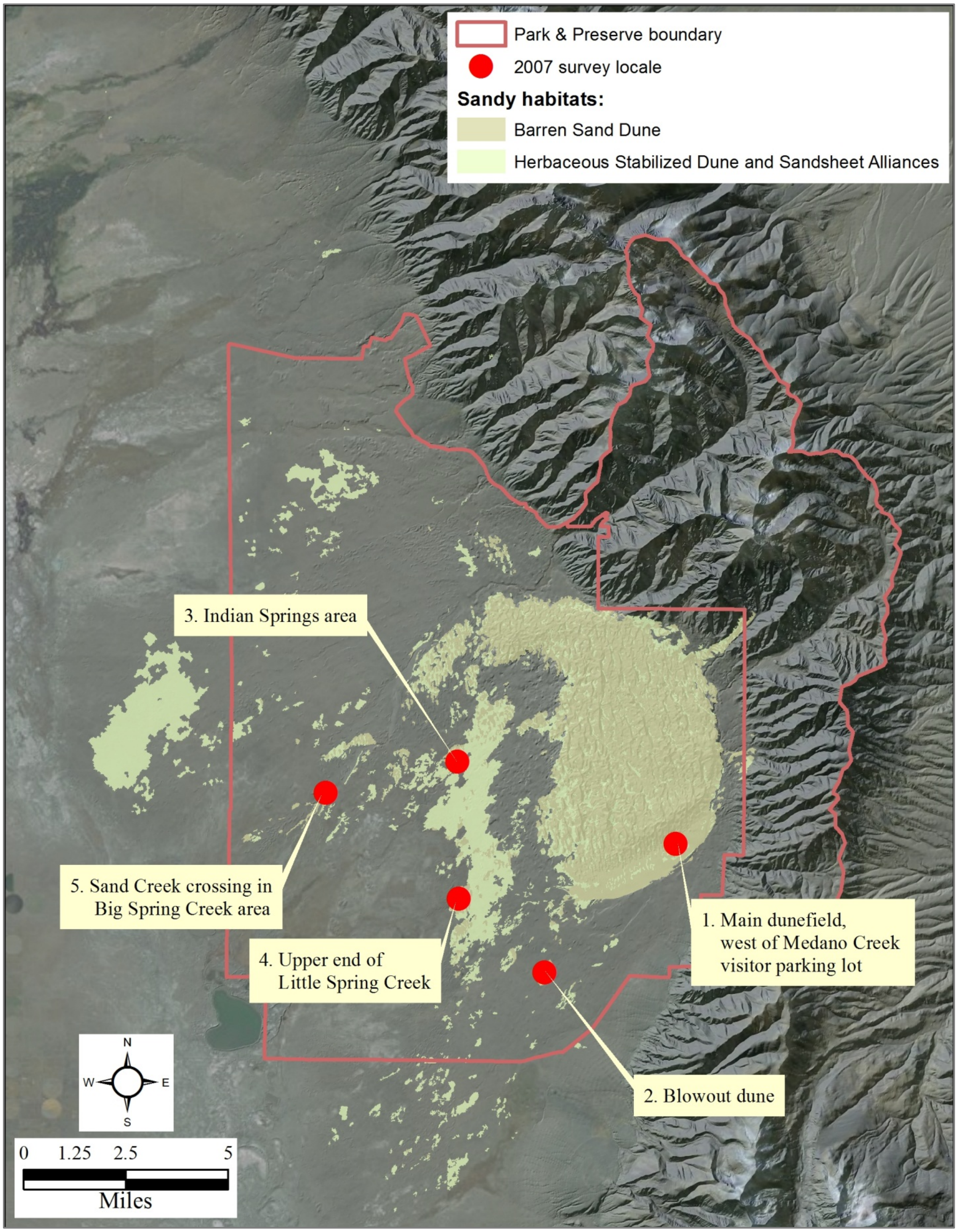


Figure 4.8.1. Approximate 2007 survey locations of Latchininsky and Gilchriest (2008).

Table 4.8.3. Observation dates and locations of GRSA insect species of concern. A "?" indicates an unconfirmed identification.

Species	Collection Trip Dates: 2-3 May	23-24 May	18-19 June	20-21 August	Locations
Great Sand Dunes tiger beetle (*Cicindela theatina*)	X	X	X	X	all
Clown beetle (*Hypocaccus* undescribed species)	X		?		1
Circus beetle (*Eleodes hirtipennis*)	X	X	X	X	all
Werner's ant-like flower beetle (*Amblyderus werneri*)			X	X	1, 3
Triplehorn's ant-like flower beetle (*Amblyderus triplehorni*)	Not observed				
Noctuid moth (*Copablepharon pictum*)				X	3
Robber fly (*Proctacanthus* undescribed species)				?	3
Giant sand treader camel cricket (*Daihinibaenetes giganteus*)		X	X	X	2, 3

The two most frequently observed species were the Great Sand Dunes tiger beetle and the circus beetle (Table 4.8.4). The noctuid moth and camel cricket also appear to be reasonably abundant. Of the two ant-like flower beetle species, one was frequently observed and collected, but the other was absent. The other species, due to difficulty of observation, were not confirmed as present in quantity. However, park staff frequently encounter most endemic insect species during routine operations (Phyllis Pineda Bovin, GRSA biologist, personal communication). Although data that would support an estimate of trend are not available, endemic and special concern insect species populations at GRSA should be regarded as stable, with the possible exception of *Amblyderus triplehorni*, which was not observed during the recent survey.

Table 4.8.4. Collection notes for 2007 surveys of Latchininsky and Gilchriest (2008)

Species	Collection Notes
Great Sand Dunes tiger beetle (*Cicindela theatina*)	Extremely prevalent on "escape" dunes. Highest densities and many mating pairs observed during early May trip. Observed during all trips, at all collection locales.
Clown beetle (*Hypocaccus* undescribed species)	Very difficult to identify in the field, only confirmed present on one collection trip. Can be found and collected by pitfall traps in blowout grass on large dune masses.
Circus beetle (*Eleodes hirtipennis*)	Observed on every collecting trip, and at all collection locales. Most frequently encountered in May. Open sand and vegetated areas, prevalent along edge of blowout dune.
Werner's ant-like flower beetle (*Amblyderus werneri*)	Many collected during June and August trips. Observed in depositional dune areas as well as being blown across dunes.

Table 4.8.4 (continued). Collection notes for 2007 surveys of Latchininsky and Gilchriest (2008)

Species	Collection Notes
Triplehorn's ant-like flower beetle (*Amblyderus triplehorni*)	Not collected or observed. Should be common in depositional areas of dunes.
Noctuid moth (*Copablepharon pictum*)	Collected only during August trip, but apparently quite abundant at that time. Collected at black lights on sand surface.
Robber fly (*Proctacanthus* undescribed species)	Not collected. One potential observation on sandsheet during August trip.
Giant sand treader camel cricket (*Daihinibaenetes giganteus*)	Collected in late May, June, and August. Most abundant during June. Primarily associated with “escape” dunes on sandsheet.

Our analysis of sandy habitat acreage over the 70 year period of comparison showed that extent was variable. The highest extent of more than 26,000 (10,250 ha) acres was mapped in 1936; subsequent years were anywhere from 4-10% less than during that first observation year (Figure 4.8.2). Total acreage of sandy habitat is, not surprisingly, related to drought severity (Figure 4.8.3). The three highest extents (1936, 1953, and 2006) occur during or subsequent to extended periods of extreme drought (-4 on the Palmer Drought Severity Index). Although there have been years of above normal precipitation recorded at GRSA during some of these drought periods, it is likely the regional drought index represents a more realistic picture of the type of precipitation trend that is capable of driving habitat change across a large area.

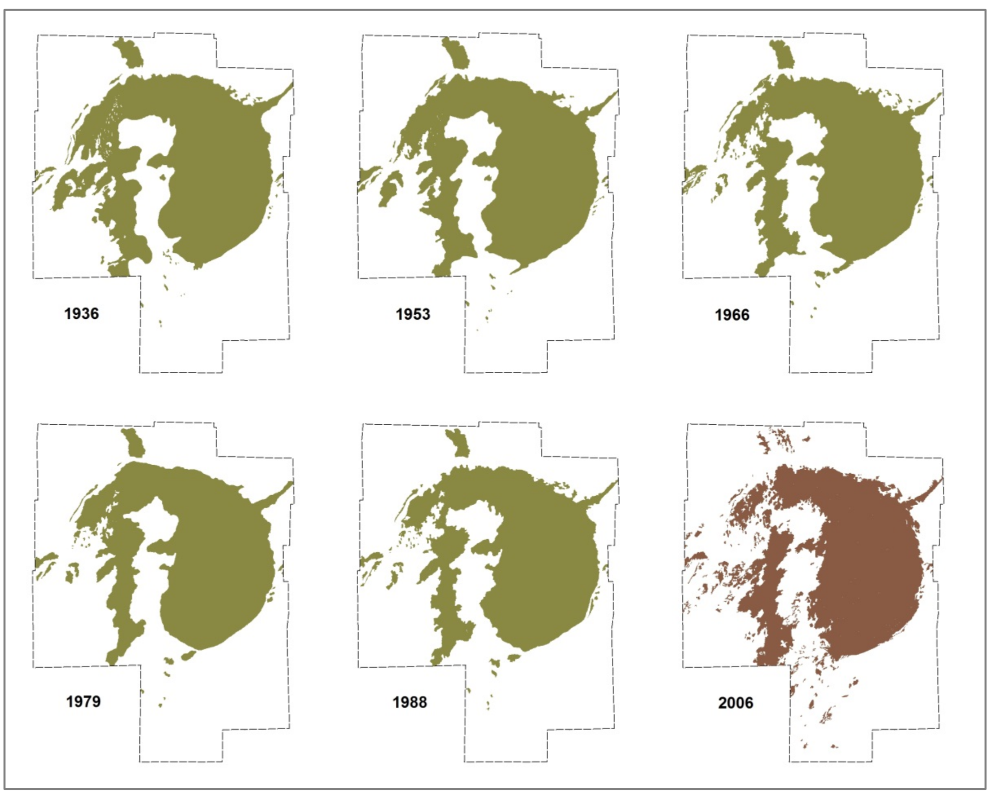


Figure 4.8.2. Change in extent of sandy habitat over a 70-year period. Data for years 1936-1988 from NPS (1998a-d and 2000), data for 2006 from Salas et al. (2011).

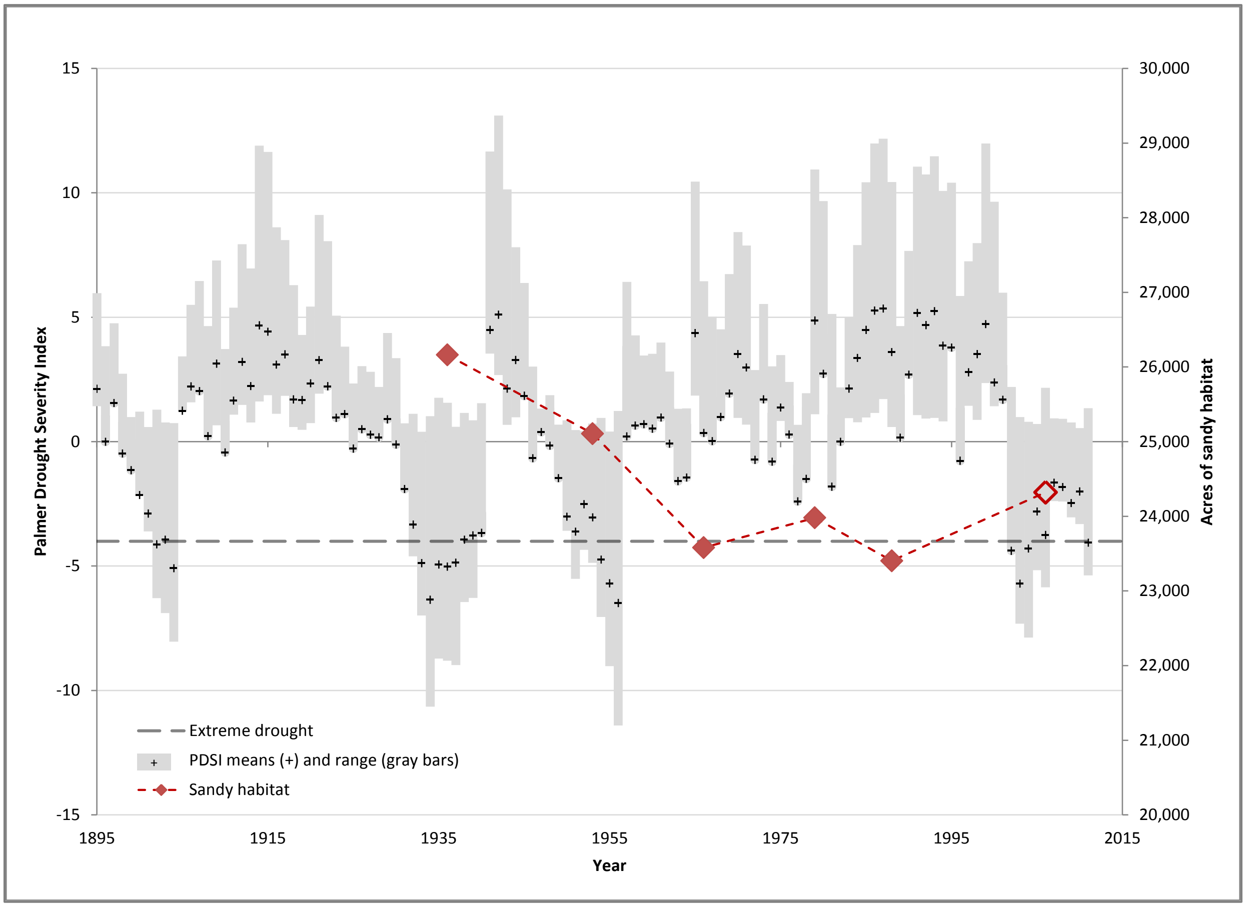


Figure 4.8.3. Comparison of sandy habitat extent and drought severity. Total 2006 acreage is shown with an open diamond, since estimation methods were different from those of previous years.

The extent of sandy habitat is likely to be naturally variable under changing climatic conditions. It is also possible, however, that some of the variation presented here is due to lack of precision in mapping from old, difficult to interpret photos. Thus, although there is a suggestion of a recent decrease in sandy habitat extent, the 2007 survey work confirmed the presence of most of the insect species of interest, and sufficient habitat to provide support for populations is extant. We ranked this resource in good condition, and the trend presumed to be stable (Table 4.8.5).

Table 4.8.5. Summary of condition assessment for endemic insects.

Indicator	Interpretation	Condition Assessment
Presence/absence of a species	Only one of the eight insect species was not reported during the most recent formal survey.	Resource is stable and in good condition.
Presence and extent of suitable habitat	Extent of sandy habitat is sufficient to support endemic insect populations.	Resource is stable and in good condition.

4.8.5 Sources of Expertise

Phyllis Pineda Bovin, NPS biologist at GRSA, provided data and review of this section.

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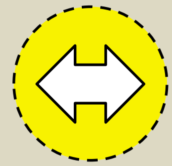
4.9 Amphibians and Reptiles

Indicators / Measures

- Presence/absence of individuals
- Presence of suitable habitat

Condition - Trend



4.9.1 Background and Importance

Impacts from human activities, especially from intensively cultivated agriculture, have largely exterminated amphibians and reptiles in extensive areas of the San Luis Valley (Hammerson 1999). The eastern side of the valley, however, in the vicinity of GRSA, retains large tracts of relatively undisturbed potential habitat for these animals. Although GRSA is not a center of herpetofaunal diversity, amphibians and reptiles were identified as resources/issues of concern and active monitoring programs for GRSA (Britten et al. 2007). In light of the recent worldwide decline of amphibian species (Stuart et al. 2004), amphibian species throughout the vicinity of GRSA are likely to be of concern at a future point.

Amphibians are known to be highly sensitive to water quality impacts (Horne and Dunson 1995, Diana and Beasley 1998, Welsh and Ollivier 1998) and other anthropogenic environmental stressors such as roads and traffic volume (Fahrig et al. 1995), habitat loss and fragmentation (Lehtinen et al. 1999), introduced predators (Stebbins and Cohen 1995), light pollution (Buchanan 2006), and climate change (IPCC 2002). Because of their environmental sensitivities and the fact that a majority of amphibian species require healthy wetland habitat for successful reproduction, amphibians are an important indicator of wetland health (Adamus et al. 2001, Mensing et al. 1998).

Although they are not as sensitive to water quality as amphibians, reptiles are an important part of the food web and are also at risk from habitat loss, fragmentation, and degradation. Declines similar to those observed in amphibian species have also been documented for reptiles (Gibbons et al. 2000, Reading et al. 2010, Böhm et al. 2013). Furthermore, the sensitivity of many reptile species to temperature and precipitation range and variability makes them a potentially important indicator of the effects of changing climate (Barrows et al. 2010).

Indicators for the status of the six amphibian and seven reptile species (Table 4.9.1) reported from the vicinity of GRSA are 1) documented presence/absence of individuals, and 2) mapped or modeled presence and extent of suitable habitat for selected species.

Table 4.9.1. Amphibian and reptile species at GRSA.

Species	Abbreviation*	Common Name
Amphibians		
Ambystoma tigrinum	AMTI	Tiger Salamander
Anaxyrus cognatus	BUCO	Great Plains Toad
Anaxyrus woodhousii	BUWO	Woodhouse's Toad
Pseudacris triseriata	PSTR	Striped Chorus Frog
Lithobates pipiens	RAPA	Northern Leopard Frog
Spea bombifrons	SCBO	Plains Spadefoot Toad
Reptiles		
Pituophis catenifer	PICA	Bullsnake
Lampropeltis triangulum	LATR	Milk Snake
Thamnophis elegans	THEL	Western Terrestrial Garter Snake
Phrynosoma hernandesi	PHHE	Short-horned Lizard
Sceloporus undulatus	SCUN	Plateau Lizard
Plestiodon multivirgatus epipleurotus	EUGA	Variable Skink
Crotalus viridis	CRVI	Western Rattlesnake

* Abbreviations based on former species name in some cases, but used herein as in Muths and Street (2002).

4.9.2 Data and Methods

The presence/absence of species documented at GRSA was assessed by using survey data collected in the summers of 2001 and 2002. Under the auspices of the DOI Amphibian Research and Monitoring Initiative, Muths and Street (2002) surveyed amphibians and reptiles in GRSA. Although their survey was intended to provide a baseline for the NPS Inventory and Montitoring effort, they advise that results should be viewed with caution because of the extreme drought conditions present at the time. As part of a broad-scale survey, Muths and Street used a grid composed of 1000 m^2 cells to select sites randomly for inventory. Forty-three of the 674 grid cells were visited one or more times during the survey. Researchers also conducted a habitat-specific survey targeting areas believed likely to support amphibians or reptiles, at sites in close proximity to water or wetlands (Figure 4.9.1, Table 4.9.2).

Sites were identified with the help of input from park natural resource staff and subject-matter experts, and were primarily in close association with Medano Creek. A visual encounter survey was performed at both grid cell sites and habitat-specific sites. In addition, pitfall trap arrays were constructed in six locations (Figure 4.9.1, Table 4.9.2). Finally, researchers collected voucher specimens of species encountered (held by USGS Fort Collins Science Center). Results from this survey were compiled and collated with habitat information produced by comparing information reported in the Colorado Herpetofaunal Atlas, Hammerson (1999) and CNHP (2013).

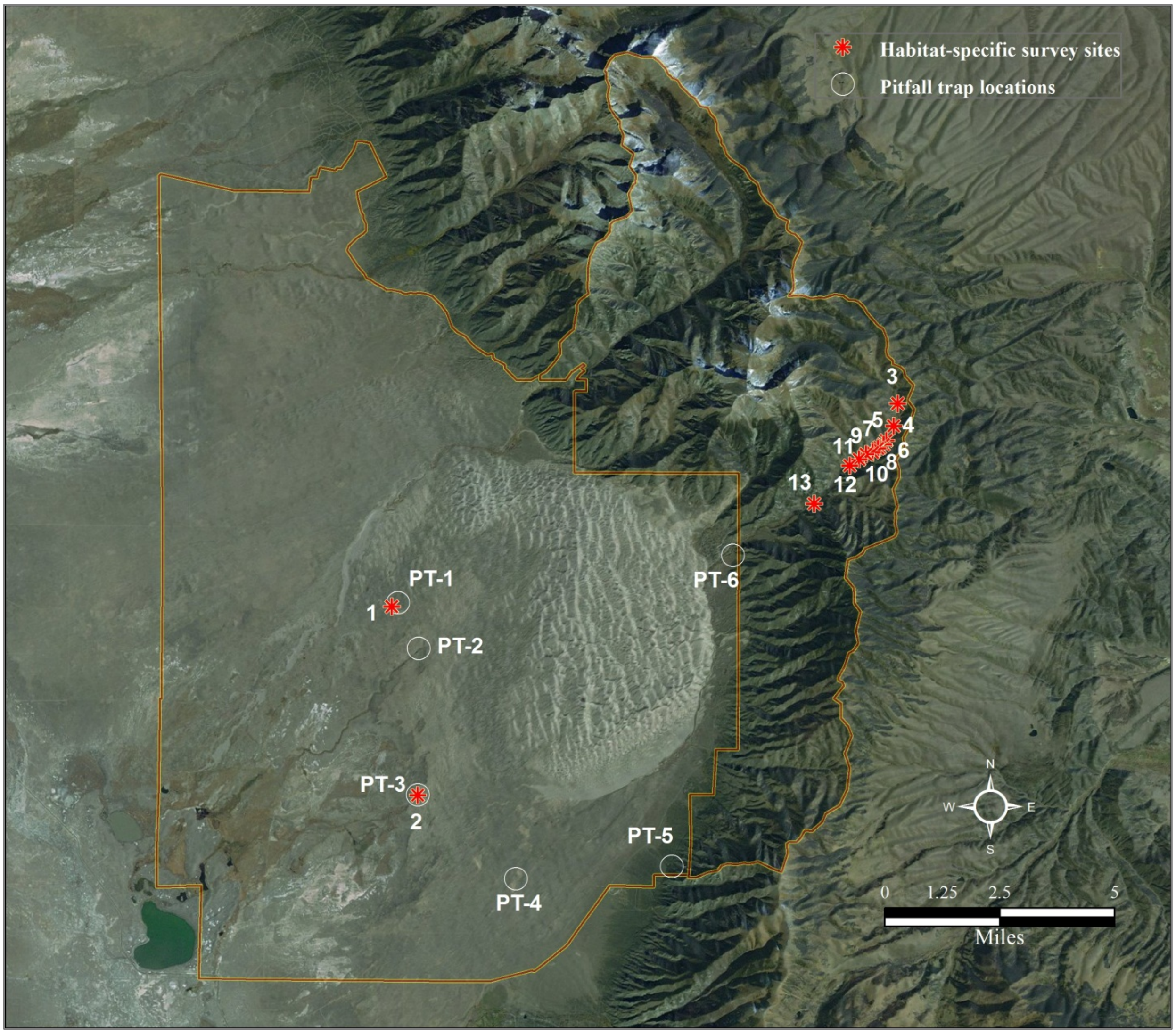


Figure 4.9.1. Pitfall trap locations and habitat-specific survey sites.

Table 4.9.2. Visual encounter survey locations for selected habitats, and pitfall trapping (PT) sites. Adapted from Muths and Street (2002).

Label	Site	Description
1	West Elk Pond	Pond with low water due to drought conditions, but with emergent vegetation around edges. Substrate of silt and mud.
2	Little Spring	Wetland in a dune area. About 30% emergent vegetation, mainly sedges. Sandy substrate, heavily used by ungulates, waterfowl, and small mammals.
3	Medano Creek start point	Creek 1-2 m side and < 1 m deep. Shaded by willows and alders. Rock and cobble substrate
4	Medano Creek bed	Creek 1-2 m side and < 1 m deep. Shaded by willows and alders. Rock and cobble substrate
5	Active beaver pond 1	Pond < 1 m deep, surrounded by willow forest. Less than 1 m deep, with 10% emergent vegetation.

Table 4.9.2 (continued). Visual encounter survey locations for selected habitats, and pitfall trapping (PT) sites. Adapted from Muths and Street (2002).

Label	Site	Description
6	Active beaver pond 2	Pond 1-2 m deep, surrounded by willow forest. 100% shallows around perimeter with 5% emergent vegetation.
7	Active beaver complex	Three ponds surrounded by willows and alders. Shallows present around entire perimeter of each pond, with 5% emergent vegetation.
8	Deserted beaver pond and Deserted beaver pond 2	Pond surrounded by willow forest. Less than 1 m deep, 100% shallows around perimeter with 3% emergent vegetation. Pond < 1 m deep. Dam washed out. No emergent vegetation.
9	Active beaver pond 3	Pond < 1m deep. 100% shallows around perimeter with 90% emergent vegetation.
10	Beaver complex 2	Five ponds up to 2 m deep. Some emergent vegetation, primarily grass.
11	Point 1 – Medano Creek	On east side of slow-moving stream about 2 m wide and <1 m deep. Surrounding vegetation of grass and willows.
12	Point 2 – Medano Creek	On north side of slow-moving stream about 2 m wide and <1 m deep. Surrounding vegetation of grass and willows.
13	Beaver complex 1	Two ponds up to 2 m deep in pine-willow forest. Some emergent vegetation, primarily grass.
PT-1	East Elk Pond	Riparian area with dense sedges and rushes.
PT-2	Indian Spring	Ecotone between riparian sedges and rushes and dense (70-80%) shrub cover.
PT-3	Little Spring	See #2 above. Ecotone between riparian sedges and rushes and sparse shrub vegetation of dune field.
PT-4	Sand Sheet	Area with shrubs and grasses 30-40% cover. No standing water.
PT-5	Denton Springs	Fifty meters above spring in a pinyon-juniper forest.
PT-6	Hawthorne	Shrub dominated area in hawthorn trees, about 100 m from stream.

Additional information was available for the short-horned lizard (*Phrynosoma hernandesi*) from studies conducted by Megan Lahti (2010) in and around GRSA.

The presence/absence of suitable habitat for herptile species at GRSA was evaluated by intersecting point locations from the survey and from CNHP data with the vegetation map to identify important habitat types for each species reported in Muths and Street (2002), along with reports of suitable habitat. For amphibian species, environmental and bioclimatic variables, such as distance to water, elevation, landform, surface roughness, as well as seasonal and annual temperature and precipitation ranges were evaluated in conjunction with vegetation communities to model potential species distributions. We initially explored inductive distribution models using Maxent software (Dudik et al. 2010) for each species. However, data points are too few and, in some cases, too imprecise, to create quality single-species models. At the recommendation of CNHP herptile zoologist Brad Lambert, we combined data points for Woodhouse's toad, plains spadefoot toad, and striped chorus frog to create a single Maxent distribution model for these three species that have very similar habitat requirements. Individual deductive models were created for tiger salamander, Great Plains toad, and northern leopard frog (note that the northern leopard frog may be locally extirpated). The reptile species were considered too widespread and generalist to be suitable for modeling, and the remaining amphibians on the list could not be modeled due to insufficient data.

Environmental inputs for the Maxent model used included the vegetation map unit; USGS 10 m National Elevation Dataset, plus derived products created by CNHP based on this data including topographic roughness, flow accumulation, and landform; distance to USGS National Hydrography Dataset waterbodies and flowlines; and the WorldClim bioclimatic variables of mean diurnal temperature range, maximum temperature of the warmest month, minimum temperature of the coldest month, and annual temperature range (Hijmans et al. 2005). Inputs for the deductive models were vegetation map unit, elevation, distance to water, and landform.

4.9.3 Reference Conditions

Reference conditions for the presence of amphibian and reptile species at GRSA are difficult to establish due to the fact that the baseline survey was designed before the present configuration of park and preserve was finalized. The list in Table 4.9.2 should be regarded as a preliminary baseline for reference condition. The documented presence of a species during survey work is the reference condition for individuals. The current extent and distribution of potentially suitable habitat is considered the reference condition, in the absence of more detailed information about habitats. Indicators were evaluated qualitatively, according to criteria in Table 4.9.3.

Table 4.9.3. Criteria for evaluating condition of individual amphibian and reptile species at GRSA.

Condition Assessment	Presence/Absence of a Species	Presence and Extent of Suitable Habitat (6 spp)
Resource in good condition	Species presence well documented	Suitable habitat extensive
Warrants moderate concern	Species present but poorly documented, or with only a single occurrence, or well documented nearby, but not within GRSA	Suitable habitat present, but of lesser extent, or unknown
Warrants significant concern	Species not found	Suitable habitat very limited

4.9.4 Condition and Trend

During the survey (Muths and Street 2002), six species were documented at discrete locations or in survey grid cells (Figure 4.9.2). An additional two species (Great Plains toad and variable skink) were detected during the field work at unreported locations. For surveyed locations, the most important ecosystem types for amphibians were the Inter-Mountain Basins Interdunal Swale Wetlands and North American Arid West Emergent Marsh, together with adjacent areas of Inter-Mountain Basins Active and Stabilized Dune or Semi-Desert Grassland. The Plains Spadefoot Toad was also found in Southern Rocky Mountain Pinyon-Juniper Woodland. Reptiles were chiefly found in upland types, especially the Active and Stabilized Dune and Pinyon-Juniper Woodland ecosystems. The Western Terrestrial Garter Snake shows the most variety of habitats, and was found in a variety of forested and woodland types as well. Ecosystem types where a species was detected during survey work are indicated by “M” (mapped) in Table 4.9.4. Because many types were not sampled, descriptions of preferred habitat from the literature are cross-walked to a list of ecosystem types derived from the GRSA vegetation map (indicated by “X”).

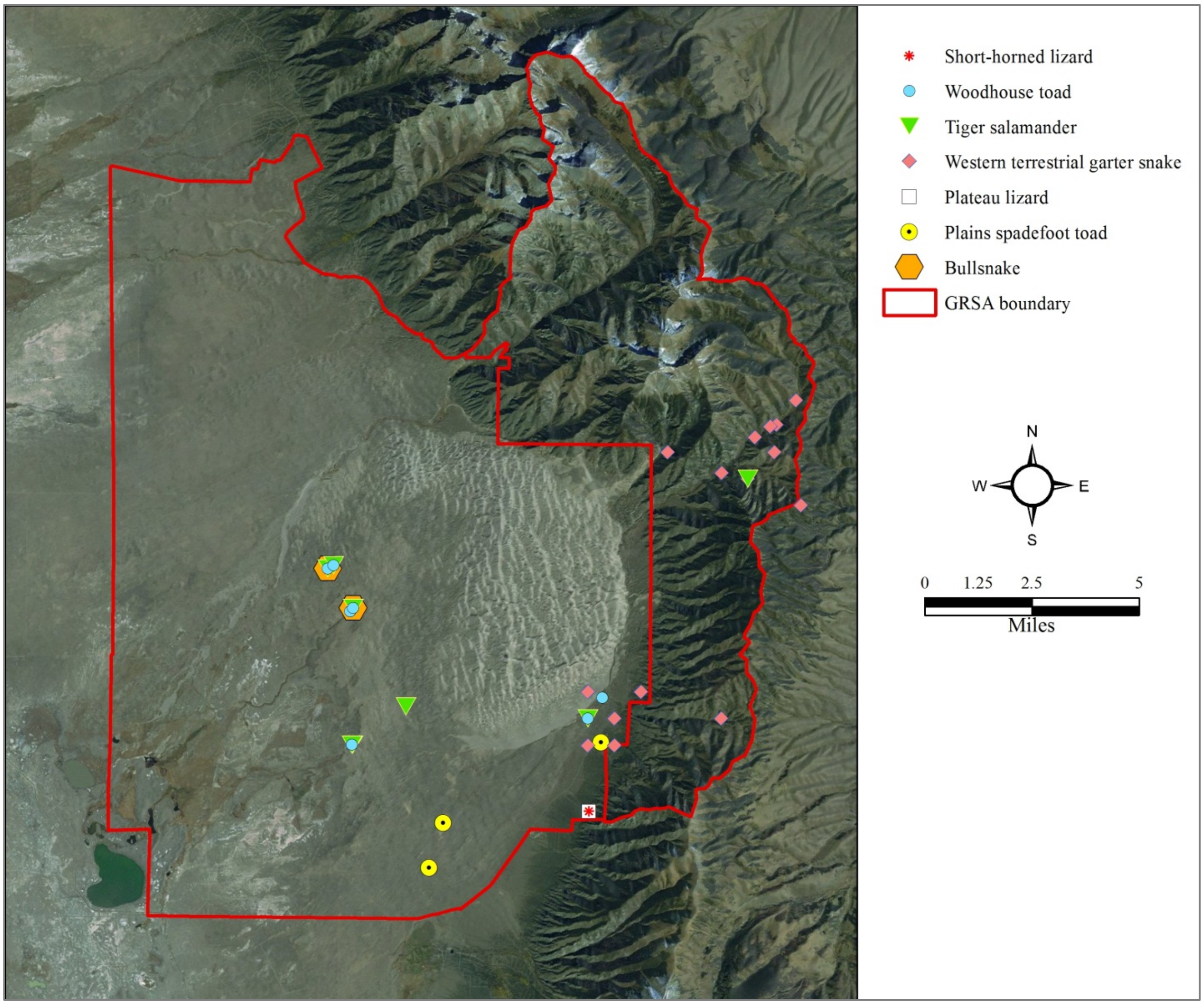


Figure 4.9.2. Approximate locations of species observed in 2001-2002.

Table 4.9.4. Ecosystem types providing potential suitable habitat for herptile species at GRSA. Species abbreviations are as shown in Table 4.9.1.

Ecosystem	AMTI	BUCO	BUWO	PSTR	SPBO	PICA	LATR	THEL	PHHE	SCUN	EUGA	CRVI
Forests												
Southern Rocky Mountain Pinyon-Juniper Woodland					M	M		M	M	M		
Southern Rocky Mountain Ponderosa Pine Woodland												
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland								M				

*Nothing in Alpine or Shrublands

Table 4.9.4 (continued). Ecosystem types providing potential suitable habitat for herptile species at GRSA. Species abbreviations are as shown in Table 4.9.1.

Ecosystem	AMTI	BUCO	BUWO	PSTR	SPBO	PICA	LATR	THEL	PHHE	SCUN	EUGA	CRVI
Forests (continued)												
Rocky Mountain Aspen Forest and Woodland	M							M				
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland												
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland												
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland								M				
Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland												
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland								M				
Grasslands												
Inter-Mountain Basins Semi-Desert Grassland	M		M					M				
Southern Rocky Mountain Montane-Subalpine Grassland												
Dunefield Etc.												
Inter-Mountain Basins Active and Stabilized Dune	M		M		M	M		M				
Inter-Mountain Basins Greasewood Flat												
Wetland - Riparian (Montane)												
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland			M									
Rocky Mountain Subalpine-Montane Riparian Shrubland	X											
Rocky Mountain Subalpine-Montane Riparian Woodland	X											
Rocky Mountain Alpine-Montane Wet Meadow	X							M				
Wetland - Riparian (Valley Floor)												
Inter-Mountain Basins Alkaline Closed Depression												
Inter-Mountain Basins Interdunal Swale Wetland	M		M									
Inter-Mountain Basins Playa												
Inter-Mountain Basins Wash												
North American Arid West Emergent Marsh	M		M									
Open water (primarily small, fishless ponds)	X											

*Nothing in Alpine or Shrublands

Figure 4.9.3 shows the results of the potential habitat distribution models that could be constructed with the available data. Potential habitat for all six species modeled exists within GRSA and the surrounding landscape, although the quality of the habitat was not estimated. The Northern leopard frog has not been reported recently within the park, but was documented during 2005 vegetation mapping field work in the vicinity of Dry Lakes. If additional occurrence points can be documented for species throughout likely habitat in the vicinity of GRSA, more powerful modeling techniques could then be applied to develop more robust maps of suitable habitat.

Individual species were evaluated against the criteria listed above. Five of thirteen species were ranked good for presence; only one was ranked poor, or warranting significant concern (Table 4.9.5). Five of six modeled amphibian species were ranked good for habitat presence, and one ranked of moderate concern. Habitat for reptile species was not evaluated. Confidence for the condition of this factor is low, although we presume that habitat is present for all species that were found during survey work.

We summarized individual species assessments into an overall resource condition assessment by using the lowest assessment of the two criteria, resulting in an overall assessment of warranting moderate concern (Table 4.9.5). Although habitats for GRSA herptile species appear to remain at levels suitable to support the presence of the species, solid evidence for this conclusion is lacking. Furthermore, there is not enough information to evaluate trends. Therefore, our confidence for this resource is low.

Table 4.9.5. Resource condition assessment for individual amphibian and reptile species.

Species	Common Name	Presence	Habitat
Amphibians			
Ambystoma tigrinum	Tiger Salamander	Good	Good
Anaxyrus cognatus	Great Plains Toad	Moderate	Good
Anaxyrus woodhousii	Woodhouse's Toad	Good	Good
Pseudacris triseriata	Striped Chorus Frog	Moderate	Good
Lithobates pipiens	Northern Leopard Frog	Moderate	Moderate
Spea bombifrons	Plains Spadefoot Toad	Good	Good
Reptiles			
Pituophis catenifer	Bullsnake	Good	Not evaluated
Lampropeltis triangulum	Milk Snake	Poor	Not evaluated
Thamnophis elegans	Western Terrestrial Garter Snake	Good	Not evaluated
Phrynosoma hernandesi	Short-horned Lizard	Good	Not evaluated
Scelorporus undulatus	Plateau Lizard	Moderate	Not evaluated
Plestiodon multivirgatus epipleurotus	Variable Skink	Moderate	Not evaluated
Crotalus viridis	Western Rattlesnake	Moderate	Not evaluated
	Overall criteria rank:	Moderate	Good

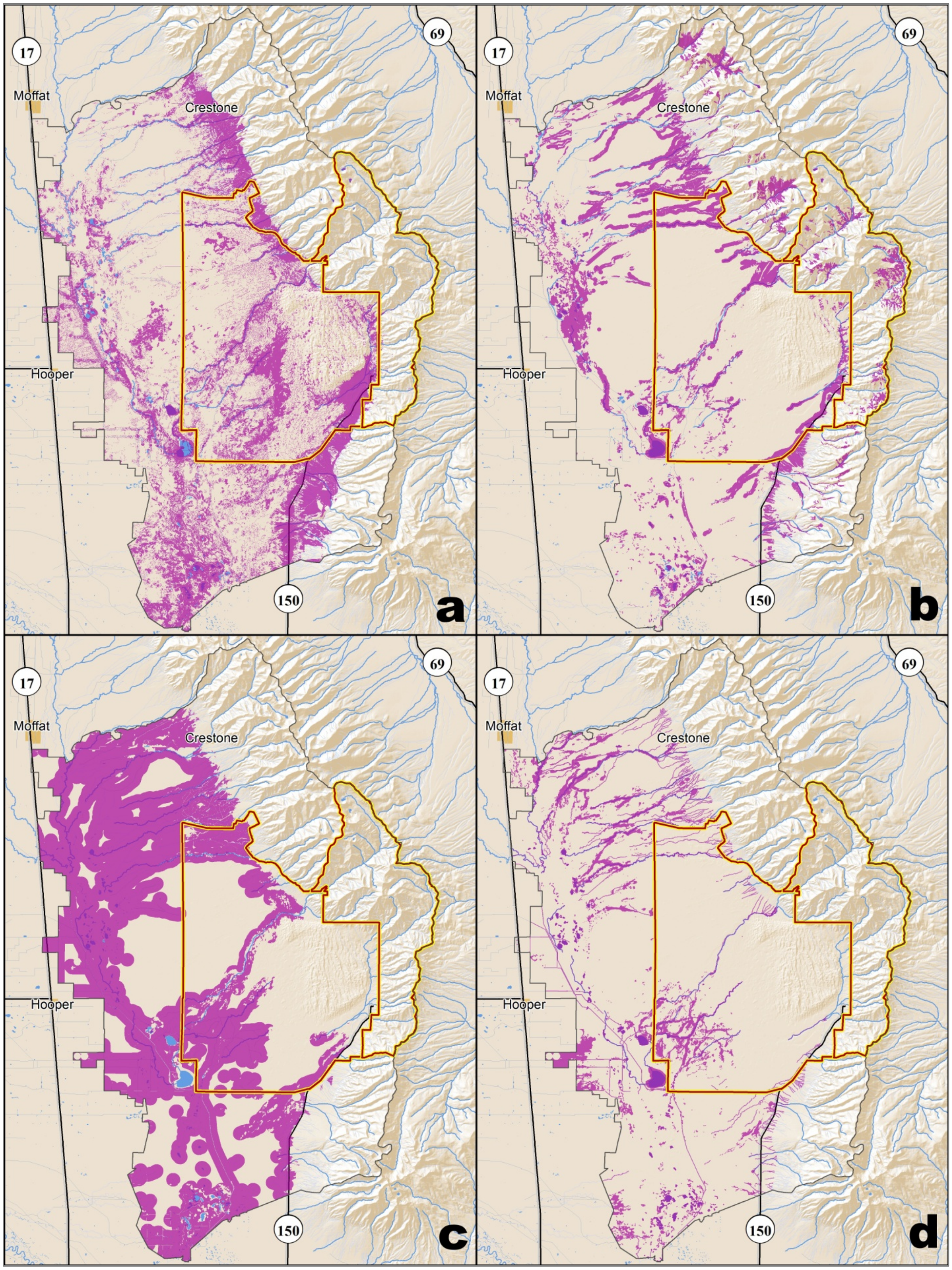


Figure 4.9.3. Potentially suitable habitat distribution models for (a) Woodhouse's toad, plains spadefoot toad, and striped chorus frog; (b) tiger salamander; (c) Great Plains toad; and (d) northern leopard frog.

4.9.5 Sources of Expertise

Brad Lambert, CNHP Herptile Zoologist provided model review and suggestions. Dr. Erin Muths, USGS provided review and comments.

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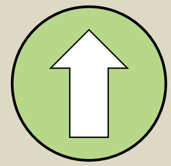
4.10 Other Species of Concern

Indicators / Measures

- Presence of individuals
- Presence/extent of suitable habitat for rare plant species

Condition - Trend



4.10.1 Background and Importance

In addition to species groups addressed in other sections (endemic insects, section 4.8; herptiles, section 4.9), there are a number of other rare, imperiled, or otherwise significant animal and plant species that are supported in the diverse habitats of GRSA. Inventory work in the area during 1997-1998 (Rondeau et al. 1998, Pineda et al. 1999), and 2002-2003 (Spackman Panjabi et al. 2004) as well as the vegetation mapping work of 2005-2006 (Salas et al. 2011) identified 29 species that are tracked or watchlisted in Colorado. A number of these species are restricted in range, either endemic to the Great Sand Dunes system, or to the San Luis Valley.

This section addresses species that are tracked by the Colorado Natural Heritage Program (CNHP) as elements of biodiversity. Although ungulates, especially elk and bison, are a key management concern for the park, they are not addressed in this assessment because the numerous in-progress studies have not yet produced completed data in a suitable format. Here we assess animal elements of biodiversity not addressed elsewhere, and rare plant species. Plant associations are not evaluated here, but are assumed to be covered as component elements of the native plant communities addressed in section 4.7. Information on rare species within the park enables park staff to meet requirements stipulated in the GRSA general management plan to mitigate “immediate and long-term impacts to rare, threatened, and endangered species” (NPS 2007).

The indicator of resource condition for animal species of concern is the presence of individuals. For plant species of concern, we evaluate extent of modeled suitable habitat in addition to the presence of individuals.

4.10.2 Data and Methods

The GRSA boundary was intersected with GIS data representing mapped species occurrences. CNHP has 70 occurrence records for tracked rare and imperiled species (conservation elements) that are within or intersect GRSA, although 3 of these records are for elements believed to no longer occur in the area. There are an additional 5 observation records for watchlisted species (Table 4.10.1). Additional information about Natural Heritage ranks and methods is provided in Appendix C.

Table 4.10.1. Rare taxa with CNHP occurrence records intersecting GRSA.

Taxa	Present in/near GRSA	No Longer Present	Watch Listed
Amphibians			1
Birds	5		
Fish	1		
Insects	10		
Mammals	3	1	
Mollusks	1		
Reptiles			
Vascular Plants	10	1	1

The presence/absence of tracked plant and animal species thought to be still extant in the vicinity of GRSA was evaluated using element occurrence data (CNHP 2013), supplemented with information provided by park staff. We also evaluated rare plant species habitat at GRSA by modeling potentially suitable habitat using methods and datasets previously developed and tested by CNHP for the production of statewide rare plant models. Plants are grouped into four habitat types (alpine, cliff, wetland, or general), and models in each group use a habitat-specific suite of environmental factors (Table 4.10.2).

Table 4.10.2. Environmental variables used in plant models.

Environmental Inputs	Units	Source	Alpine	Cliff	Wetland	General
Annual Growing Degree Days (average air temp above 0 °C)	degree-days	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*			X	X
Annual Precipitation	cm	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*	X		X	
Annual Precipitation Frequency (days in a year with any precip.)	proportion	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*			X	X
April Minimum Temperature	°C	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*		X	X	X
Aspect	relative levels of northness and eastness	Derived from USGS 30m Digital Elevation Model (DEM) for Colorado. 2006.	X	X		X

* Daymet datasets were originally obtained from http://www.daymet.org/.The Daymet data has subsequently been moved to http://daymet.ornl.gov, and, as of this writing the new period-of-record summaries were not available in the same format as used in the model process. The Daymet model uses spatially referenced ground observations of daily maximum and minimum temperature and precipitation that have been obtained from the Cooperative Summary of the Day network of weather stations archived and distributed by the National Climate Data Center (now part of the Global Historical Climatology Network (GHCN)-Daily dataset), and from the SNOwpack and TELemetry (SNOTEL) dataset managed and distributed by the Natural Resources Conservation Service.

Table 4.10.2 (continued). Environmental variables used in plant models.

Environmental Inputs	Units	Source	Alpine	Cliff	Wetland	General
Depth to Bedrock	cm	Pennsylvania State University Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling. 1998. (Derived from NRCS STATSGO)	X			X
Elevation	m	USGS 30m Digital Elevation Model (DEM) for Colorado. 2006.	X	X	X	X
Distance to Water	m	Derived from USGS High Resolution National Hydrography Dataset. 2010.				X
Distance to Wetlands	m	Derived from USGS High Resolution National Hydrography Dataset. 2010.				X
Geology	categorical	USGS National Gap Analysis Program. 1:500,000 Scale Geology for the Southwestern U.S. 2004.	X	X		X
Landform	categorical	USGS National Gap Analysis Program. Ten Class DEM Derived Landform for the Southwest United States. 2004.		X		
Local Relief	m	Derived from USGS 30m Digital Elevation Model (DEM) for Colorado. 2006.		X		
May Minimum Temperature	°C	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*	X	X	X	X
Number of Frost Days (days in a year with air temp < 0 °C)	number of days	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*	X			
Slope	degrees	Derived from USGS 30m Digital Elevation Model (DEM) for Colorado. 2006.	X	X	X	
Soil pH	pH	Pennsylvania State University Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling. 1998. (Derived from NRCS STATSGO)	X		X	
Soil Texture	categorical	Pennsylvania State University Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling. 1998. (Derived from NRCS STATSGO)	X			
Spring Precipitation (March, April, May)	cm	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*		X		X
Spring Snow Depth (March, April, May – not averaged but used separately)	mm	National Operational Hydrologic Remote Sensing Center Snow Data Assimilation System (SNODAS) Data Products at NSIDC for 2004 – 2011.	X			
Summer Precipitation (June, July, August)	cm	Daymet - Climatological summaries for the conterminous United States 1980-1997 (1km)*		X		X
Vegetation type	categorical	USGS National Gap Analysis Program. Provisional Digital Land Cover Map for the Southwestern United States. 2004.	X	X		X

* Daymet datasets were originally obtained from http://www.daymet.org/.The Daymet data has subsequently been moved to http://daymet.ornl.gov, and, as of this writing the new period-of-record summaries were not available in the same format as used in the model process. The Daymet model uses spatially referenced ground observations of daily maximum and minimum temperature and precipitation that have been obtained from the Cooperative Summary of the Day network of weather stations archived and distributed by the National Climate Data Center (now part of the Global Historical Climatology Network (GHCN)-Daily dataset), and from the SNOwpack and TELemetry (SNOTEL) dataset managed and distributed by the Natural Resources Conservation Service.

Environmental attributes for model points were derived from digital raster and vector data in ArcGIS 10 (ESRI 2010). Datasets were processed to a common projection, rasterized if necessary, clipped to the Colorado boundary, resampled as necessary to a uniform cell size of 30 m, and snapped to a common raster so that all cells from all inputs stacked. Each raster was then converted to ASCII format. Models were constructed with data from known locations of the target species using element occurrence and observation records from the CNHP databases. Element occurrence records were reviewed, updated, and filtered prior to modeling to ensure that the most accurate information was used. Element occurrence polygons were converted to point locations. Species were modeled using Maxent software (version 3.3.1e, Dudik et al. 2010). The level of presence points withheld by the procedure for testing was set at 20%. Initial logistic model output was trimmed by using the equal training sensitivity and specificity threshold as a starting point. The resulting model surface was reviewed by Colorado botanists and ecologists. Models were then revised according to feedback received, usually by removing portions of range by using a mask such as watershed or ecoregion boundaries, or by increasing the threshold cut-off value to more accurately reflect the known distribution of the species. For further information on modeling techniques and data sources, see Appendix D.

4.10.3 Reference Conditions

Reference conditions for the presence of rare animal and plant species at GRSA are based on the results of inventory work in the region. The documented presence of a species is the reference condition for individual species. For plants, the current extent and distribution of potentially suitable habitat is considered the reference condition for habitat, in the absence of more detailed information. Indicators were evaluated qualitatively, according to criteria in Table 4.10.3.

Table 4.10.3. Criteria for evaluating condition of individual animal and plant species at GRSA.

Condition Assessment	Presence/Absence of a Species	Presence and Extent of Suitable Habitat (plants)
Resource in good condition	Species presence documented (or documented nearby for birds)	Suitable habitat present
Warrants moderate concern	Species presence documented nearby, but not within GRSA	Suitable habitat present, but of very limited extent
Warrants significant concern	Species not found, or with historic (>25 years ago) documentation only	Suitable habitat not present, species not at edge of range

A species was considered documented as present if there were CNHP element occurrences intersecting GRSA boundaries, or if the species was documented during the recent vegetation mapping work. Species documented nearby are those with occurrence in the area, but not within GRSA. We considered the case of species documented only historically within GRSA, but more recently documented in the vicinity, as of moderate concern. Species with only historic occurrences, both within and in the vicinity of GRSA, are of significant concern.

Rare plant suitable habitat was considered present if significant amounts of higher probability habitat (shown as dark green in Figure 4.10.1a-c, p. 180 below) fell within GRSA boundaries. A moderate assessment was used if primarily lower probability habitat (shown as light green) was present and/or the species is at the edge of its range, in which case habitat might be naturally restricted. Suitable habitat was considered extremely limited if only lower probability habitat was present, and this was restricted to a small area within GRSA.

For animal species of concern, the group ranking was determined by a simple majority. For plant species of concern, group ranking was determined by simple majority of presence rank, and the habitat rank was used to determine trend, on the assumption that conditions for rare plants depend on available protected habitat. Trends were assessed qualitatively, taking into account the nature of the habitat protection in and near GRSA. An overall assessment for species of concern was determined by considering the overall condition of plant and animal subgroups.

4.10.4 Condition and Trend

Among the rare and imperiled animal species, four bird species, three mammal species, one fish, and one mollusk species are represented by CNHP element occurrence records (Table 4.10.4). The Rio Grande cutthroat trout is the only rare species at GRSA with standing under the U.S. Endangered Species Act; it is a candidate for listing. The Rio Grande sucker is also a fish species of concern, and has been reintroduced in the GRSA vicinity, but there are no CNHP element occurrence records for the species in this area (data are held by Colorado Parks and Wildlife). Unless otherwise noted, species-specific information presented below is taken from CNHP (2013).

Table 4.10.4. Rare fish, bird, and mammal species within GRSA.

Scientific Name	Common Name	# GRSA Records	Last Observed	NHP Rank	Status*
Fish					
Catostomus plebeius	Rio Grande Sucker	(reintroduced)	?	G3G4 / S1	BLM / USFS, SE
Oncorhynchus clarkii virginalis	Rio Grande Cutthroat Trout	7	1997	G4T3 / S3	C BLM/ USFS, SC
Birds					
Amphispiza belli	Sage Sparrow	3	1998	G5 / S3B	USFS
Buteo regalis	Ferruginous Hawk	2	1998	G4 / S3B,S4N	BLM/ USFS, SC
Plegadis chihi	White-faced Ibis	1	1997	G5 / S2B	BLM
Sterna forsteri	Forster's Tern	1	1994	G5 / S2B, S4N	
Mammals					
Perognathus flavescens relictus	Plains Pocket Mouse subsp	6	1998	G5T2 / S2	
Perognathus flavus sanluisi	Silky Pocket Mouse subsp.	3	1998	G5T3 / S3	
Thomomys talpoides agrestis	Northern Pocket Gopher subsp.	3	1998	G5T3 / S3	
Mollusks					
Promenetus umbilicatellus	Umbilicate Sprite	1	unknown	G4 / S3	

* C = US ESA Candidate, USFS = US Forest Service Sensitive Species, BLM = Bureau of Land Management Sensitive Species, SE = Colorado endangered, SC = Colorado species of concern

Fish

The Rio Grande cutthroat trout (RGCT, *Oncorhynchus clarkii virginalis*) occurs only in Colorado and New Mexico within the Rio Grande watershed. The subspecies is considered vulnerable and is a Candidate for both federal and state protection, as well as listed as a sensitive species with both the BLM and USFS. Competition with introduced non-native salmonid species is the greatest threat to this subspecies, but hybridization with other stocked native species as well as hydrological modifications and impacts to water quality also play a role. Within GRSA, the RGCT is found within the Medano Creek watershed, which has been the target of restoration efforts for the trout and other native fish. In 1988, Medano Creek was chemically treated to remove non-native fish, and stocked with RGCT. Occasional stocking to enhance populations in the drainage has continued, and they remain in stable condition (Alves et al. 2008). RGCT are also stocked in the Sand Creek and Deadman Creek drainages, but are not the only salmonids present. Other cutthroat lineages present in lakes in the upper reaches of both of these drainages include Snake River cutthroat in Deadman Lakes, and Greenback x Yellowstone cutthroat trout (called the “Pikes Peak Native” strain) in Sand Creek Lakes (Bramblett and Zale 2002, Alves et al. 2004).

The Rio Grande sucker (*Catostomus plebeius*) is endemic to the Rio Grande Basin in northern New Mexico and south central Colorado. During the past century, this species had been extirpated from most of its historic range, until by 1994 the existing population in Colorado was restricted to a small reach of Hot Creek, on the west side of the San Luis Valley (Rees and Miller 2005). Recently, the Rio Grande sucker has been re-introduced into several streams in the Rio Grande Basin and the San Luis Valley, including Medano Creek (Rees and Miller 2005).

Birds

The Sage Sparrow (*Amphispiza belli*) is a migratory species that breeds primarily in lower elevation sagebrush communities. It is considered globally secure but locally vulnerable and is listed as a sensitive species by Region 2 of the U.S. Forest Service due to loss of habitat as well as apparently naturally low population size.

The Ferruginous Hawk (*Buteo regalis*)is a widespread but not abundant species that is a Candidate for state protection in Colorado and is considered sensitive in the state by both the USFS and BLM. It is apparently secure both globally and during the non-breeding season in Colorado, but is regarded as vulnerable during breeding due to sensitivity to disturbance and loss of habitat and food species (primarily prairie dogs).

The White-faced Ibis (*Plegadis chihi*) is a migratory species that winters in South America and breeds throughout western North America. The San Luis Valley is considered an important nesting area for the species in Colorado. It is considered imperiled or critically imperiled in seven states, including Colorado, as well as two Canadian provinces due to its reliance on disappearing marshy habitats and its sensitivity to pesticides. It is considered a sensitive species in Colorado by the BLM. Within GRSA, the species was last recorded on Zapata Ranch in June 1997 during a CNHP survey. This breeding colony is considered an A-Ranked occurrence.

A small disjunct breeding population of Forster's Tern (*Sterna forsteri*) occurs in Colorado, where it is considered imperiled during breeding due to loss of freshwater marshes as nesting sites and increased human disturbance. The species was recorded in the vicinity of the San Luis Lakes State Wildlife Area in 1994.

There are two records of the Long-billed Curlew (*Numenius americanus*) near GRSA from 1975, but the species is considered possibly locally extirpated in the San Luis Valley. This species was not included in the analysis.

Mammals

While the plains pocket mouse is known from Minnesota and North Dakota south to western Texas and New Mexico and as far west as Utah, the subspecies *Perognathus flavescens relictus* is only known from the Great Sand Dunes area in the San Luis Valley. The most recent records for the subspecies are from surveys conducted in 1997 and 1998, including two A-Ranked occurrences. Not much is known about this mouse, but the subspecies is considered imperiled because of the small number of records and its extremely limited range.

Similarly, the overall range of the silky pocket mouse extends from central Mexico north to South Dakota and Wyoming, and west to eastern Utah, but the subspecies *Perognathus flavus sanluisi* is endemic to the San Luis Valley. The three records documented in the vicinity of GRSA are historic, from surveys from 1909 to 1972. More recent surveys from the late 1990s have documented the subspecies within a couple of miles of the park. The subspecies does not appear to be abundant at any location where it is found.

Northern pocket gophers occur throughout the northern Great Plains from southern Canada to northern New Mexico and Arizona. The subspecies *Thomomys talpoides agrestis* is endemic to the San Luis Valley. There are only eight records for this species in the valley, all but one of which are historic (at least 100 years old). The single recent record is from a CNHP survey that documented the subspecies a mile north of GRSA, within the Baca Grande subdivision.

Historically, the wolverine ranged from central Colorado and northeastern Utah across the Rocky Mountains into Canada and Alaska. There are historic records of wolverine (*Gulo gulo*) occurring along the Sangre de Cristo Mountains and San Juan Mountains, including what is now the preserve portion of GRSA, but the most recent Colorado records for wolverine (from the mid-1990s) occur further north. Wolverines have not been sighted in the Sangre de Cristos since the late 1970s. This species was not included in the analysis.

Mollusks

Specimens of the umbilicate sprite (*Promenetus umbilicatellus*) were collected in the vicinity of the Medano Ranch in 1981, but this species has not been documented in the area since. This freshwater snail is found throughout western North America.

Individual animal species of concern were evaluated according to the criteria listed above. Seven of ten species were ranked in good condition; two ranked of moderate concern, and a single species was ranked in poor, or warranting significant concern (Table 4.10.5).

Table 4.10.5. Resource condition assessment for individual animal species of concern.

Scientific Name	Common Name	Condition Assessment
Fish		
Catostomus plebeius	Rio Grande Sucker	Good
Oncorhynchus clarkii virginalis	Rio Grande Cutthroat Trout	Good
Birds		
Amphispiza belli	Sage Sparrow	Good
Buteo regalis	Ferruginous Hawk	Good
Plegadis chihi	White-faced Ibis	Good
Sterna forsteri	Forster's Tern	Good
Mammals		
Perognathus flavescens relictus	Plains Pocket Mouse subsp.	Good
Perognathus flavus sanluisi	Silky Pocket Mouse subsp.	Moderate
Thomomys talpoides agrestis	Northern Pocket Gopher subsp.	Moderate
Mollusks		
Promenetus umbilicatellus	Umbilicate Sprite	Poor
	Animal group rank:	**Good**

The majority of species were ranked as good condition, therefore we consider that rare animal species as a group at GRSA are in good condition. Additional survey work for the mammal species would help to increase documentation for these animals in the area.

Eleven plant species of concern have been documented in or near GRSA (Table 4.10.6). Suitable habitat was modeled for ten of these species.

Table 4.10.6. Rare plant species at GRSA.

Scientific Name	Common Name	# GRSA Records	Last Observed	NHP Rank	Status*	Model Group
Astragalus bodinii	Bodin milkvetch	1	2006	G4 / S2		general
Castilleja puberula	downy indian-paintbrush	2	2006	G2G3 / S2S3		alpine
Cleome multicaulis	slender spiderflower	7	2006	G2G3 / S2S3	BLM	general
Draba grayana	Gray's Peak whitlow-grass	1	1985	G2 / S2	USFS	alpine
Draba smithii	Smith whitlow-grass	10	2006	G2 / S2	USFS	cliff
Erigeron philadelphicus	Philadelphia fleabane	3	2006	G5 / S1		wet
Oreocarya pustulosa	catseye	6	2006	G5TNR / S1		general
Phacelia denticulata	Rocky Mountain phacelia	1	2006	G3 / SU		general

* USFS = US Forest Service Sensitive Species, BLM = Bureau of Land Management Sensitive Species

Table 4.10.6 (continued). Rare plant species at GRSA.

Scientific Name	Common Name	# GRSA Records	Last Observed	NHP Rank	Status*	Model Group
Platanthera sparsiflora var. ensifolia	canyon bog orchid	2 obs	1997	G4G5T4? / S3		wet
Silene kingii	King's campion	1	2006	G2G4Q / S1		N/A
Woodsia neomexicana	New Mexico cliff fern	1	1954	G4? / S2		cliff

* USFS = US Forest Service Sensitive Species, BLM = Bureau of Land Management Sensitive Species

Plants

Astragalus bodinii is found in five western states plus Alaska and six Canadian provinces. It is ranked as imperiled to critically imperiled in seven of these 12 locations. There are 11 known occurrences of the species in Colorado, seven of which have not been observed for more than 30 years. The single documented occurrence in GRSA is from the recent vegetation mapping project. Little is known about this species, but it is encouraging that it has been found in a new area.

Castilleja puberula is an alpine species endemic to Colorado. There are 25 known occurrences of the species although half of them are historic (25 to 100 years old). The two occurrences on GRSA were documented during the recent vegetation mapping project. The species is ranked as vulnerable and potentially imperiled because of its restricted range and apparent naturally low abundance. As with all alpine species, changing climate may pose a threat to its persistence.

Cleome multicaulis ranges to central Mexico north to Colorado, with a small disjunct population in Wyoming. It is considered imperiled in Colorado, critically imperiled in Wyoming, Arizona, and Texas, and possibly extirpated in New Mexico. Its habitat of moist alkaline meadows and old lake beds is naturally rare, and is primarily threatened by hydrologic modifications. There is also some evidence that populations may be adversely affected by the trampling action of large ungulates (Riley 2001). It is considered a sensitive species by the BLM. From its known range in North America, Colorado appears to have the healthiest population, with 53 recorded occurrences (16 historic), all in the San Luis Valley. There are seven known occurrences in and near GRSA, including three A-Ranked occurrences, in the Medano/Zapata Ranch and San Luis Lake area. It is an annual, and may depend on periodic soil disturbance from species such as the northern pocket gopher described above.

Draba grayana is a Colorado alpine endemic that is ranked as imperiled. It is restricted to the high peaks of central and northcentral mountain ranges in the state, reaching the southern end of its range in the Sangre de Cristos. There are 27 records for the species in Colorado, however, the occurrence at the north end of the preserve has not been observed since the mid-1980s. Because habitat in this area is little disturbed, it is likely that the occurrence is still extant.

Draba smithii is a Colorado endemic known from 28 occurrences in six counties (Alamosa, Archuleta, Custer, Las Animas, Mineral, and Saguache). It commonly occurs at seeps and springs in cliff faces and talus slopes at moderate to high elevation. The species is ranked as imperiled because of its restricted range, specific habitat niche, and increasing threats from hydrologic modification, road development, and recreational disturbance. There are six known occurrences (one historic) in GRSA, all primarily within the preserve. Most of these were last observed during the recent vegetation mapping effort, including one A-Ranked population in the vicinity of Medano Creek.

Erigeron philadelphicus is widespread throughout North America, but is considered critically imperiled in Colorado and imperiled in Wyoming and a couple of Canadian provinces. It is quite rare in Colorado, with only seven documented occurrences in southern Colorado; three of these have not been observed within the past 20 years. As a wetland species it is sensitive to hydrologic modifications and other threats to wetlands. There are three known occurrences in GRSA, all documented during the recent vegetation mapping project.

Oreocarya pustulosa (= *Cryptantha cinerea* var. *pustulosa*) is known from the states of Utah, Colorado, Arizona, and New Mexico, but is rare in Colorado where it is ranked as critically imperiled. It is not ranked or is under rank review in the remaining three states. There are 10 occurrences documented in Colorado, all in the San Luis Valley. Six of these are within GRSA, two of which are A-ranked, all on the north and eastern edge of the dunes at the base of the mountains. The area of mapped occurrences is small (a total of about 33 acres), but may not represent the complete extent of local populations (Phyllis Pineda Bovin, GRSA biologist, personal communication).

Phacelia denticulata is considered globally vulnerable, known only from Wyoming, Colorado, and New Mexico. There are nine recorded occurrences in Colorado, six of them historic (last observed from 27 to over 100 years ago). There is one occurrence within GRSA, documented during the recent vegetation mapping project.

Platanthera sparsiflora var. *ensifolia* is a regional endemic occurring in six states in the western U.S. It is a watch-listed species in Colorado and so not actively tracked, though observations of this plant are recorded in the CNHP Observations database. There are 37 observations of this variety in Colorado, occurring mostly in the western half of the state. Two observations were recorded at GRSA during a 1997 CNHP survey.

There is some question whether or not *Silene kingii* is a distinct species. It is known from Utah, Colorado, and Wyoming and is considered critically imperiled in Colorado and imperiled in Wyoming due to the very small number of occurrences. Utah lumps this species with *Silene uralensis* (=*Lychnis apetala*) and as such does not track or rank it separately. There are only two known records of this species in Colorado, one of which is in the Little Medano Creek drainage within GRSA, identified during the vegetation mapping effort.

Woodsia neomexicana is a fern found primarily in the southwestern U.S., with disjunct populations in South Dakota. It grows in crevices in barren rock slopes and cliffs. Overall it is apparently secure in its range, but is ranked as imperiled in Colorado due to limited habitat and few numbers of individuals in each occurrence. There are 30 records of this species in southern and eastern Colorado, 12 of them historic (last observed from 23 to 65 years ago). There is one historic record for this species in GRSA from 1954. There are more recent occurrences (2004) on the western edge of the San Luis Valley, along the San Juan Mountains.

Rorippa coloradensis has only ever been collected in Colorado, but has not been found since the type collection was made in the late 1800s. This species is considered possibly extinct, and was not included in the analysis. The type specimen is thought to have been collected near San Luis Lake.

Rare plant habitat

Habitat distribution models for ten rare vascular plant species were constructed with available data. Potential habitat for all species modeled exists within GRSA and the surrounding landscape (Figure 4.10.1a-c), although the quality of the habitat was not estimated.

Individual plant species of concern were evaluated according to the criteria listed above. Nine of eleven species were ranked in good condition; two species were ranked poor, or warranting significant concern (Table 4.10.7), due to the fact that there are no recent observations of the occurrences. Modeled potential suitable habitat was present for all ten modeled species, although in lesser amounts for three species (Table 4.10.7). The overall rank for the plant species of concern is good, and we believe trends for these species are improving, due to the continued documentation of new occurrences, and the increased habitat protection afforded by the designation of the park and preserve, as well as other conservation efforts in the area.

Table 4.10.7. Resource condition assessment for individual plant species of concern.

Species	Common Name	Presence	Habitat
Astragalus bodinii	Bodin milkvetch	Good	Good
Castilleja puberula	downy indian-paintbrush	Good	Good
Cleome multicaulis	slender spiderflower	Good	Good
Draba grayana	Gray's Peak whitlow-grass	Poor	Moderate
Draba smithii	Smith whitlow-grass	Good	Good
Erigeron philadelphicus	Philadelphia fleabane	Good	Good
Oreocarya pustulosa	catseye	Good	Good
Phacelia denticulata	Rocky Mountain phacelia	Good	Moderate
Platanthera sparsiflora var. ensifolia	canyon bog orchid	Good	Good
Silene kingii	King's campion	Good	Not modeled
Woodsia neomexicana	New Mexico cliff fern	Poor	Moderate
	Overall plant group rank:	Good	Good

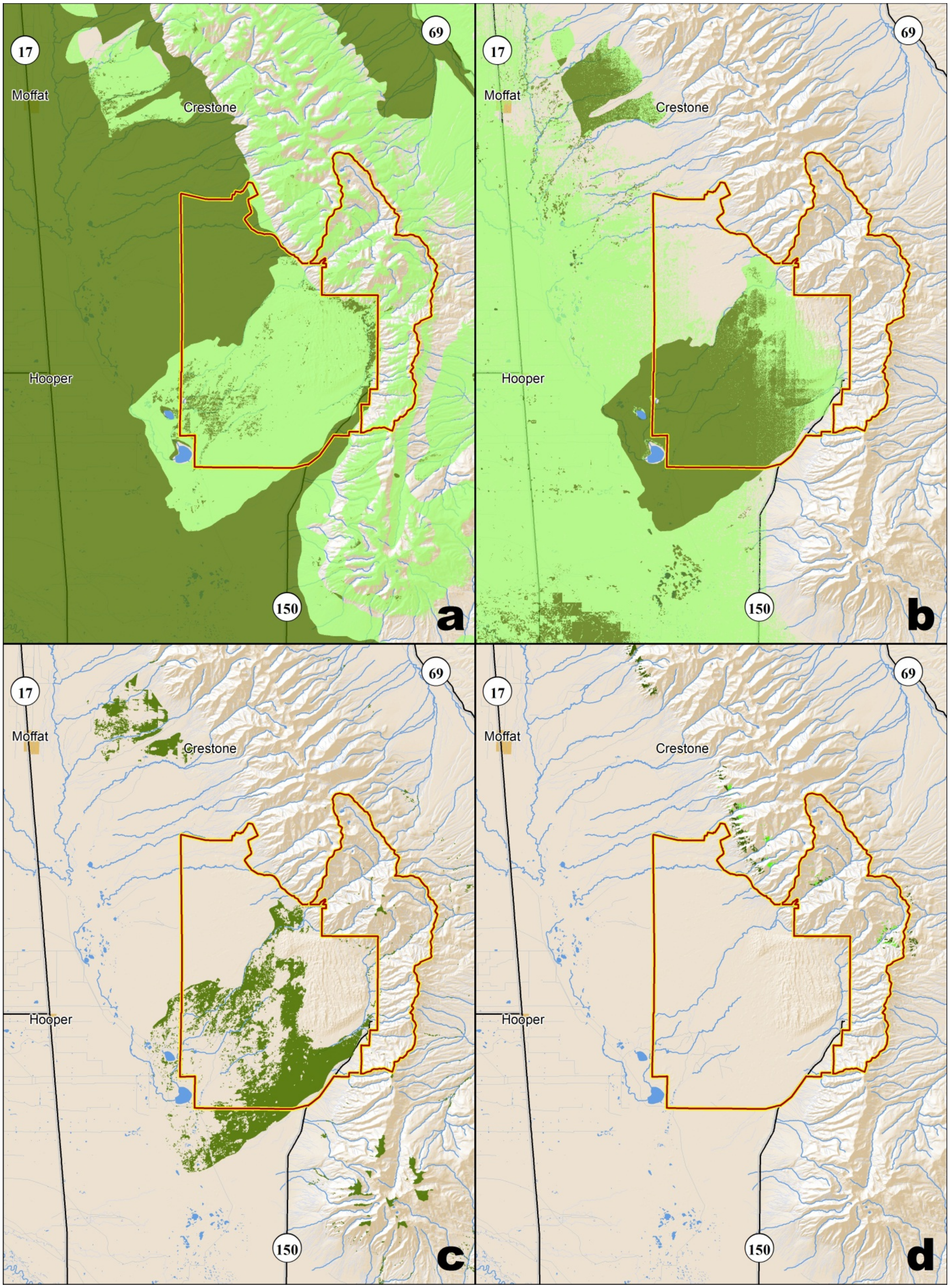


Figure 4.10.1.a. Modeled suitable habitat for rare plant species at GRSA: (a) *Astragalus bodinii*, (b) *Cleome multicaulis,* (c) *Oreocarya pustulosa*, (d) *Phacelia denticulata.*

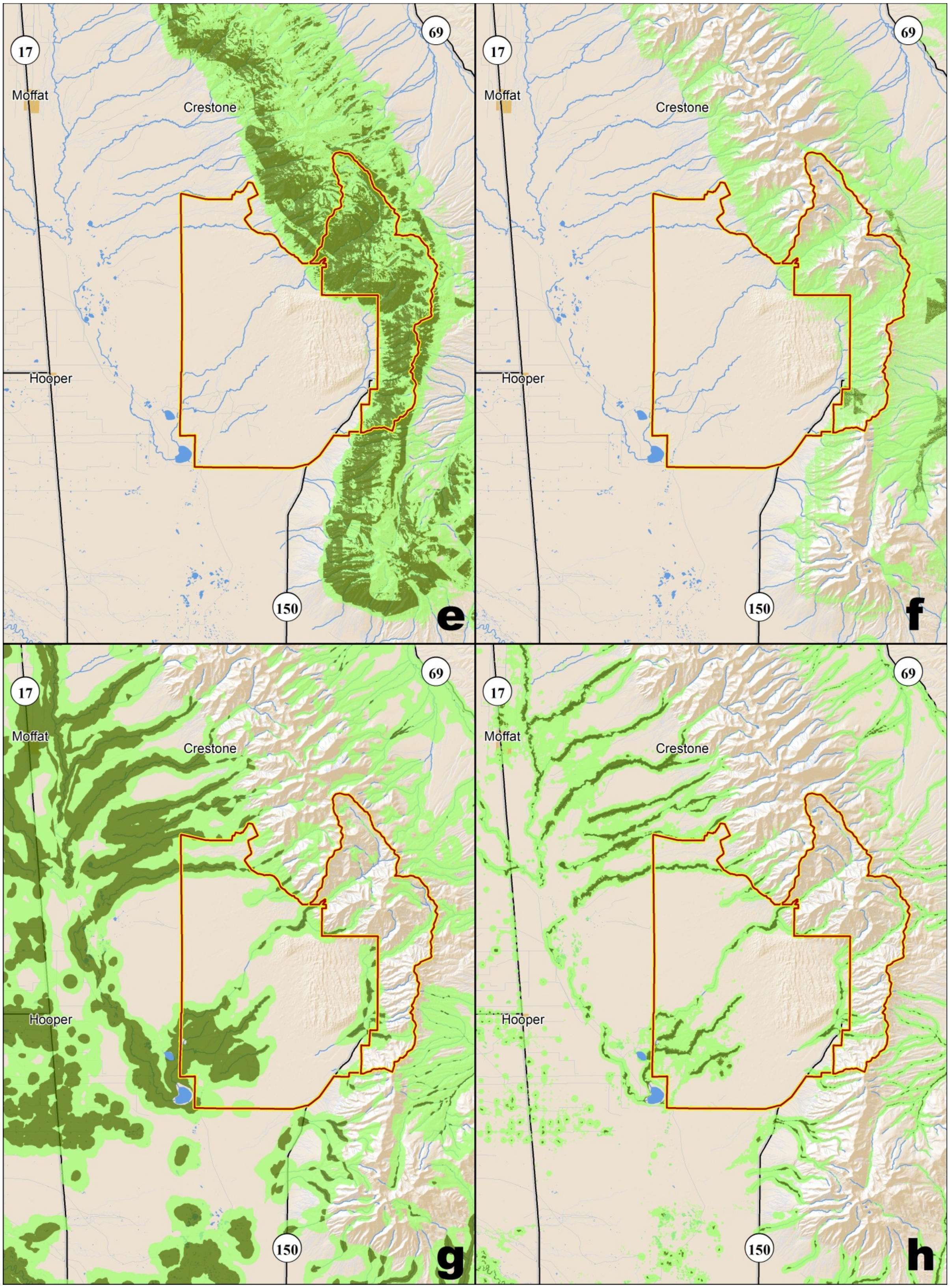


Figure 4.10.1.b. Modeled suitable habitat for rare plant species at GRSA: (e) *Draba smithii* , (f) *Woodsia neomexicana,* (g) *Erigeron philadelphicus,* (h) *Platanthera sparsiflora* var*. ensifolia.*

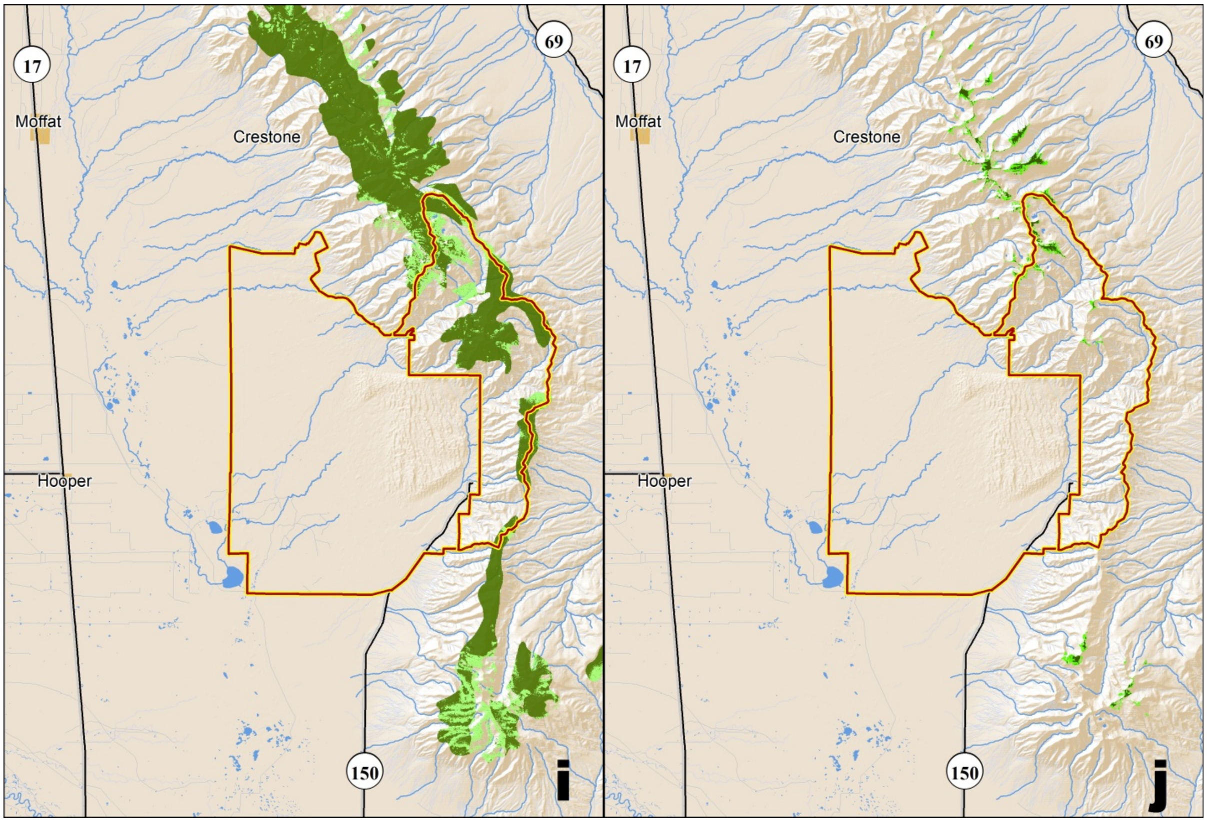


Figure 4.10.1.c. Modeled suitable habitat for rare plant species at GRSA: (i) *Castilleja puberula,* (j) *Draba grayana.*

The overall species of concern condition assessment (Table 4.10.8) is considered good, and with an improving trend due to increased habitat protection within GRSA and the vicinity. Continued survey work, especially for mammals, would help document the condition of the resource.

Table 4.10.8. Summary of condition assessments for species of concern.

Indicator	Interpretation	Condition Assessment
Presence/absence of a species	Although a few plant and animal species are lacking recent observations within GRSA, the generally low levels of disturbance within GRSA and vicinity increase the likelihood that even species not recently observed are in good condition.	Resource is stable and in good condition.
Presence and extent of suitable habitat (plants)	Potentially suitable habitat for ten rare plant species is present within GRSA, and in many cases, represents a central portion of the distribution. The increasing protection for habitat within and near GRSA indicates improving condition for this resource.	Resource is improving and in good condition.

4.10.5 Sources of Expertise

Model review was provided by Susan Spackman-Panjabi, CNHP Senior Botanist and Jill Handwerk, CNHP Botany Team Leader. This section was also reviewed by GRSA natural resource staff and ROMN staff.

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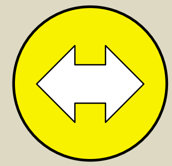
4.11 Invasive / Exotic Plants and Aquatics

Indicators / Measures

- Presence of species with high invasive potential
- Presence or dominance of other non-native species

Condition - Trend



4.11.1 Background and Importance

The terms non-native, alien, and exotic are all used to describe species that have been introduced to an area. Introduced species vary widely in their potential to cause harmful changes to ecosystems; most non-native species are not invasive, although they are usually indicative of some type of disturbance. Executive Order 13112 defines an invasive species as "…an alien (or non-native) species whose introduction does, or is likely to cause economic or environmental harm or harm to human health." Invasive species include all taxa of organisms, not just plants. These species can degrade habitat quality by displacing native species that provide important food, nesting material, or cover (e.g., Jakle and Gatz 1985, Trammel and Butler 1995). Heavy infestation of non-native species can also alter fire, soil water, and nutrient dynamics (Sheley and Petroff 1999). Finally, such infestations may hamper recreational activities and detract from visitor experiences (NPS 2009).

Within Colorado, a noxious weed is an alien (not indigenous to Colorado) plant or parts of an alien plant that have been designated by rule as being noxious or has been declared a noxious weed by a local advisory board, and meets one or more of the following criteria (Colorado Revised Statutes Title 35, Article 5.5 “Colorado Noxious Weed Act”):

1) Aggressively invades or is detrimental to economic crops or native plant communities;
2) Is poisonous to livestock;
3) Is a carrier of detrimental insects, diseases, or parasites;
4) The direct or indirect effect of the presence of this plant is detrimental to the environmentally sound management of natural or agricultural ecosystems.

The Colorado Department of Agriculture currently tracks 96 plant species as noxious weeds, at four levels of importance (CODA 2012). In addition, there are currently seven animal and eight plant aquatic nuisance animal species designated in Colorado Department of Natural Resources code of regulations (2 CCR 405-8).

We evaluated the condition of GRSA with reference to invasive species using two indicators: 1) presence of species with high invasive potential, and 2) presence or dominance of other non-native species. We also report on relative cover of non-native plants by ecosystem.

4.11.2 Data and Methods

Invasive/exotic plants

Non-native plant species recorded during the vegetation classification plot sampling for GRSA (Salas et al. 2011) were assigned an invasiveness score developed by Rocchio (2007). Species with an invasiveness score of 3 or 4 were considered to be invasive species. These species to determine relative vegetative cover (dominance) of invasive plant species, as well as for all non-native species identified. Additionally, we display the results of the Wood and Rew (2005) survey as a comparison and complement to the vegetation classification plot data (Figure 4.11.1). Species targeted in this survey were considered to have the highest invasive potential. The 2005 survey was limited to about 6,000 acres of the park and preserve, focusing on high use areas in drainage bottoms on the east side of the dunes, and open ranchlands on the west side. Points and polygons where target species were found were mapped with GPS.

Relative cover of non-native species in vegetation classification plots was also evaluated by ecosystem, as mapped by Salas et al. (2011). All vegetation sampling points, both inside and outside the park were used and closely related ecosystems were lumped (e.g., dry-mesic and mesic mixed conifer ecosystems were combined and aspen-mixed conifer was lumped with aspen). All points that fell within the "na" value of the vegetation map's ecosystem field were found to have been classified as emergent marsh and so were lumped with that ecosystem.

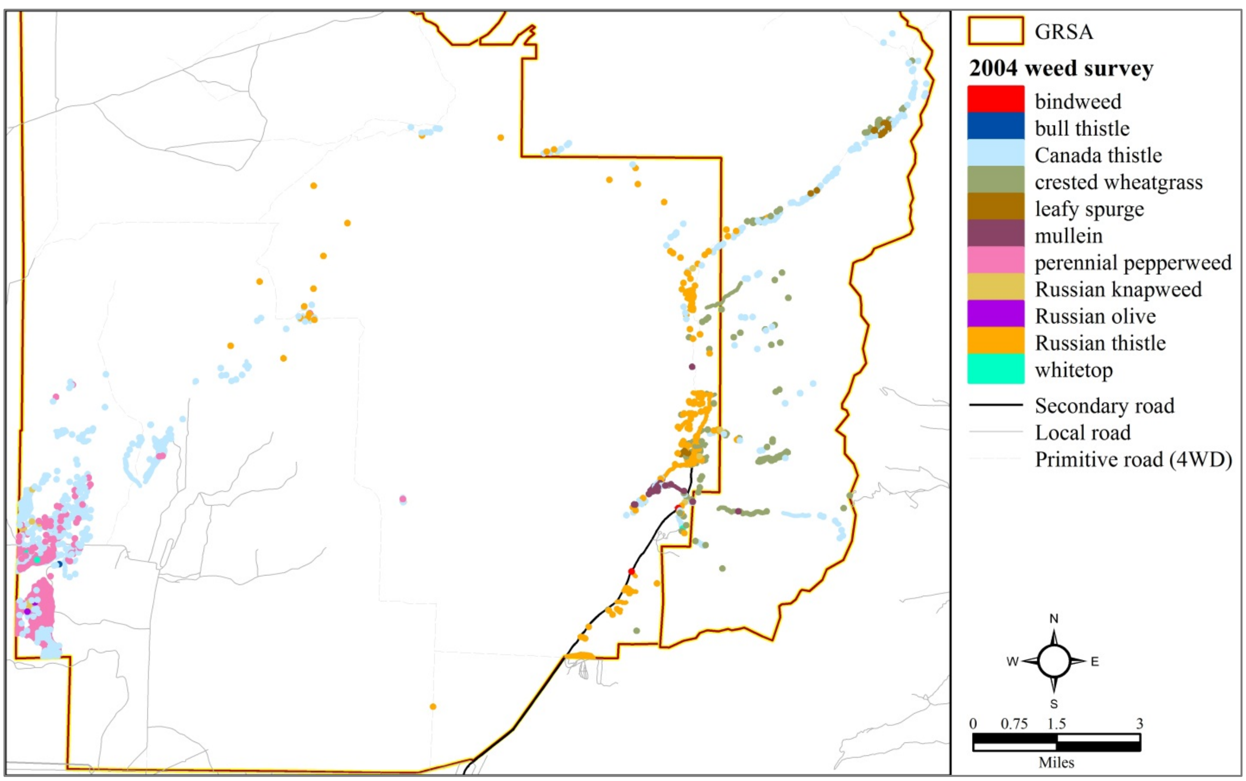


Figure 4.11.1. Mapped noxious weed species from Wood and Rew (2005)

Invasive/exotic aquatics
There have not been any systematic surveys of GRSA for invasive aquatic species. We relied on information provided by GRSA staff, and reports of aquatic nuisance species obtained from the Nonindigenous Aquatic Species Database (USGS 2012).

4.11.3 Reference Conditions
The ideal condition for GRSA would be the complete absence of non-native species, representing conditions during pre-settlement times. Because this type of reference condition is not feasible for a unit with the history and extent of GRSA, we instead consider a baseline reference condition as conditions under which the integrity of park and preserve ecosystems remains essentially unimpaired, and natural processes that are affected by species composition are able to operate within the natural range of variation. We adapted the three-class condition scale presented in Bennetts et al. (2012) to evaluate the condition of ecosystems with reference to invasive species (Table 4.11.1). Data that would allow the assessment of trends are not available.

Table 4.11.1. Reference condition assessment criteria for invasive species.

Condition Assessment	Criteria
Resource in good condition	Species with high invasive potential have been documented on adjacent lands or within the San Luis Valley, but not confirmed as present within the park and preserve. OR If present, distribution is limited in extent, and infestations are generally sparse. OR The only non-native species documented within the park and preserve are those with lower invasive potential.
Warrants moderate concern	Species with high invasive potential have been documented within the park and preserve, but are present in small, localized patches that are amenable to control. Non-native species are present, but not dominant. Native ecosystems are still functioning, and not in immediate danger of alteration.
Warrants significant concern	Species with high invasive potential are present within the park and preserve, and are extensive in some areas, threatening to alter the functioning of native plant or aquatic communities. AND/OR Non-native species, whether invasive or not, are dominant in a native plant community, or there is a clear trend toward such degradation.

4.11.4 Condition and Trend
Non-native plant species, including invasives, have been documented in and near GRSA by a number of studies. As of 2003, the GRSA herbarium documented 44 non-native plant species within the park (Table 4.11.2), including 5 highly invasive species (Spackman Panjabi et al. 2004). A 2004 survey by Montana State University targeted 15 noxious weeds on GRSA, and found and mapped 11 of them (Woods and Rew 2005). This was a targeted survey, focusing on noxious weeds, within a limited survey area (described in section 4.11.2). In contrast, the vegetation classification and mapping effort in 2005-2006 for GRSA recorded noxious weeds and other non-native plant species as an incidental part of the larger vegetation classification effort. As a result, Salas et al. (2011) did not record all of

the same noxious weeds mapped in 2004, but did record a number of other invasive species. Salas et al. (2011) documented 29 non-native species within the park, and an additional 16 in the vicinity.

Table 4.11.2. Non-native plant species documented within GRSA vegetation mapping area.

Scientific Name	Common Name	Invasiveness Score[1]	CO Noxious Weed List[2]	2006[3]	2004[4]	2003[5]
Acroptilon repens	Russian knapweed	4	B		x	
Agropyron cristatum	crested wheatgrass	4	-			x
Agrostis exarata	spike bentgrass	3	-			x
Agrostis gigantea	redtop	3	-	x		
Agrostis stolonifera	creeping bentgrass	3	-	x		x
Alopecurus pratensis	meadow foxtail	3	-			x
Amaranthus blitoides	prostrate pigweed	-	-			x
Amaranthus retroflexus	rough pigweed	-	-			x
Bassia hyssopifolia	fivehorn smotherweed	3	-	x		
Bassia scoparia	burningbush / kochia	4	-			x
Bromus arvensis	field brome	4	-			x
Bromus catharticus	rescuegrass	1	-	x		
Bromus inermis	smooth brome	4	-	x		x
Bromus tectorum	cheatgrass / downy brome	4	C	x	x	x
Camelina microcarpa	false flax	3	-			x
Capsella bursa-pastoris	shepherd's purse	4	-			x
Cardaria draba	whitetop / hoary cress	4	B		x	
Cardaria pubescens	hairy whitetop	4	-			x
Cerastium fontanum	mouse-ear chickweed	3	-			x
Chamaesyce serpyllifolia	thymeleaf sandmat	2	-	x		
Chenopodium album	lambsquarters / white goosefoot	3	-			x
Chenopodium capitatum	blite goosefoot	-	-	x		
Chenopodium glaucum	pale lamb's-quarters / oakleaf goosefoot	3	-			x
Cirsium arvense	Canada thistle	4	B	x	x	x
Cirsium vulgare	bull thistle	4	B		x	
Convolvulus arvensis	field bindweed	4	C		x	x
Dactylis glomerata	orchardgrass	3	-			x
Descurainia sophia	herb sophia / flixweed	3	-	x		x
Elaeagnus angustifolia	Russian olive	4	B		x	
Erodium cicutarium	filaree / redstem stork's bill	4	C			x
Euphorbia esula	leafy spurge	4	B		x	x

[1] Invasiveness score from Rocchio (2007): 4 = highly invasive, 1 = less invasive.

[2] Colorado Noxious Weed List (CODA 2012): A = designated for eradication; B = manage to halt the spread; C = designated for integrated management and further research.

[3] 2006 = Salas et al. (2011); [4]2004 = Woods and Rew (2005); [5]2003 = Spackman Panjabi et al. (2004).

Table 4.11.2 (continued). Non-native plant species documented within GRSA vegetation mapping area.

Scientific Name	Common Name	Invasiveness Score1	CO Noxious Weed List2	20063	20044	20035
Festuca ovina	sheep fescue	2	-			x
Gnaphalium uliginosum	marsh cudweed	-	-			x
Halogeton glomeratus	saltlover / halogeton	4	C	x		
Lactuca serriola	prickly lettuce	3	-	x		
Lepidium latifolium	perennial pepperweed	4	B	x	x	
Melilotus officinalis	sweetclover	3	-			x
Nasturtium officinale	watercress	-	-			x
Phleum pratense	timothy	3	-	x		x
Plantago major	common plantain	3	-	x		
Poa pratensis	Kentucky bluegrass	4	-	x		x
Polygonum arenastrum	devil's sholaces / oval-leaf knotweed	3	-			x
Polypogon monspeliensis	annual rabbitsfoot grass	3	-	x		
Portulaca oleracea	little hogweed	3	-	x		x
Rumex acetosella	bitterdock / sheep sorrel	2	-			x
Salsola collina	slender Russian thistle	-	-	x		x
Salsola tragus	prickly Russian thistle	4	-	x	x	x
Silene dioica	red catchfly	-	-	x		
Sisymbrium altissimum	tall tumblemustard	4	-			x
Sonchus arvensis ssp. *uliginosus*	moist sowthistle	4	C			x
Sonchus asper	spiny sowthistle	3	-	x		
Sonchus oleraceus	sow thistle	3	-			x
Stellaria media	common chickweed	-	-	x		
Taraxacum officinale	common dandelion	3	-	x		x
Thinopyrum intermedium	intermediate wheatgrass	3	-			x
Thlaspi arvense	field pennycress	3	-			x
Tragopogon dubius	yellow salsify	2	-	x		x
Trifolium pratense	red clover	3	-			x
Trifolium repens	white clover	3	-	x		x
Ulmus pumila	Siberian elm	4	-			x
Verbascum thapsus	common mullein	4	C	x	x	x
Veronica anagallis-aquatica	water speedwell	3	-	x		
Veronica peregrina ssp. *xalapensis*	hairy purslane speedwell	-	-	x		

[1] Invasiveness score from Rocchio (2007): 4 = highly invasive, 1 = less invasive.

[2] Colorado Noxious Weed List (CODA 2012): A = designated for eradication; B = manage to halt the spread; C = designated for integrated management and further research.

[3] 2006 = Salas et al. (2011); [4]2004 = Woods and Rew (2005); [5]2003 = Spackman Panjabi et al. (2004).

Of the 63 non-native species that have been recorded within GRSA since 2003, 50 have invasive scores of 3 or 4. Twenty-three species have the highest invasive score of 4, and 11 of those are on the Colorado Noxious Weed List (Table 4.11.3). Within the GRSA vegetation mapping area, 155 of 601 (26%) vegetation classification plots contained non-native species, with 93 plots (15.5%) having species with and invasive score of 3 or 4 (Figure 4.11.2). Figure 4.11.3 provides a comparison of the percent cover of the 11 noxious weeds recorded from the 2004 survey. Data from vegetation mapping plots confirm that 2004 weed survey efforts were generally concentrated in appropriate areas within the park and preserve. Exceptions may be the Sand Creek montane area, northern areas adjacent to Crestone, and areas immediately to the south of the main park entrance. Neither the 2004 weed survey nor the vegetation classification surveyed the area north of Sand Creek and south of Deadman Creek (or, of course, the dunes themselves), so these should not be regarding as comprehensive weed surveys. However, the vegetation classification plot results do confirm that areas of highest visitor use and the Medano Ranch parcel have some of the highest concentrations of weeds.

Table 4.11.3. Relative vegetative cover of non-native species by ecosystem.

Ecosystem	Sampling Points	Ave. Rel. Cover of Non-natives	Max. Rel. Cover of Non-natives
Alpine			
North American Glacier and Ice Field	1	0%	0%
Rocky Mountain Alpine – lumped	67	0.1%	4%
Forest & Woodland			
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	17	0.1%	1%
Rocky Mountain Subalpine Spruce-Fir - lumped	34	0.3%	9%
Southern Rocky Mountain Mixed Conifer - lumped	41	0.2%	4%
Southern Rocky Mountain Pinyon-Juniper Woodland	30	1.4%	35%
Southern Rocky Mountain Ponderosa Pine Woodland	9	0.9%	8%
Rocky Mountain Aspen – lumped	65	0.2%	3%
Shrubland			
Rocky Mountain Lower Montane-Foothill Shrubland	23	1.8%	26%
Rocky Mountain Cliff, Canyon and Massive Bedrock	1	0%	0%
Inter-Mountain Basins Semi-Desert Shrub-Steppe	7	0.2%	1%
Grassland			
Southern Rocky Mountain Montane-Subalpine Grassland	22	1.3%	12%
Inter-Mountain Basins Semi-Desert Grassland	20	2.0%	20%
Dunefield-Sandsheet-Sabkha			
Inter-Mountain Basins Active and Stabilized Dune	77	0.8%	37%
Inter-Mountain Basins Greasewood Flat	24	2.2%	48%
Wetland – Riparian			
Inter-Mountain Basins Alkaline Closed Depression	33	1.0%	9%

Table 4.11.3. Relative vegetative cover of non-native species by ecosystem.

Ecosystem	Sampling Points	Ave. Rel. Cover of Non-natives	Max. Rel. Cover of Non-natives
Wetland – Riparian (continued)			
Inter-Mountain Basins Interdunal Swale Wetland	7	0.8%	4%
Inter-Mountain Basins Playa	9	0%	0%
Inter-Mountain Basins Wash	1	0%	0%
North American Arid West Emergent Marsh	33	2.8%	46%
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	25	3.1%	24%
Rocky Mountain Subalpine-Montane Riparian Shrubland & Woodland – lumped	21	0.2%	3%
Rocky Mountain Alpine-Montane Wet Meadow	32	0.2%	3%

For invasive plant species, the condition criteria indicate that this resource issue at GRSA is moderate.

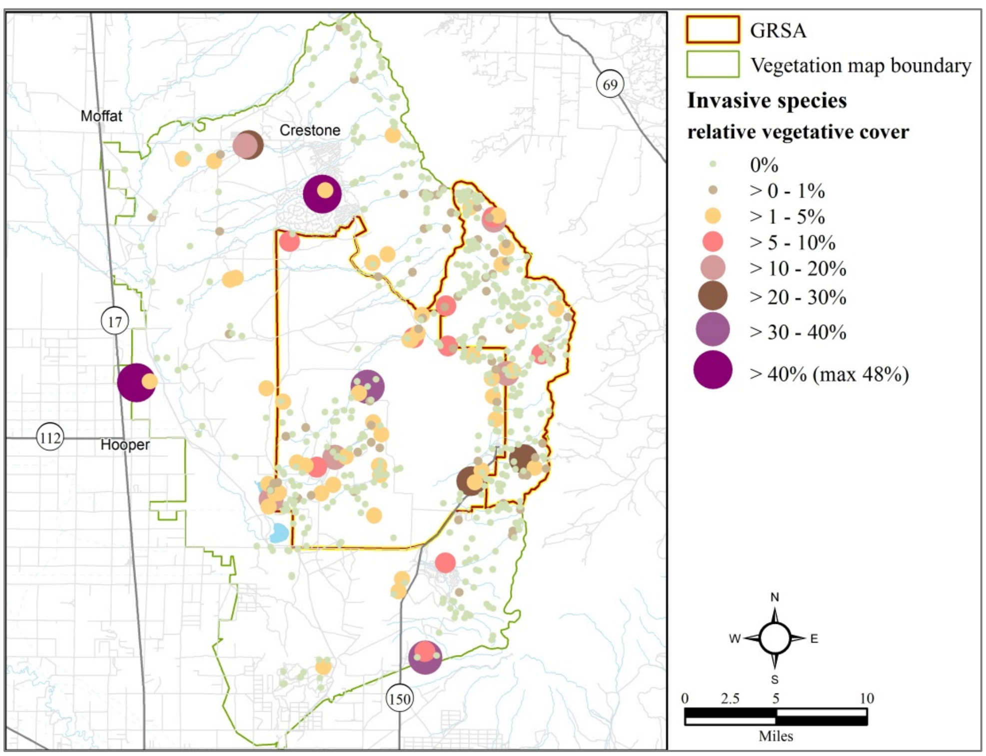


Figure 4.11.2. Relative cover of plant species with invasive score of 3-4 in vegetation mapping plots of Salas et al. (2011).

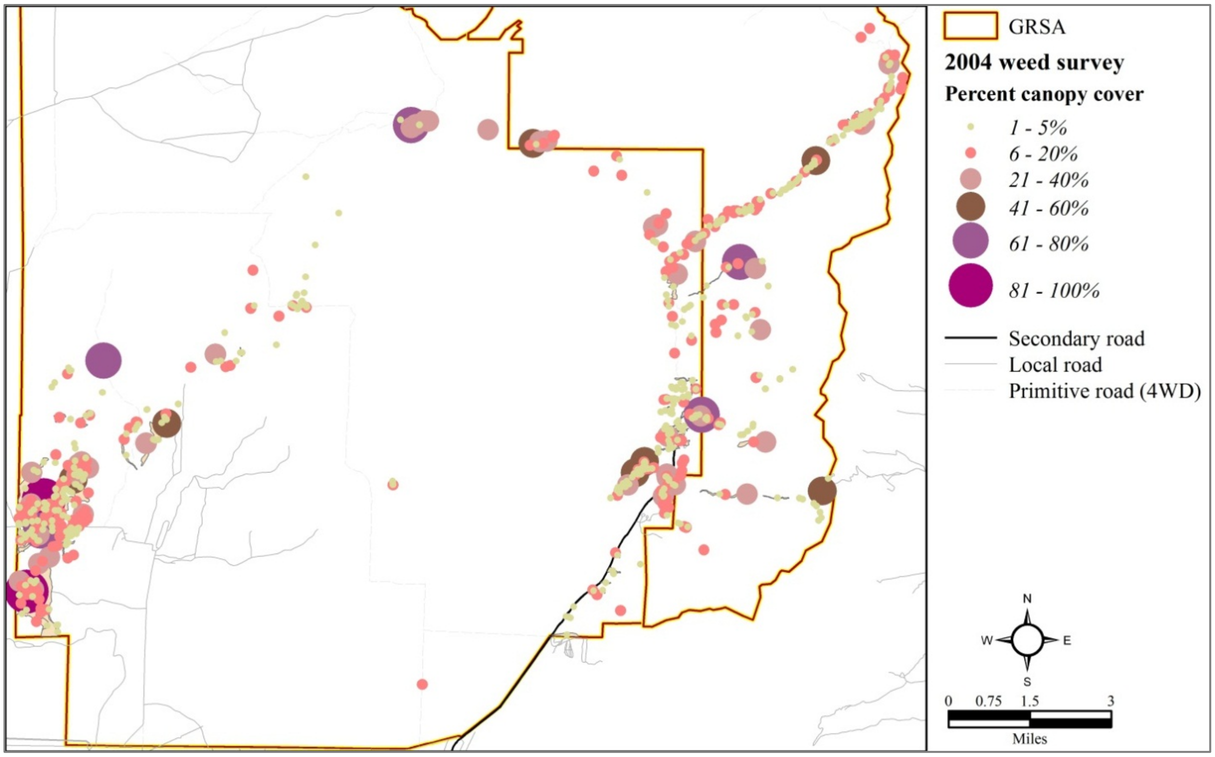


Figure 4.11.3. Percent canopy cover of noxious weeds from Wood and Rew (2005).

Five species on the Colorado Noxious Weed List were found within the park and preserve during the vegetation classification sampling (Figure 4.11.4); cheatgrass (*Bromus tectorum*), Canada thistle (*Cirsium arvense*), halogeton (*Halogeton glomeratus*), perennial pepperweed (*Lepidium latifolium*), and mullein (*Verbascum thapsus*). Another species on the list, whitetop (*Cardaria draba*) was only found in plots outside of the park, but close to the boundary, just south of Head Lake. Cheatgrass was recorded in four plots within GRSA, Canada thistle in 12 (and another 13 plots outside of GRSA), halogeton occurs in one plot in the park and an another three plots outside, perennial pepperweed was found in three plots within GRSA and another two plots outside, and mullein was found in a single plot within the park. Subsequent to the revision of the Colorado Noxious Weed Act that began in 2003, prickly Russian thistle (*Salsola tragus* and *Salsola collina*), no longer appears on the Colorado Noxious Weed List, which was restructured to focus on the most important species for eradication and control planning. However, it is an invasive non-native and was still listed at the time of the 2004 survey (Woods and Rew 2005). It was found in 24 plots within GRSA, as well as three plots outside of the park. In total, 10% of the vegetation classification plots within park and preserve boundaries had noxious weeds. Figure 4.11.4 provides a comparison of the seven weed species mapped during the 2004 survey.

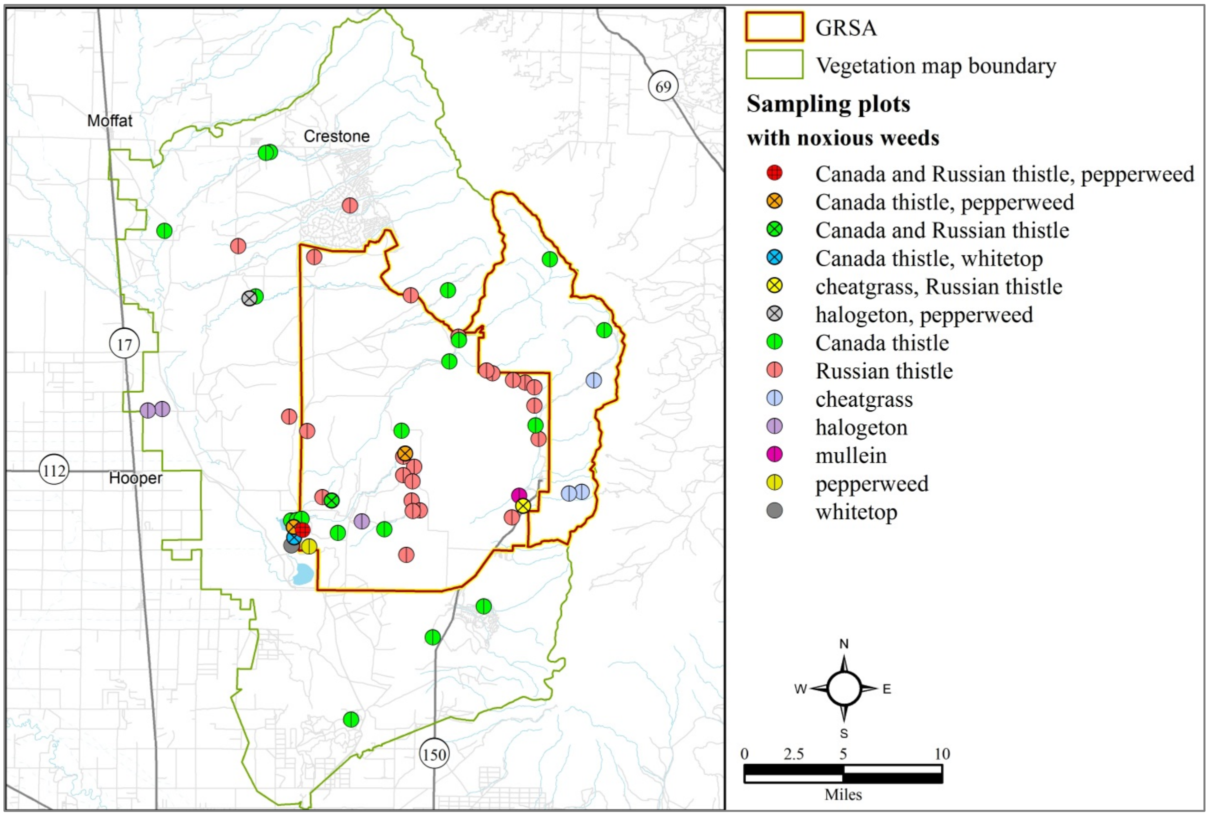


Figure 4.11.4. Noxious weed species in GRSA vegetation mapping plots (Salas et al. 2011)

When non-native species in vegetation mapping plots are compared by ecosystem (Table 4.11.2), the lower elevation wetland and riparian ecosystems have the highest mean relative vegetative cover of non-native species, with 3.1% and 2.8% for Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland and North American Arid West Emergent Marsh, respectively.

Although 61 nonindigenous aquatic animal species have been reported in the Rio Grande headwaters area (Table 4.11.4), only non-native trout have been reported to date within GRSA. Brook trout (*Salvelinus fontinalis*) are present in the lower reaches of Sand Creek (Bramblett and Zale 2002).Species of particular concern to GRSA are the American bullfrog, and the common carp, which have been documented in the vicinity of San Luis Lake. The introduced parasite *Myxobolus cerebralis*, which causes whirling disease in some trout and salmon species, has been present within GRSA in fish stocked in the gravel pit ponds on Sand Creek. These ponds were removed during 2010-2012, and the area was retested for whirling disease (personal communication, Phyllis Pineda Bovin). The invasive aquatic plant species Eurasian watermilfoil (*Myriophyllum spicatum*), has been reported in the San Luis Valley (CODA 2012), but not confirmed as present within GRSA. Finally, the freshwater diatom *Didymosphenia geminata* (commonly called didymo or rocksnot), although native to low-nutrient cold-water streams of the area, has the potential to become a problem in warmer, nutrient-rich systems because it is expanding its geographic range into such areas (Spaulding and Elwell 2007). The current condition for aquatic invasive species is ranked as good, under the assumption that whirling disease has been eliminated from the park.

Table 4.11.4. Nonindigenous aquatic animal species documented within the Rio Grande drainage (USGS NAS 2012).

Group	Family	Scientific Name	Common Name	Status	Location
Amphibians-Frogs	Ranidae	*Lithobates catesbeianus**	American Bullfrog	Collected	Blanca wetlands, Alamosa golf course
Crustaceans-Crayfish	Cambaridae	*Orconectes rusticus**	rusty crayfish	Collected	Sanchez reservoir
Fishes	Anguillidae	*Anguilla rostrata**	American eel	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Callichthyidae	*Corydoras* sp. **	corydoras	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Catostomidae	*Catostomus catostomus**	longnose sucker	Established	Rio Grande drainage
Fishes	Catostomidae	*Catostomus commersonii**	white sucker	Established	San Luis Valley
Fishes	Centrarchidae	*Lepomis gibbosus**	pumpkinseed	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Centrarchidae	*Lepomis gulosus**	warmouth	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Centrarchidae	*Lepomis macrochirus**	bluegill	Established	San Luis Valley
Fishes	Centrarchidae	*Micropterus dolomieu**	smallmouth bass	Established	San Luis Valley
Fishes	Centrarchidae	*Micropterus salmoides**	largemouth bass	Established	San Luis Valley
Fishes	Centrarchidae	*Pomoxis nigromaculatus**	black crappie	Established	San Luis Valley
Fishes	Characidae	*Gymnocorymbus ternetzi***	black tetra	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Characidae	*Hemigrammus ocellifer***	head-and-taillight tetra	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Characidae	*Paracheirodon innesi***	neon tetra	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Cichlidae	*Oreochromis aureus***	blue tilapia	Established	San Luis Valley
Fishes	Cichlidae	*Oreochromis mossambicus***	Mozambique tilapia	Established	Commercial catfish farm Hooper
Fishes	Cichlidae	*Pterophyllum* sp. **	freshwater angelfish	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Cichlidae	*Symphysodon discus***	red discus	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Clupeidae	*Dorosoma petenense**	threadfin shad	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Cottidae	*Cottus bairdii**	mottled sculpin	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Cyprinidae	*Carassius auratus***	goldfish	Unknown	San Luis Valley
Fishes	Cyprinidae	*Ctenopharyngodon idella***	grass carp	Unknown	Rio Grande drainage

*Species are not indigenous to the Rio Grande drainage, but are native to some portion of North America.

**Species are not native to North America.

Table 4.11.4 (continued). Nonindigenous aquatic animal species documented within the Rio Grande drainage (USGS NAS 2012).

Group	Family	Scientific Name	Common Name	Status	Location
Fishes	Cyprinidae	*Cyprinus carpio***	common carp	Established	Sanchez reservoir, SLV
Fishes	Cyprinidae	*Platygobio gracilis**	flathead chub	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Cyprinidae	*Tinca tinca***	tench	Established	near Monte Vista
Fishes	Esocidae	*Esox lucius**	northern pike	Established	Sanchez reservoir, SLV
Fishes	Fundulidae	*Fundulus sciadicus**	plains topminnow	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Fundulidae	*Fundulus zebrinus**	plains killifish	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Gasterosteidae	*Culaea inconstans**	brook stickleback	Established	San Luis Valley
Fishes	Ictaluridae	*Ameiurus natalis**	yellow bullhead	Established	San Luis Valley
Fishes	Ictaluridae	*Ictalurus furcatus***	blue catfish	Established	San Luis Valley
Fishes	Ictaluridae	*Ictalurus punctatus***	channel catfish	Established	San Luis Valley
Fishes	Ictaluridae	*Pylodictis olivaris***	flathead catfish	Unknown	San Luis Valley
Fishes	Loricariidae	*Hypostomus* sp.*	suckermouth catfish	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Loricariidae	*Otocinclus* sp. *	suckermouth catfish	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Loricariidae	*Pterygoplichthys disjunctivus**	vermiculated sailfin catfish	Failed/Extirpated/Eradicated	Smith Lake
Fishes	Percidae	*Perca flavescens**	yellow perch	Established	Sanchez reservoir, SLV
Fishes	Percidae	*Sander vitreus**	walleye	Established	Sanchez reservoir, SLV
Fishes	Poeciliidae	*Gambusia affinis**	western mosquitofish	Established	San Luis Valley
Fishes	Poeciliidae	*Poecilia latipinna**	sailfin molly	Established	San Luis Valley, Valley View hotsprings
Fishes	Poeciliidae	*Poecilia mexicana***	shortfin molly	Established	San Luis Valley
Fishes	Poeciliidae	*Poecilia reticulata***	guppy	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Poeciliidae	*Xiphophorus hellerii***	green swordtail	Established	San Luis Valley, Valley View hotsprings
Fishes	Poeciliidae	*Xiphophorus maculatus***	southern platyfish	Established	San Luis Valley
Fishes	Poeciliidae	*Xiphophorus variatus***	variable platyfish	Failed/Extirpated/Eradicated	San Luis Valley

*Species are not indigenous to the Rio Grande drainage, but are native to some portion of North America.

**Species are not native to North America.

Table 4.11.4 (continued). Nonindigenous aquatic animal species documented within the Rio Grande drainage (USGS NAS 2012).

Group	Family	Scientific Name	Common Name	Status	Location
Fishes	Salmonidae	*Oncorhynchus clarkii behnkei**	Snake River finespotted cutthroat trout	Established	San Luis Valley
Fishes	Salmonidae	*Oncorhynchus clarkii bouvieri**	Yellowstone cutthroat trout	Established	San Luis Valley
Fishes	Salmonidae	*Oncorhynchus clarkii lewisi**	west slope cutthroat trout	Established	Rio Grande drainage
Fishes	Salmonidae	*Oncorhynchus clarkii pleuriticus**	Colorado River cutthroat trout	Established	San Luis Valley
Fishes	Salmonidae	*Oncorhynchus clarkii x mykiss**	cutbow trout	Unknown	Rio Grande drainage
Fishes	Salmonidae	*Oncorhynchus mykiss**	rainbow trout	Established	San Luis Valley
Fishes	Salmonidae	*Oncorhynchus mykiss aguabonita**	California golden trout	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Salmonidae	*Oncorhynchus nerka**	kokanee, sockeye	Established	San Luis Valley
Fishes	Salmonidae	*Salmo salar sebago**	landlocked Atlantic salmon	Failed/Extirpated/Eradicated	Near Creede
Fishes	Salmonidae	*Salmo trutta***	brown trout	Established	San Luis Valley
Fishes	Salmonidae	*Salvelinus fontinalis**	brook trout	Established	San Luis Valley
Fishes	Salmonidae	*Salvelinus namaycush**	lake trout	Failed/Extirpated/Eradicated	San Luis Valley
Fishes	Salmonidae	*Thymallus arcticus**	Arctic grayling	Failed/Extirpated/Eradicated	San Luis Valley
Mollusks-Gastropods	Lymnaeidae	*Radix auricularia***	European ear snail	Unknown	Smith Lake, Sherman Lake at Home Lake
Mollusks-Gastropods	Thiaridae	*Melanoides tuberculate***	red-rim melania	Established	Valley View hotsprings

*Species are not indigenous to the Rio Grande drainage, but are native to some portion of North America.

**Species are not native to North America.

The overall condition assessment for invasive plants and aquatic species was determined by the procedure of selecting the lowest rank of component indicators as the condition assessment (Table 4.11.5). In the absence of detailed trend information, and after discussion with park staff, we chose to represent the this resource as stable, reflecting ongoing control and eradication efforts.

Table 4.11.5. Condition assessment interpretation for invasive/exotic species at GRSA.

Indicator	Interpretation	Condition Assessment
Presence of species with high invasive potential	A number of plant species with the potential to spread have been documented within the park and preserve, but native ecosystems are still functioning and not in immediate danger of alteration. Invasive aquatic species are absent or have been eradicated.	Warrants Moderate Concern
Presence of other non-native species	Non-native plant species are present, but not dominant in any native plant communities. Non-native aquatic species (trout) are present, but not invasive.	Warrants Moderate Concern

4.11.5 Sources of Expertise

Phyllis Pineda Bovin, NPS Biologist, GRSA provide information about weed mapping and invasive control efforts at GRSA, and reviewed this section. Susan Spackman Panjabi, CNHP Senior Botanist provided general information about Colorado noxious weeds.

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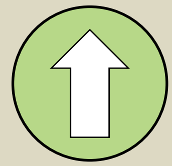
4.12 Air Quality

Indicators / Measures

- Visibility haze index
- Level of ozone
- Atmospheric wet deposition in total N and total S

Condition - Trend



4.12.1 Background and Importance

Under the Clean Air Act (CAA), the U.S. Environmental Protection Agency (EPA) sets limits on certain air pollutants, including limits on how much can be in the air anywhere in the United States. These National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) regulate pollutants that are considered harmful to human health and the environment (US EPA 2012). The CAA also establishes requirements for the prevention of significant deterioration of air quality, in order that areas where air quality is currently better than required by NAAQS can be protected from significant new air pollution, even if NAAQS would not be exceeded by such. The National Park Service Air Resources Division (NPS-ARD) air monitoring protocols incorporate the EPA's NAAQS natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition. These three factors were used as indicators for this assessment.

Visibility is "the greatest distance at which an observer can just see a black object viewed against the horizon sky" (Malm 1999). Air pollution can significantly degrade visibility, reducing the color and detail in park landscape views and negatively affecting visitor experience. Both fine particulates (e.g., soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility.

Ozone is a gaseous product of the reaction of nitrogen oxides (NO_x) and volatile organic compounds in the presence of sunlight. It is one of the most widespread pollutants affecting vegetation and public health in the U.S. (NPS-ARD 2013a). Ozone is not only harmful to human health, but can also affect vegetation. Some plants are highly sensitive to ozone damage, which occurs when ozone penetrates plants and oxidizes plant tissue. Over time ozone damage may change species composition as ozone-sensitive species are replaced by tolerant species (NPS-ARD 2013b).

Atmospheric deposition (air pollutants deposited to ecosystems) occurs in both wet deposition through rain, snow, cloud or fog and as dry deposition via dust and gases. Atmospheric nitrogen and sulfur deposition can change water chemistry and thereby impact aquatic vegetation, invertebrate communities, amphibians, and fish. Effects are not limited to aquatic systems; chemical changes in soils from deposition may also affect soil microorganisms, plants, and trees. Nitrogen deposition can alter the composition of vegetation communities, favoring some plant species and inhibiting the growth of others (NPS-ARD 2013c).

Although GRSA is located in a sparsely populated area, it is downwind of many pollution sources. Risk assessments concluded that ecosystems within GRSA are at very high risk from nutrient enrichment (Sullivan et al. 2011a and b), and at high risk from acidification (Sullivan et al. 2011c and d). High elevation ecosystems in the preserve are particularly sensitive to nitrogen and sulfur deposition, and receive more deposition than lower elevations due to greater amounts of snow and rain. At higher elevations, the short growing season and shallow soils limit the capacity of soils and plants to buffer or absorb sulfur and nitrogen. High elevation lakes at GRSA (Figure 4.12.1) are especially sensitive to acidification from sulfur and nitrogen deposition and excess nitrogen enrichment, although lakes at GRSA were predicted to have more buffering capacity than high elevation lakes in Rocky Mountain and Grand Teton national parks (Nanus et al. 2009). Alpine plant communities can be especially vulnerable to changes in species balance due to nitrogen enrichment.

Figure 4.12.1. Upper Sand Creek Lake. Photo credit: CNHP.

4.12.2. Data and Methods

We followed the guidance provided by NPS-ARD for evaluating air quality in a Natural Resource Condition Assessment (NPS-ARD 2011). Interpolated air quality datasets were obtained from the

NPS Air Quality Estimates website (NPS-ARD 2012). Available data included annual statistics for visibility, ozone, and atmospheric wet deposition calculated from data collected at each monitor location and averaged over five years to derive the five-year average statistic. Because GRSA is a Class 1 area, additional information was available from Colorado's state implementation plan for regional haze (CDPHE 2011).

Visibility is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. Representative monitoring data collected from the IMPROVE visibility monitoring network was used to establish baseline conditions (for the 2000-2004 period) for GRSA. As required under the Regional Haze Rule, baseline visibility conditions, as well as progress goals and changes in visibility are expressed in terms of deciview (dv) units. The deciview is a unit of measurement of haze, implemented in a haze index that is derived from calculated light extinction, and that is designed so that uniform changes in haziness correspond approximately to uniform incremental changes in perception, across the entire range of conditions, from pristine to highly impaired (US EPA 2003). Under ideal visibility conditions, where the only impairment is from natural Rayleigh light scatter, maximum standard visual range would be about 243 miles, or 391 km (US EPA 1999).

Monitoring photographs show how air pollutants affect visibility at GRSA (Figure 4.12.2). Although there are some exceptionally clear days at GRSA (a), average natural visibility is around 100 miles (160 km) due to pollution (b), and on poor visibility days, the visual range can be reduced to less than 35 miles, or 56 km (c).

Figure 4.12.2. Visibility spectrum at GRSA (a) dv = 1, VR (km) = 340; (b) dv = 10, VR (km) = 150; (c) dv = 21, VR (km) = 50 (IMPROVE 2006).

Information about ozone indicator species was obtained from the USDA Forest Service Forest Inventory and Analysis National Program (USFS 2007).

In 2005, GRSA received a limited assessment of airborne contaminants as a secondary park in the Western Airborne Contaminants Assessment Project, which examined concentrations and biological effects of airborne contaminants (Landers et al. 2008). The project made a baseline inventory of semi-volatile organic compounds (SOCs), metals, and nutrient contaminants across various ecosystem components. At GRSA, lichens and conifer needles were sampled to measure food-web bioaccumulation of nitrogen, sulfur, mercury, and other metals. Airborne exposure of SOCs was estimated by a passive air sampling device. GRSA was among the parks with the highest SOC concentrations in vegetation (especially lichens), primarily due to current-use pesticide residues.

4.12.3. Reference Conditions

Visibility

Natural visibility, or conditions that would be found in the absence of human-caused impairment is the long-term reference condition for visibility goals of regional haze plans. The natural visibility for GRSA is 1.24 dv for the 20% best days and 6.7 dv for the 20% worst days. The long-term natural regional haze plan visibility goal for 2064 is represented by the latter number (CDPHE 2007). The reference conditions for visibility used in this assessment (Table 4.12.1). are based on the departure of average conditions from the estimated natural conditions NPS-ARD (2013d). Conditions for visibility are based on five-year average visibility minus estimated average natural visibility, where average visibility is the mean of visibility between 40th and 60th percentiles. Interpolated five-year averages are used within the contiguous U.S. (NPS-ARD 2013d).

Table 4.12.1 Reference conditions for air quality indicators.

Condition Assessment	Visibility (dv = Average visibility – estimated avg. natural conditions)	Ozone Concentration	Wet Deposition (total N and total S)
Resource in good condition	< 2 dv	≤ 60 ppb	< 1 kg/ha/yr
Warrants moderate concern	2-8 dv	61-75 ppb	1-3 kg/ha/yr
Warrants significant concern	>8 dv	≥ 76 ppb	>3 kg/ha/yr

Ozone

Ozone reference conditions are based on the US EPA ozone standard which stipulates that the three-year average of the fourth-highest daily maximum eight-hour average ozone concentrations measured at each monitoring location in an area must not exceed 75 parts per billion (ppb) for compliance. For parks within the contiguous U.S., NPS-ARD reference conditions (Table 4.12.1) are based on estimates of ozone condition from the interpolation of the five-year averages of the fourth-highest daily maximum eight-hour ozone concentration (NPS-ARD 2013d).

Wet Deposition

Reference conditions specified by NPS-ARD for atmospheric deposition (Table 4.12.1) are based on wet deposition only, due to the lack of dry deposition information for most areas. Wet deposition for GRSA is calculated by multiplying nitrogen or sulfur concentrations in precipitation by a normalized precipitation amount (NPS-ARD 2013d).

4.12.4. Condition and Trend

Air quality indicator data for five consecutive five-year average estimates (Table 4.12.2) were available. We followed the methods for determining air quality conditions and trends given in NPS-ARD (2013d). Estimates for ozone, wet deposition, and visibility are given, along with their assigned condition categories according to criteria in Table 4.12.1.

Visibility

All five-year average values for visibility condition at GRSA fell within the moderate condition assessment, indicating that visibility is degraded from the good reference condition of <2 dv above the natural condition. However, the overall trend of visibility for GRSA during the period 1989-2008 showed a significant improving trend (NPS-ARD 2010). There are no adjustments for visibility condition, therefore this category remains *Warrants Moderate Concern*.

Table 4.12.2. Condition results for air quality indicators at GRSA.

Data Range	Visibility (dv)	Ozone (ppb)	Total N (kg/ha/yr)	Total S (kg/ha/yr)
2001-2005	2.7 (moderate)	72.1 (moderate)	1.00 (moderate)	0.45 (good)
2003-2007	4.0 (moderate)	71.5 (moderate)	0.96 (good)	0.45 (good)
2004-2008	4.0 (moderate)	71.4 (moderate)	1.05 (moderate)	0.48 (good)
2005-2009	4.0 (moderate)	72.2 (moderate)	0.9 (good)	0.4 (good)
2006-2010	3.8 (moderate)	71.3 (moderate)	0.9 (good)	0.4 (good)

Ozone

All five-year average values for ozone levels at GRSA fell within the moderate condition assessment, with an essentially stable trend (Table 4.12.2).

Eight plant species found within GRSA have been identified as ozone-sensitive (Table 4.12.3), and all are appropriate for use as bioindicator species in the event of increased foliar ozone damage risk in the future (Kohut 2007). Sensitive species are those that typically exhibit foliar injury at or near ambient ozone concentrations in controlled conditions and/or are species for which ozone foliar injury symptoms have been documented in the field by more than one expert observer. A species must meet all or most of the following criteria in order to be considered a bioindicator for ozone injury (NPS-ARD 2006):

- species exhibits foliar symptoms in the field at ambient ozone concentrations that can be easily recognized as ozone injury by subject-matter experts
- species ozone sensitivity has been confirmed at realistic ozone concentrations in exposure chambers
- species are widely distributed regionally
- species are easily identified in the field

Table 4.12.3. Ozone sensitive bioindicator species known to occur within GRSA.

Scientific Name	Common Name
Amelanchier alnifolia	Saskatoon serviceberry
Apocynum androsaemifolium	spreading dogbane
Oenothera elata	evening primrose

Table 4.12.3 (continued). Ozone sensitive bioindicator species known to occur within GRSA.

Scientific Name	Common Name
Pinus ponderosa	ponderosa pine
Populus tremuloides	quaking aspen
Rhus trilobata	Skunkbush
Rudbeckia laciniata	cut-leaf coneflower
Salix scouleriana	Scouler's willow

An example of foliar damage from ozone on quaking aspen is shown in Figure 4.12.3. Plants in the park and preserve have not been assessed for ozone injury, but a risk assessment concluded that the risk of plant injury from ozone was low at the park and preserve based on the fact that exposure levels were relatively low (Kohut 2007). If parks were evaluated in Kohut (2007) as at high risk for ozone injury to vegetation, the condition category is adjusted to the next worse condition category. GRSA was evaluated as being at low risk, and retains a *Warrants Moderate Concern* rating for ozone levels.

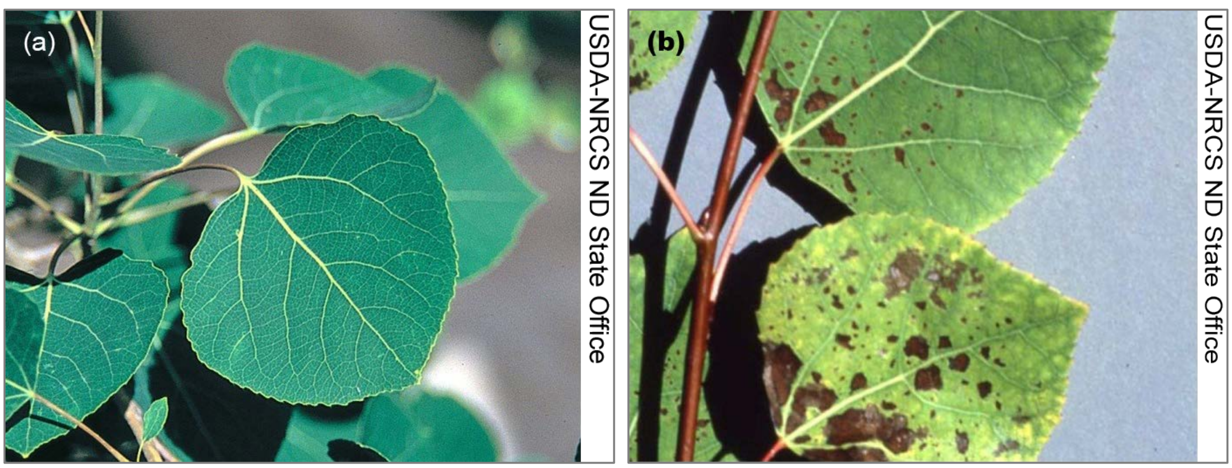


Figure 4.12.3. Quaking aspen (*Populus tremuloides*), healthy leaves (a), and ozone-damaged leaves (b).

<u>Wet Deposition</u>

Five-year average values for total N at GRSA were generally good or close to the good condition assessment, with a slight improving trend, while total S values were all in the good category (Table 4.12.2). Methods outlined in NPS-ARD (2013d) call for the overall wet deposition condition to be determined by which of the two measures (Total N and Total S) have the ranking of most concern. Thus, for the period 2004-2008, the ranking would have been *Warrants Moderate Concern*. Improvements in the Total N category over the next two reporting periods would now allow this category to be ranked *Resource is in Good Condition*. However, the presence and extent of sensitive vegetation types and number of high-elevation lakes within the park and preserve give it a high sensitivity rating relative to acidification effects and nutrient enrichment effects from atmospheric deposition. Under these circumstances the condition category is adjusted to the next worse condition category. GRSA was determined to have a very high ecosystem sensitivity ranking for nutrient enrichment (Sullivan et al. 2011a and b), so its *Resource is in Good Condition* assessment is adjusted to *Warrants Moderate Concern* for deposition.

In the period 2001-2010, wet deposition levels in GRSA have decreased slightly or remained essentially stable. Furthermore, sulfur and nitrogen wet-deposition levels have changed over the past 25+ years throughout the United States (Figure 4.12.4). The implementation of Title IV of the Clean Air Act has substantially reduced emissions of SO_2 and NO_x from power plants (the primary source of these pollutants). In addition, emissions from other sources have also decreased (NAPAP 2011), supporting a trend of slight decrease or stability.

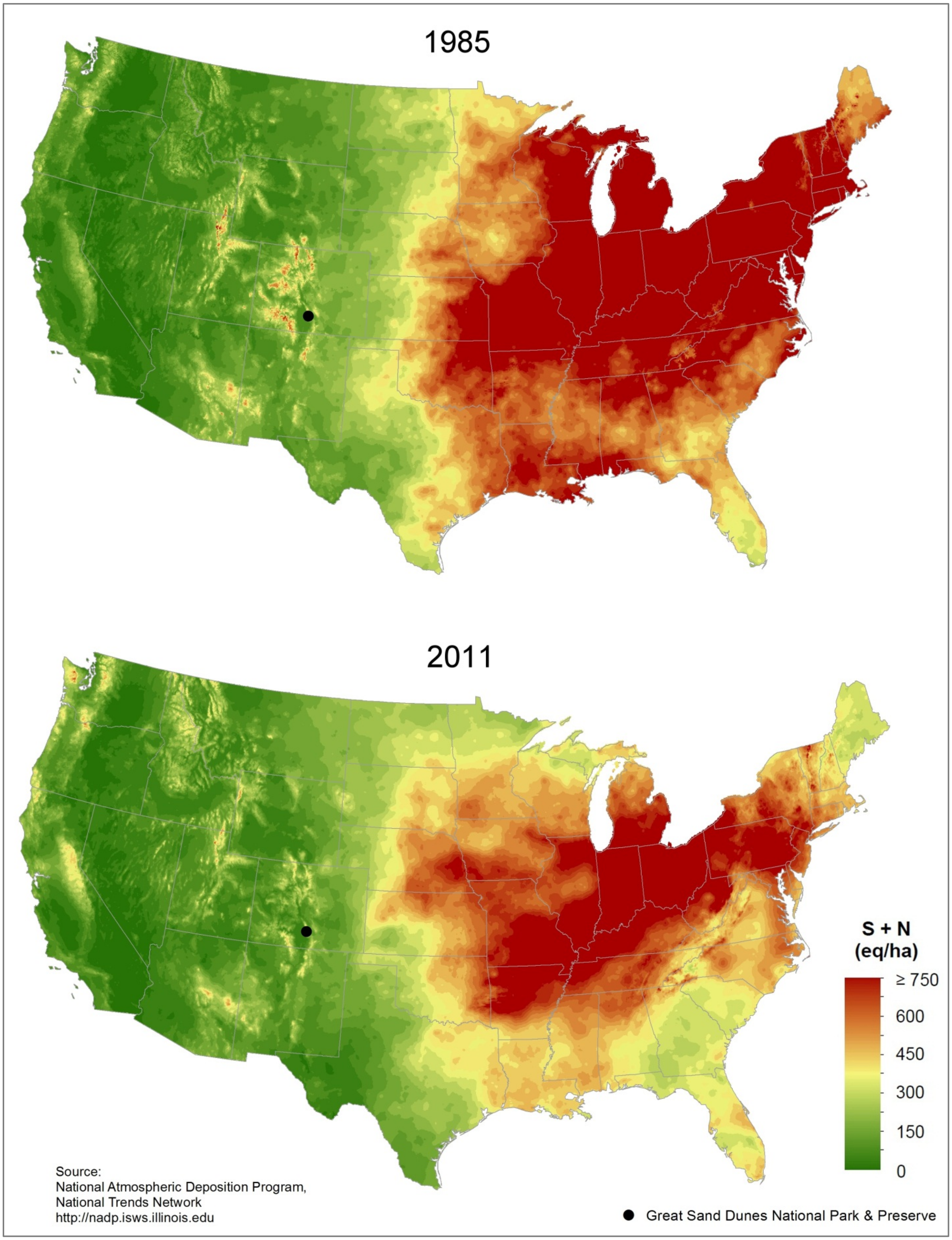


Figure 4.12.4. Change in total sulfur and nitrogen wet deposition between 1985 and 2011 (NADP 2013).

Overall Condition and Trend

The three main indicators are averaged to produce an overall air quality condition. Each indicator in the *Warrants Significant Concern* category is assigned nine points, each indicator in the *Warrants Moderate Concern* category is assigned five points, and each indicator in the *Resource is in Good Condition* category is assigned one point. The points for ozone, wet deposition, and visibility are averaged, and the resulting value is compared to the scale below to determine overall air quality condition (NPS-ARD 2013d).

Overall Air Quality Trend Assessment		
Score 1 to ≤ 3	**Score > 3 to ≤ 6**	**Score > 6 to 9**
Resource in Good Condition	Warrants Moderate Concern	Warrants Significant Concern

Because all three indicators are scored as *Warrants Moderate Concern*, GRSA receives an overall condition score of 5, in the *Warrants Moderate Concern* category. Good trend information was only available for visibility, which was improving (NPS-ARD 2010). Because local trends were not available for the other two indicators, this constitutes uncertainty in the assessment, and, based on the information for the five-year averages we chose to represent the trend as stable.

4.12.5. Sources of Expertise

Data were provided by the National Park Service's Air Resources Division, which oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units and provide air quality analysis and expertise related to all air quality topics.

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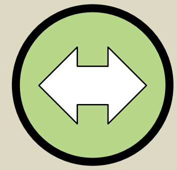
4.13 Natural Lightscapes

Indicators / Measures

- Bortle Dark-Sky Scale
- Limiting magnitude
- Sky brightness (SQM)
- Anthropogenic Light Ratio (ALR)

Condition – Trend



4.13.1 Background and Importance

Resources and values that exist in the absence of human-caused light at night are organized under the term "natural lightscapes" by the NPS. National parks are generally managed to preserve park resources and values, including natural visibility, both in daytime and at night (NPS 2006). The introduction of artificial light, either directly or indirectly, into the natural environment results in light pollution. Two forms of light pollution affect our perception of the world at night: sky glow is the brightening of the night sky due to light scattered in the atmosphere from anthropogenic sources, while glare is the direct shine of a light (NPS 2012). Light pollution due to glare is most pronounced in urban and developed areas. The scattered light of sky glare produces a widespread brightening of the night sky, reducing contrast, and making it difficult or impossible to see stars and faint objects. In remote or otherwise dark areas, as the eye adapts to the ambient light level with increased sensitivity, visual impacts from light pollution may be perceived at long distances, impeding visibility for park visitors (NPS 2012).

Most species rely on natural patterns of light and dark for navigation, to cue behaviors, or hide from predators. Artificial night lighting has been shown to have physiological and behavioral consequences for a variety of taxonomic groups, including mammals, birds, insects, fish, reptiles, and amphibians (Rich and Longcore 2006, Hölker et al. 2010). Plants are also affected by artificial lighting, but the consequences of light pollution to this taxonomic group are largely unknown (Briggs 2006). Furthermore, a substantial proportion of species, estimated by Hölker et al. (2010) as 30% of all vertebrates and > 60% of all invertebrates, are nocturnal, and adapted to dark habitats.

Night sky conditions at GRSA were assessed using both qualitative and quantitative indicators and measures. Qualitative indicators are Bortle Dark Sky score, limiting magnitude, and sky brightness. Anthropogenic light ratio (ALR) was used as a quantitative indicator.

4.13.2 Data and Methods

A baseline assessment was conducted at GRSA on November 20, 2006 at a single location near the southern boundary of the park. An assessment using improved methodology was conducted in 2012. Data were collected at Alpine Camp in the northwest portion of the park (October 15, 2012), and at the Medano Ranch Road on the south side of the park (October 16, 2012). Due to the change in methods between the two assessments, real trend data are not available.

The Bortle Dark Sky Scale was proposed by John Bortle (Bortle 2001) based on 50 years of astronomical observations. Bortle's qualitative approach uses a nine-class scale that requires no special equipment and only a basic knowledge of the night sky (Bortle 2001, Moore 2001). The Bortle scale uses both stellar objects and familiar descriptors to distinguish among the different classes, and covers conditions ranging from the darkest skies to the brightest urban areas (Table 4.13.1).

Table 4.13.1. Bortle Dark-Sky Scale*

Bortle Scale	LM	Milky Way (MW)	Astronomical Objects	Zodiacal Constellations	Airglow and Clouds	Nighttime Scene
Class 1 Excellent Dark Sky Site	>7.6	MW shows great detail, and appears 40° wide in some parts; Scorpio-Sagittarius region casts an obvious shadow	Spiral galaxies (M33 and M81) are obvious objects; the Helix nebula is visible with the naked eye	Zodiacal light is striking as a complete band, and can stretch across entire sky	The horizon is completely free of light domes, very low airglow	Jupiter and Venus annoy night vision, ground objects are barely lit, trees and hills are dark
Class 2 Typical Truly Dark Site	7.1-7.5	MW shows great detail and casts barely visible shadows	The rift in Cygnus star cloud is visible; the Prancing Horse in Sagittarius and Fingers of Ophiuchus dark nebulae are visible, extending to Antares	Zodiacal band and gegenschein are visible	Very few light domes are visible, with none above 5° and fainter than the MW; airglow may be weakly apparent, and clouds still appear as dark voids	Ground is mostly dark, but objects projecting into the sky are discernible
Class 3 Rural Sky	6.6-7.0	MW still appears complex; dark voids and bright patches and a meandering outline are visible	Brightest globular clusters are distinct, pinwheel galaxy visible with averted vision	Zodiacal light is easily seen, but band of gegenschein is difficult to see or absent	Airglow is not visible, and clouds are faintly illuminated except at zenith	Some light domes evident along horizon, ground objects are vaguely apparent
Class 4 Rural - Suburban Transition	6.1-6.5	MW is evident from horizon to horizon, but fine details are lost	Pinwheel galaxy is a difficult object to see; deep sky objects such as M13 globular cluster, Northern Coalsack dark nebula, and Andromeda galaxy are visible	Zodiacal light is evident, but extends less than 45° after dusk	Clouds are just brighter than the sky, but appear dark at zenith	Light domes are evident in several directions (up to 15° above the horizon), sky is noticeably brighter than terrain
Class 5 Suburban Sky	5.6-6.0	MW is faintly present, but may have gaps	The oval of Andromeda galaxy is detectable, as is the glow in the Orion nebula, Great rift in Cygnus	Only hints of zodiacal light may be glimpsed	Clouds are noticeably brighter than sky	Light domes are obvious to casual observers, ground objects are easily seen

*Also incorporates the Bortle Dark-Sky Scale Key for the Summer Sky for Latitudes 30° to 50° N, White et al. (2012).

Table 4.13.1 (continued). Bortle Dark-Sky Scale*

Bortle Scale	LM	Milky Way (MW)	Astronomical Objects	Zodiacal Constellations	Airglow and Clouds	Nighttime Scene
Class 6 Bright Suburban Sky	5.1-5.5	MW only apparent overhead, and appears broken as fainter parts are lost to sky glow	Cygnus, Scutum, and Sagittarius star fields just visible	Zodiacal light is not visible; constellations are seen, and not lost against a starry sky	Clouds appear illuminated and reflect light	Sky from horizon to 35° glows with grayish color, ground is well lit
Class 7 Suburban-Urban	4.6-5.0	MW may be just barely seen near the zenith	Andromeda galaxy (M31) and Beehive cluster (M44) are rarely glimpsed	Zodiacal light is not visible, and brighter constellations are easily seen	Clouds are brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color
Class 8 City Sky	4.0-4.5	MW not visible	Pleiades are easily seen, but few other objects are visible	Zodiacal light not visible, constellations are visible but lack key stars	Clouds are brilliantly lit	Entire sky background has uniform washed out glow, with light domes reaching 60° above the horizon
Class 9 Inner City Sky	<4.0	MW not visible	Only the Pleiades are visible to all but the most experienced observers	Only the brightest constellations are discernible	Clouds are brilliantly lit	Entire sky background has a bright glow, ground is illuminated

*Also incorporates the Bortle Dark-Sky Scale Key for the Summer Sky for Latitudes 30° to 50° N, White et al. (2012).

Limiting magnitude (LM) is a qualitative measurement of the brightness of the faintest stars visible to the naked eye (Bortle 2001), and like the Bortle Scale, is easily used by amateur astronomers with no special equipment. The method estimates brightness by using star counts of 25 reference sample areas with mapped stars having known brightness values (Moore 2001).

The quantitative indicators and measures used to assess the park's night sky condition are based on methodology that uses images from a wide-field CCD camera (Duriscoe et al. 2007). The data reported for GRSA quantitative indicator/measures were collected by the NPS Natural Sounds and Night Skies Division (NSNSD). The goals in measuring night sky brightness are to describe the quality of the nighttime environment, quantify how much it deviates from natural conditions, and track how it changes with time due to changes in natural conditions, as well as artificial lighting in areas within and outside of the national parks (Duriscoe et al. 2007). Night sky data were collected from two locations.

The suggested quantitative parameter for evaluating the condition of a nightsky is the amount of anthropogenic light averaged over the entire sky, measured in human visual spectrum (Moore et al. 2013). This parameter is expressed as a ratio of anthropogenic to natural light, known as the Anthropogenic Light Ratio (ALR). The average anthropogenic light is calculated by removing the natural light night sky component from the total observed sky brightness. A natural night sky has an average brightness across the entire sky of 78 nL (nanoLamberts, a measure of luminance), due to components such as the Milky Way, zodiacal light, airglow, and other starlight. Consequently, a ratio of 0.0 indicates pristine natural conditions where the anthropogenic component was 0 nL and natural component was 78 nL. A ratio of 1.0 indicates that anthropogenic light is equivalent to the natural light from the night sky, that is, an anthropogenic component of 78 nL and natural component of 78 nL (Moore et al. 2013). A synthetic Sky Quality Meter score was also generated from the data.

4.13.3 Reference Conditions

An ideal night sky reference condition would be the absence of any light pollution. However, results from night sky data collection throughout more than 100 national parks suggest that light pollution is present to some extent in most areas (NPS 2012). We used interim guidance thresholds for night sky quality (Moore et al. 2013) as reference conditions.

Bortle Dark-Sky Scale, Limiting Magnitude, and SQM

A night sky with a Bortle Dark-Sky Scale class 1, or a corresponding limiting magnitude >7.6 is considered in the best possible condition (Bortle 2001). Such conditions are now so rare that few people have ever experienced them (Moore 2001). For NPS units having significant natural resources, including GRSA, a Bortle Class of 1-3 indicates good night sky condition (Table 4.13.2). Scores of Class 5 and or above are of degraded quality that may introduce ecological disruption and are considered to be of significant concern. Likewise, a limiting magnitude value above 6.8 is indicative of good condition, and a LM score of less than 6.2 is of significant concern.

Preliminary suggestions for sky brightness metrics were proposed in Duriscoe et al. (2007), and the NSNSD generates synthetic SQM measurements from the all-sky data collected under current methods (Jeremy White, Physical Scientist, NPS-NSNSD, personal communication). Reference conditions for night sky brightness at a site can vary somewhat based on a variety of factors, including the time of night, terrain features, moon phase, position of the Milky Way, atmospheric aerosols, and solar activity (Duriscoe et al. 2007). SQM values of 21.6 are generally considered to represent natural (unpolluted) conditions (Moore et al. 2013, Table 4.13.2).

Table 4.13.2. Functional impacts of condition determinations (Moore et al. 2013).

Condition Assessment	Bortle Class	Typical Limiting Magnitude	Synthetic Sky Quality Meter
Resource in Good Condition	Bortle Class 1-3	6.8-7.6	21.60
Warrants Moderate Concern	Bortle Class 4	6.3-6.7	21.20-21.59
Warrants Significant Concern	Bortle Class 5-9	<6.2	<21.20

Anthropogenic Light Ratio (ALR)

The threshold levels for ALR were developed by NSNSD as part of the State of the Parks Program, and are used here as interim guidance (Moore et al. 2013). The ALR is intended to be applied spatially across an entire park (Table 4.13.3). For the ALR, light flux is totaled above the horizon (the terrain is omitted)and the anthropogenic and natural components are expressed as a unitless ratio.

Table 4.13.3. ALR thresholds for Level 1 Parks and Wilderness Areas.

Condition Assessment	**Threshold for Level 1 Parks** *At least half of park area should meet this criteria* **Additional Threshold for Areas Managed as Wilderness** *At least 90% of wilderness area should meet this criteria*
Resource in Good Condition	ALR < 0.33 (<26 nL average anthropogenic light in sky)
Warrants Moderate Concern	ALR 0.33–2.00 (26–156 nL average anthropogenic light in sky)
Warrants Significant Concern	ALR > 2.00 (>156 nL average anthropogenic light in sky)

4.13.4 Condition and Trend

Bortle Dark-Sky Scale, Limiting Magnitude, and SQM

The Bortle Scale assessment was Class 3 at both sites, indicating moderate quality, equivalent to a rural sky. The limiting magnitude estimation was 6.9 at both sites, which is comparable to the Class 3 Bortle Scale score. These two scores indicate a *Resource in Good Condition* assessment. The synthetic SQM measure at the Alpine Camp site was 21.27, and the Medano Ranch Road site was slightly brighter at 21.18. These scores are in the *Warrants Moderate Concern* range. Overall, the human experience at GRSA would be one of being in a natural environment where natural features of the night sky are readily visible, and there is negligible impact to visual adaptation to dark conditions.

Anthropogenic Light Ratio (ALR)

NSNSD data collected at the two sites resulted in an ALR score of 0.2, representing conditions 20% brighter than natural. This score is well under the threshold level for a *Resource in Good Condition* assessment.

With only a single indicator falling in the *Warrants Moderate Concern* range, and from the overall character of the night sky (Figure 4.13.1), it is clear that GRSA night sky conditions are in good condition (Table 4.13.4). At the recommendation of NSNSD staff we used the ALR score to determine the overall rank (Table 4.13.4).

GRSA is located on the east side of the San Luis Valley, about 25 miles northeast of Alamosa. Alamosa is the largest municipality within the valley, and its light dome is visible near the center of the sky panoramas. Due to the flatness of the San Luis Valley, smaller towns of Monte Vista, Del Norte, Center, and Crestone are also visible from some higher elevations of GRSA, as are highways and rural lights for many miles around. Lighting within the park is concentrated in the area around the visitor center and Pinyon Flats Campground.

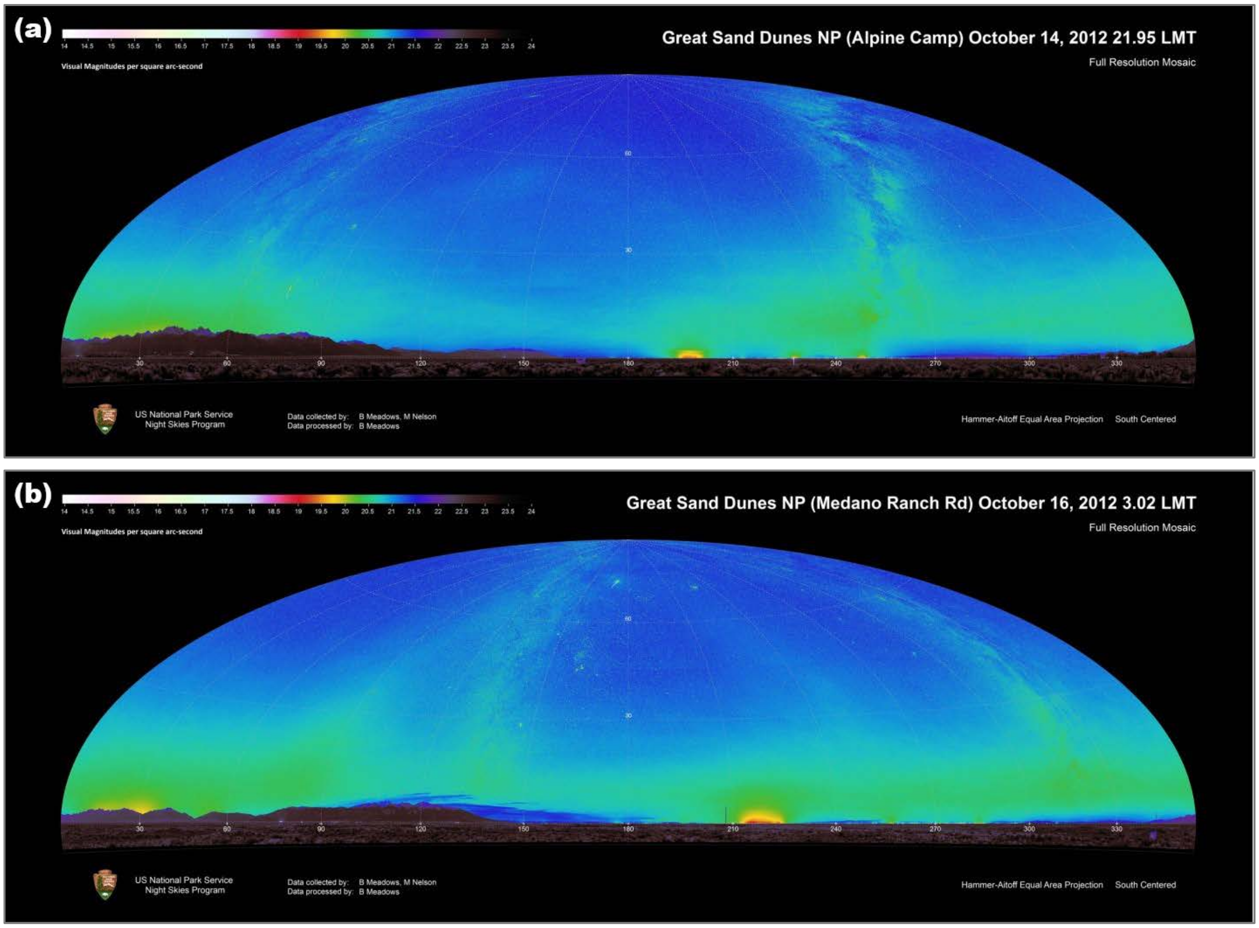


Figure 4.13.1. All-sky panoramas at GRSA. Alpine Camp site (a), and Medano Ranch Road (b). South is at the center of the image.

Table 4.13.4. Summary of condition assessments for night sky.

Indicator	Interpretation	Condition Assessment
Bortle Class	Class 3 score indicates quality equivalent to a rural sky	Resource is in Good Condition
Typical Limiting Magnitude	LM score of 6.9 corresponds to Bortle Class 3	Resource is in Good Condition
Synthetic Sky Quality Meter	Readings of 21.20-21.59 indicate some degradation.	Resource Warrants Moderate Concern
ALR	A score of 0.2, representing conditions 20% brighter than natural, is well under the threshold for a good condition assessment.	Resource is in Good Condition
	Overall Condition Assessment (ALR):	**Resource is in Good Condition**

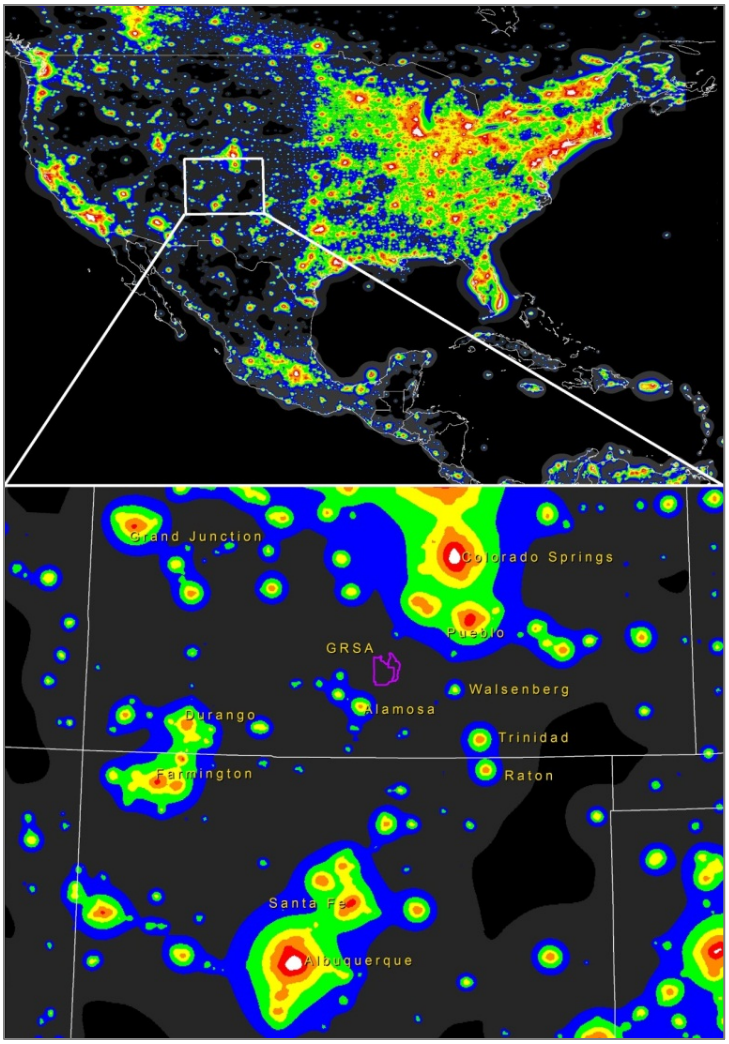


Figure 4.13.2. Artificial brightness in North America and the vicinity of GRSA (Cinzano et al. 2001).

Although GRSA is situated within a largely light free zone, it lies between the large southern Front Range cities of Colorado Springs and Pueblo, and Albuquerque, the primary population center of New Mexico (Figure 4.13.2). These larger distant cities contribute to visible light domes in the northeast, on the left portion of the panoramas. The lack of real trend information is an element of uncertainty in the assessment. Based on discussion with NSNSD staff, we chose to represent conditions as stable until additional information is available.

4.13.5 Sources of Expertise

Information, data, and standards developed by the NPS Natural Sounds and Night Skies Division (NSNSD) were provided by Chad Moore and Jeremy White of the Night Skies Team. Team scientists measure, restore, and promote the proper management of the night sky resource for U.S. national parks.

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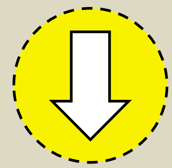
4.14 Soundscapes and Acoustic Resources

Indicators / Measures

- Day/Night median dBA
- Percent of time aircraft and other extrinsic noise audible
- Percent of time sound levels exceed thresholds.

Condition – Trend



4.14.1 Background and Importance

Although the management policies currently refer to the term soundscape as the aggregate of all natural sounds that occur in a park, differences exist between the physical sound sources and human perceptions of those sound sources. The physical sound resources (i.e., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location are referred to as the acoustic environment, while the human perception of that acoustic environment is defined as the soundscape. Clarifying this distinction will allow managers to create objectives for safeguarding both the acoustic environment and the visitor experience. Although humans don't require natural quiet for survival, park visitors prefer sounds of nature and natural quiet while visiting parks. A 2002 visitor study indicated that noise and lack of solitude were two of the most common elements detracting from visitors' experience (Le and Littlejohn 2003). During a broader national park study, 72% of visitors said that one of the most important reasons for preserving national parks is to provide opportunities to experience natural peace and the sounds of nature (Haas and Wakefield 1998). The presence of other, human-produced sounds within the soundscape degrade a person's ability to detect the natural sounds, and are considered undesirable.

The ability to produce and detect sound is crucial to most wildlife species, and anthropogenic sounds can disrupt this essential communication (Barber et al. 2010). Although different species have varying reactions to noise and other human disturbance, some documented responses of wildlife to noise include increased heart rate in elk, antelope, and Rocky Mountain bighorn sheep (NPS 1994, Weisenberger et al. 1996); altered movement and activity patterns of mountain sheep (Bleich et al. 1994); reduced hunting effectiveness of bats (Siemers and Schaub 2010); and changes in the density and composition of avian communities (Bayne et al. 2008, Francis et al. 2009). Furthermore, noise pollution can also influence the composition of plant communities via its effects of animal pollinators and seed dispersers (Francis et al. 2012).

Sound also plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USDA 1992, Anderssen et al. 1993, NPS 1994,).

Sound intensity and pressure levels are typically measured in the logarithmic decibel scale. Consequently, a 3 dB increase in sound pressure level is a doubling of sound energy. In addition, a 6 dB increase in ambient level at a particular frequency would effectively reduce the detection distance for sounds in that frequency by half for both wildlife and park visitors. Common dB levels are shown in Table 4.14.1 for comparison. A-weighted decibels (herein abbreviated dBA) are adjusted to reflect the relative loudness of sounds in air as perceived by the human ear. The A-weighted decibel values of sounds at low frequencies are reduced to compensate for the fact that the human ear is less sensitive at low audio frequencies.

Indicators for the condition of natural soundscapes at GRSA are:

- Median day and night existing ambient (median dBA), and comparison with estimated natural ambient.
- Percent of time aircraft and other extrinsic noise are audible.
- Percent of time sound levels exceed thresholds.

Table 4.14.1. Comparative examples of noise level of common sounds (NIDCD 2007).

Noise Level (dB)	Sound	Effect
130	Jet takeoff (100-200 ft.)	Threshold of pain begins around 125 dB
120	Thunderclap (near)	Regular exposure to levels over 100 dB for >1 min. risks permanent hearing loss.
110	Chain saw, jackhammer	
100	Garbage truck, cement mixer	
90	Power lawnmower	Hearing damage begins at 85 dB (8 hrs.)
80	Garbage disposal, dishwasher	Annoying; interferes with conversation
70	Vacuum cleaner, hair dryer	Intrusive
60	Normal public conversation	Comfortable hearing level is under 60 dB
50	Quiet conversation	
40	Refrigerator running	
30	Whisper	Very quiet
20	Rustling leaves	
10	Normal breathing	Barely audible

4.14.2 Data and Methods

Acoustical monitoring data were collected from September 24-October 10, 2008 near the northwest corner of GRSA (Figure 4.14.1), and analyzed to identify audible sound sources, as well as the percent of time sounds were above particular levels (Lynch 2008). The total percent time extrinsic sounds were audible was used to calculate the natural ambient sound level.

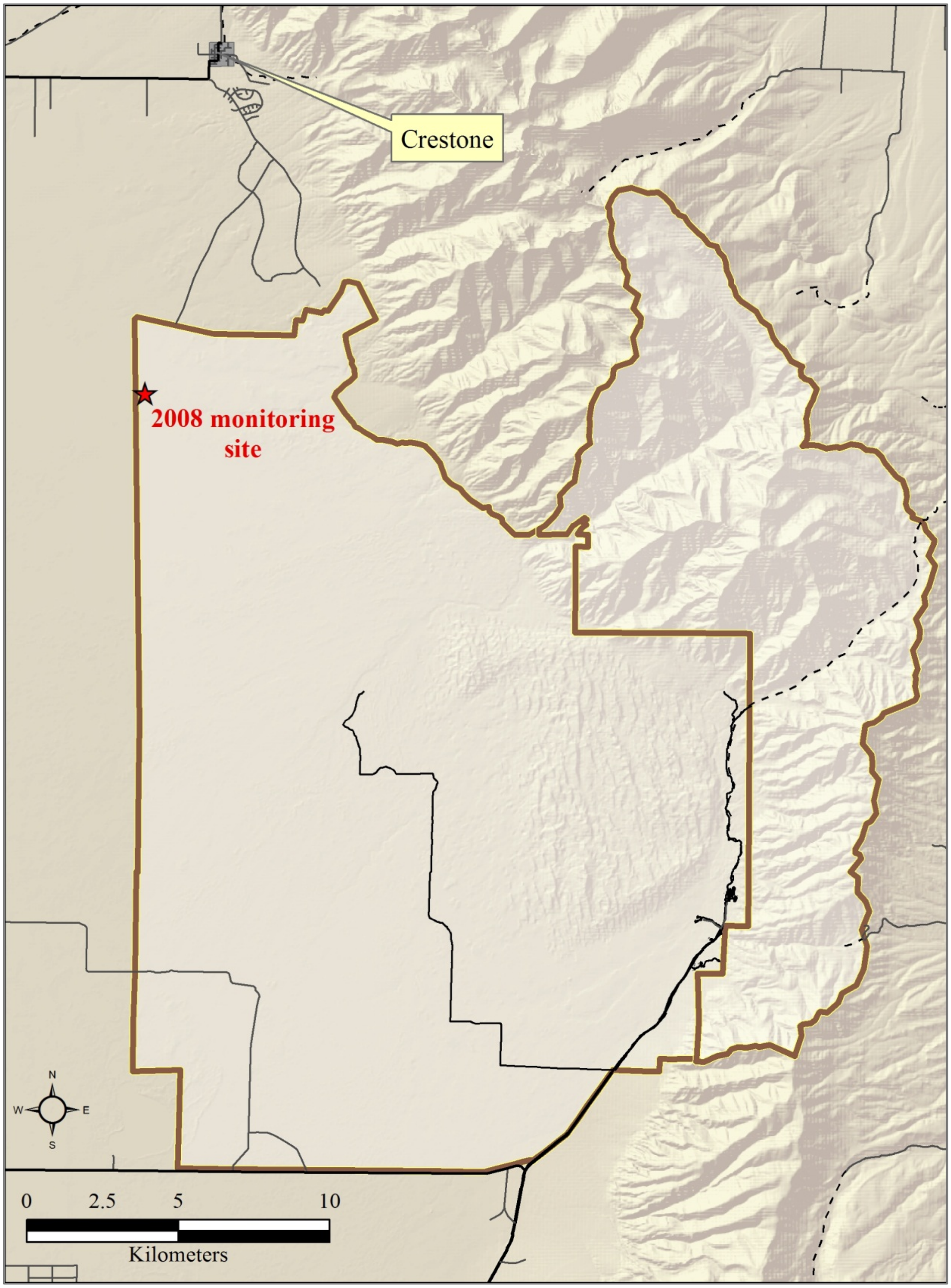


Figure 4.14.1. Location of acoustic monitoring site at GRSA.

Existing ambient sound level encompasses all sound sources, while natural ambient sound level is an estimate that attempts to remove the sound energy attributed to all extrinsic or anthropogenic noises from the existing ambient. In addition to reporting on the current acoustical levels, the percent of time when sound levels exceeded four key thresholds was recorded. Thresholds were 35 dBA (levels that can have adverse health effects); 45 dBA (maximum recommended for sleeping); 52 dBA, (speech interference for public speaking, i.e., interpretive programs); and 60 dBA (limit for normal voice communications at close range). Finally, the percentage of time that extrinsic sounds (aircraft, vehicle noise, etc.) were audible was documented. Additional details are available in Lynch (2008).

4.14.3 Reference Conditions

The natural ambient sound level (the environment of sound that exists in the absence of human-caused noise) would be considered as the reference condition for areas within the park and preserve. Until information for other areas within GRSA is available, we summarize the results of the 2008 single-location monitoring in a general way (Table 4.14.2). Results for this site are likely to be similar to those in other remote areas of the park and preserve. Trend information is not available.

Table 4.14.2. Reference conditions used to evaluate soundscape at GRSA.

Condition Assessment	Description
Resource is in Good Condition	Natural sounds are predominant in the wilderness and backcountry adventure management zones. Noises in the frontcountry zone are mostly appropriate for that area. Inappropriate noises, if they occur are short in duration and very infrequent. Noise levels that interfere with wildlife behavior or auditory signals are infrequent to rare.
Warrants Moderate Concern	Natural sounds dominate the wilderness and backcountry adventure management zones. Noises in the frontcountry zone are usually appropriate for that area. Inappropriate noises are mostly short in duration and relatively infrequent, but enough that some visitors might be annoyed. Wildlife may exhibit some response (e.g., fleeing from noises), but this is not enough to influence their survival or reproduction.
Warrants Significant Concern	Inappropriate sounds are frequently heard in the wilderness and backcountry adventure management zones. Noises in the frontcountry zone are the dominant sounds and inappropriate noises are too frequent and/or often of long duration. Inappropriate noises are long enough or frequent enough that many visitors are likely annoyed. The survival and/ or reproduction of wildlife is negatively impacted.

Primary sources of sound at GRSA

The most common natural sounds that are heard from within the park and preserve include weather related sounds (i.e., wind, rain, thunder), sounds of running water and forest trees rustling and creaking in the wind, wildlife sounds including elk bugling, coyote howling, bighorn duels, bird songs/calls, small mammal sounds of pika, marmot, and chickaree alarm calls, chorus frogs, insect activity (i.e., bees and flies), and at times, complete stillness. One of the rarest and most intriguing sounds that can be heard in the dunefield is the phenomenon of "singing" or "booming" sand, which is caused by avalanches of sand moving down the face of a dune. Under the right conditions, an audible vibration develops when sufficient quantities of sand avalanche and compress the air in the moving sand.

Aircraft noise is audible in all areas of the park and preserve. Human-produced sounds that are common within or near the park and preserve include traffic noise in developed areas (designated as the Frontcountry Management Zone in the GMP). Some vehicular noise would occasionally be audible on or near backcountry access roads, primarily during daylight hours. Visitor and staff conversations and interactions with infrastructure are the other primary human-produced noises within GRSA, and are likely to be most audible in the Frontcountry and Dunes Play management zones.

Desired conditions and management zones for natural sounds

Desired conditions for the acoustical environment of the park and preserve are based on both noise levels that might be detrimental to natural resources (e.g., wildlife), as well as on human perception of the acoustical environment, as it relates to visitor experience. Desired conditions common to all alternatives in the General Management Plan (NPS 2007), are that the natural soundscape is preserved and visitors have opportunities throughout most of the park to experience natural sounds, while the sounds of civilization are generally confined to developed areas. In wilderness areas, the use of motorized equipment will conform to the requirements of the Wilderness Act “minimum requirements procedures” and related NPS policies (NPS Director’s Order - 41). The National Park Service will continue to collect baseline data on park soundscapes to understand characteristics and trends in natural soundscapes and to assist in management.

Under the preferred alternative adopted in the general management plan (NPS 2007), much of the southern half of the park and preserve is included in the natural/wild zone, where natural soundscapes are predominant. In addition, most of the northern portion of the park and preserve is zoned as backcountry adventure area, where visitors have opportunities to experience natural soundscapes.

4.14.4 Condition and Trend

The existing and natural ambient statistics, and percent time over thresholds for the 2008 sampling period were reported separately for day and night periods. Daytime dBA levels were higher than nighttime levels at the monitoring site. Sound levels for both periods were quite low in comparison with common sounds that would be experience in developed areas (Table 4.14.3).

Table 4.14.3. Existing and natural ambient statistics in dBA (Lynch 2008).

Ambient Type	Day (08:00-19:59)	Night (20:00-07:59)
Existing Ambient (L_{50})	20.5	17.3
Natural Ambient (L_{nat})	15.0	14.7

Extrinsic noise sources detected during the 2008 monitoring included aircraft (jet, propeller, and helicopter), and vehicles. Aircraft of various types accounted for the majority of extrinsic sound sources, and were audible 56.3% of the time during daylight hours (Lynch 2008). Commercial jet overflights are the source of most extrinsic night-time noise (Table 4.14.4).

Table 4.14.4. Extrinsic sound sources and percent time audible (Lynch 2008).

Sound Source	24 Hour	n Events	Day (07:00-18:00)	Night (19:00-06:00)
Jet	36.5	100.4	47.5	25.6
Propeller	6.5	19.1	9.6	3.4
Helicopter	0.5	1.0	0.9	0.0
Vehicle	0.9	1.5	1.8	0.0
All Aircraft	42.5	119.6	56.3	28.7
All Vehicle	0.9	1.5	1.8	0.0
All Extrinsic Sounds	**42.7**	**120.0**	**56.7**	**28.7**

The percent of day and night that existing sound levels were above the four threshold levels described above is also greater during daytime hours, but still very low overall (Table 4.14.5).

Table 4.14.5. Percent of time above metrics for four dBA levels (Lynch 2008).

Threshold	Day (08:00-19:59)	Night (20:00-07:59)
35 dBA – Adverse health	10.38	2.54
45 dBA - Sleep	2.16	0.21
52 dBA – Interpretive programs	0.16	0.05
60 dBA – Normal conversation	0.01	0.00

Monitoring results indicated that human caused sounds increased the ambient sound levels above estimated natural levels by about 5 dB during daytime hours (7am to 7pm). Anthropogenic sound levels were essentially equivalent to natural ambient levels during the dark early morning hours (2am to 6am), and close to ambient for three or four hours prior to that (Lynch 2008). In general, GRSA appears to be a very quiet place, although monitoring at additional sites could confirm this and provide trend information. As far as can be determined from a single monitoring period, the natural soundscape of GRSA is in good condition (Table 4.14.6), and stable. However, trend confidence is low.

Table 4.14.6. Summary of conditionassessment for natural sounds.

Indicator	Interpretation	Condition Assessment
Existing and natural ambient statistics in dBA	Existing and natural ambient sound levels are quite low, natural sounds are predominant.	Natural ambient is in good condition
Extrinsic sound sources and percent time audible	The primary extrinsic source is aircraft noise, with a small component of vehicle noise during daylight hours.	Percent time audible for human caused sounds is in good condition
Percent time above metrics for four dBA levels	Human caused sounds raise natural ambient levels more in the daytime than at night. Overall, GRSA is very quiet.	Percent time above exceedance levels is in good condition

Table 4.14.6 (continued). Summary of conditionassessment for natural sounds.

Indicator	Interpretation	Condition Assessment
Overall Rank:	Natural sounds are predominant in the wilderness and backcountry adventure management zones. Noises in the frontcountry zone are mostly appropriate for that area. Inappropriate noises, if they occur are short in duration and very infrequent. Noise levels that interfere with wildlife behavior or auditory signals are infrequent to rare.	**Resource is in Good Condition**

4.14.5 Sources of Expertise

Information for this section was provided in part by the scientists of the NPS Natural Sounds Program. They provide technical assistance to parks in the form of acoustical monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes.

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Chapter 5: Discussion

In this chapter we summarize the information presented in this assessment (Table 5.1). We first present an overall summary of the condition of natural resources at Great Sand Dunes National Park and Preserve, organized according to the three primary divisions of our analysis framework: 1) landscape level patterns, 2) biological integrity, and 3) supporting environment. Secondly, we summarize our assessment of park resource conditions in the context of management implications and research needs. Finally, a single-page resource brief for each resource is included.

Table 5.1. Overall Resource Condition Summary.

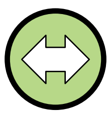
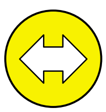
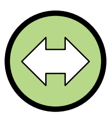
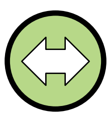
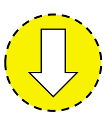
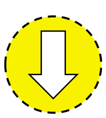
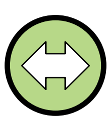
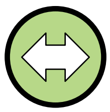
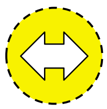
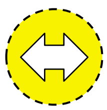
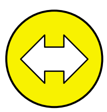
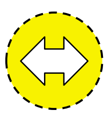
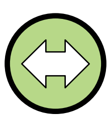
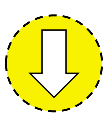
Condition / Trend	Resource	Rationale for Overall Condition/Trend Assessment	Data Gaps
Landscape Level Patterns			
	Landscape condition	The region is relatively undeveloped, with the exception of agriculture and small towns in the San Luis Valley. Lands in and near GRSA are largely undisturbed.	Better mapping of ungulate disturbance is needed.
	Landscape composition and connectivity	Ecosystem diversity and patch size distribution were rated in good condition. Although GRSA remains connected to native ecosystems in the larger montane landscape, reduced or absent connectivity across the floor of the San Luis Valley indicates moderate concern.	Species-specific connectivity studies could help evaluate this resource.
	Hydrology	There is slight evidence for a recent decline in surface flows and groundwater levels.	Longer period of record data may help resolve the level of concern for this resource.
	Dune system	Wind and precipitation patterns appear stable in the long term, and these, together with the extent and relative proportions of dune system components currently mapped are sufficient to maintain the system.	Conditions may be significantly altered with changing climate conditions, not analyzed herein.
	Fire	Fire extent and frequency in GRSA appear to be similar to that of the larger landscape, and fire prone ecosytem acreage is largely in low to moderate departure from natural fire regimes.	A spatial component for the vegetation condition models developed in the fire management is absent.
	Forest pests and pathogens	Native forest damage-causing agents (primarily western spruce budworm) appears to be within the range of documented variation for the region, and was rated good. However, the presence and spread of WPBR is of moderate concern.	Conditions may be significantly altered with changing climate conditions, not analyzed herein.
Biological Integrity			
	Native ecosystems	Characteristic native ecosystems of the region are well represented in GRSA, and are generally in good condition, with good size occurrences, and in largely undisturbed landscape context.	Conditions may be significantly altered with changing climate conditions, not analyzed herein.

Table 5.1 (continued). Overall Resource Condition Summary.

Condition / Trend	Resource	Rationale for Overall Condition/Trend Assessment	Data Gaps
Biological Integrity (continued)			
	Endemic Insects	Seven of eight endemic sand dune insects have been recently documented at GRSA, and sandy habitat is extensive.	Basic life history information is lacking for most species. Additonal inventory work could add to our understanding of these species.
	Amphibians and reptiles	Habitats for GRSA herptile species appear to be stable at levels sufficient to support populations. However, occurrence documentation is lacking for some species, indicating moderate concern.	Comprehensive inventory and monitoring plan development.
	Other species of concern	Occurrences of rare plants and animals at GRSA are generally well documented, and habitat for most rare plants is present. Increasing habitat protection in GRSA and the vicinity indicates improving good condition.	Rare mammal species need updated inventory in GRSA.
	Invasive / exotic plants and aquatics	A number of species with high invasive potential have been documented within GRSA, but native ecosystems have not been impaired.	Repeated comprehensive mapping of the most serious invasives.
Supporting Environment			
	Air quality	All three indicators were scored as warranting moderate concern. Trend information was only available for visibility.	Trend information for ozone and deposition.
	Night sky	Overall, the human experience at GRSA would be one of being in a natural environment where natural features of the night sky are readily visible, and there is negligible impact to visual adaptation to dark conditions. The Anthropogenic Light Ratio (ALR) for GRSA was evaluated as good.	Trend information is lacking.
	Soundscapes	Initial soundscape monitoring indicates that GRSA is a very quiet park, and this resource is in good condition.	Repeated measurements at other locations. Trend information is lacking.

5.1 Overall Condition Summary

5.1.1 Landscape Level Patterns

The landscape level resources assessed for GRSA at the scale of the upper Rio Grande watershed were condition, composition, and connectivity. The landscape condition, as measured by anthropogenic disturbance extent and intensity, is good, especially for public lands surrounding the San Luis Valley. GRSA is part of a diverse landscape of regional ecosystem types, and acts as a key connection in the connectivity of core areas within the Sangre de Cristo Mountains. Although connectivity of this range with the San Juan Mountains to the west is now primarily around the perimeter of the San Luis Valley, there are a few remaining connections between GRSA and other areas across the valley floor. Landscape conditions are generally stable, with local and regional conservation and management efforts offsetting the agricultural and renewable resource development that has impacted the area.

The landscape level resources assessed for GRSA center around either the persistence of the dune system with a sustainable hydrologic regime, or the condition of forest and woodland communities that are affected by fire, natural pests, or introduced pathogens. The dune system, the resource central to the park mission, is stable and in good condition. There is some concern that hydrologic resources, groundwater levels in particular, may be declining. Furthermore, changing climatic conditions can certainly put these coupled resources at risk.

Fire regime patterns for GRSA appear to be in good condition, especially in comparison with the larger landscape. Wildfire as well as other natural forest damage agents are able to operate within the natural range of variation, as far as is known. The presence and spread of the introduced pathogen responsible for white pine blister rust warrants moderate concern. This agent has the potential to change the composition of ecosystems in the park and preserve. Although efforts to combat the pathogen are ongoing, the lifespan of affected trees is likely to lead to further deterioration of five-needle pine forests at GRSA before control, resistance, and restoration activities can effect a stabilization and improvement in this situation.

5.1.2 Biological Integrity

The biological integrity of GRSA includes native ecosystems, plants, and animals (both native and introduced) throughout the park and preserve. Native ecosystems were assessed in seven groups, representing vegetation types from the valley floor to the alpine peaks. Overall, native ecosystems within GRSA are in good condition, especially those of higher elevations in the preserve. Grasslands and wetland-riparian areas of lower elevations are of most concern, largely due to a legacy of disturbance from previous ranching use, as well as ongoing ungulate grazing.

In addition to regionally characteristic and common plants and animals, GRSA is also home to a number of rare species. Endemic insects are present in good condition; only a single species was not reported during the most recent survey effort. Furthermore, the sandy habitat required by these insects is extensive both within and near GRSA. Although GRSA does not have extensive habitat for all of its herptile species, most appear to be present. Because population levels and habitat extent are unknown for most species, this resource was ranked of moderate concern. Rare animal and plant species at GRSA are generally in good condition. Various inventory and survey work in the area since the mid-1990s has provided good baseline information for many species, although repeat observations of many of these species of concern would help establish trend information for the future. Due to ongoing regional conservation efforts, including the enlargement of the former monument into the park and preserve, these species are probably now more protected than at any time since settlement.

Although native plant and animal communities are generally in good condition at GRSA, there are enough invasive introduced species present to pose a threat to the composition and function of plant communities, and, by extension, the wildlife species that use them. Consequently, this resource is ranked of moderate concern. Weed mapping and subsequent control efforts have so far prevented significant deterioration of park resources due to invasive species.

5.1.3 Supporting Environment

Resources evaluated as part of the supporting environment at GRSA are air quality, night skies, and natural soundscapes. These resources represent not only abiotic factors that affect the survival of components of biological integrity, but also the extent to which park visitors are able to experience the environment of the park as intended. The condition of night skies and natural soundscapes is good, GRSA represents a primarily unaltered natural environment, and is situated in an area where there are few impacts to these resources from outside the park. Air quality at GRSA is of moderate concern, primarily due to sources of pollution outside the park and preserve.

5.2 Management Implications and Information Gaps

5.2.1 Landscape Level Patterns

Landscape disturbance assessment agrees with ROMN observations about grazing ungulate disturbance on the west side of the sand dunes. Additional research to clarify the effects of native ungulate grazing, the legacy of historic agricultural use, and the natural disturbance regime that is characteristic of the component ecosystems would be useful. Connectivity of GRSA with the larger landscape, although not directly under NPS control, may be of potential management concern if future conditions lead to the isolation of GRSA within a degraded landscape. The continued participation of GRSA and other NPS program staff in regional conservation and management efforts will help ensure continued preservation of the larger landscape. Species-specific connectivity modeling, especially for larger mammals of management concern, may provide additional management insight for desired conditions.

Attention to the effects of hydrological alterations in the area, together with extensive court proceedings and modeling, has thus far enabled the NPS to preserve the hydrologic factors on which the dunes depend. However, changing climatic conditions are likely to impact the dunes and the hydrology of the area in the coming decades. Current groundwater monitoring, as well as a focus on vigilant management of the dune system and attendant hydrologic resources, should help managers prepare adaptive strategies for changing conditions as they arise. Additional assessment and scenario-planning for how the condition and persistence of GRSA natural resources might change under future climate conditions would assist NPS staff with adaptive management efforts. Likewise, the effects of changing climate on fire conditions as well as forest pest and pathogens, and the interactions of these factors with spatial patterns of landscape composition and connectivity are generally unknown for the vicinity of GRSA.

5.2.2 Biological Integrity

Native ecosystems at GRSA have been recently mapped, but there is no formal mechanism to ensure that mapping is periodically updated. This resource is also likely to be affected by changing climate in the future, and would benefit from a climate change vulnerability assessment of some kind.

Species of management concern at GRSA are understudied. Endemic insects in particular are lacking basic life-history studies that could support population inventory and monitoring efforts. Continued survey and monitoring would help clarify trends for this resource in the future, although the development of a practical monitoring plan will be challenging. Amphibian and reptile species at GRSA would also benefit from additional survey effort to provide more detailed population and habitat information. Further occurrence documentation would help identify areas where management intervention could improve conditions, and potentially allow the development of habitat models for more species. Likewise, other relatively rare taxa within GRSA, especially small mammals, need additional comprehensive inventory efforts to document their population status and inform management actions.

Monitoring and control efforts for invasive species are well underway, but need to keep up with what may be quickly changing conditions. The completion and implementation of a weed management plan will assist park staff in continuing or improving this trend. Repeated mapping of priority weed species, and survey for new infestations would be beneficial for this resource issue.

5.2.3 Supporting Environment

Measurement and monitoring techniques for air quality, night sky, and natural sounds are becoming very well developed, so that condition assessment is more easily quantifiable. While this development has been in progress, trend information for these resources has not accumulated in a standard format. This information gap will presumably be addressed in the future.

5.3 Resource Briefs

Resource briefs included below summarize the importance, indicators, reference condition, and status and trend assessment results for each resource.

Great Sand Dunes National Park & Preserve
Landscape Condition Resource Brief

CNHP /Renée Rondeau

Importance

Natural disturbance in terrestrial ecosystems due to wildfire, severe weather events (wind, flooding, etc.), drought, landslide, animal activity, or other factors is an ongoing process and determinant of patterns in functioning ecosystems, communities, and populations. However, these natural disturbance regimes have now in many locations been disrupted or altered by human activities. The extent and intensity of anthropogenic disturbance in the landscape can have direct or indirect effects on GRSA's natural resources; the most viable habitats are likely to be located in areas least altered by human activity.

Indicators / Measures

- Landscape Disturbance Index

Reference Condition

A disturbance score of 0 represents best possible landscape condition, with essentially no detectable anthropogenic impacts present. Since not all impacts can be spatially represented in our analysis, the effects from a set of mappable anthropogenic disturbances are regarded as the baseline reference condition. Condition was ranked by considering the proportion of GRSA acreage in disturbance score classes.

Status and Trends

The landscape surrounding GRSA has few areas of high or very high disturbance impact, and remains relatively undeveloped. The floor of the San Luis Valley is primarily affected by irrigated, tilled agriculture (moderate disturbance), with areas of expanding urban and exurban development, but still retains substantial area with little to no impact. GRSA as a whole has more than 80% of its area with no or very low disturbance. Impacts within GRSA are due to the few local and primitive roads, occasional structures, and the degraded rangeland of the former ranch lands.

Anthropogenic disturbance within the larger analysis area is expected to increase slightly in the future, but less so than in more populated areas. Increasing anthropogenic disturbance in the analysis area does not necessarily translate to increased disturbance within GRSA, and landscape disturbance within the park can reasonably be expected to remain at more-or-less current levels. Over time, however, park lands may become increasingly isolated from similar, low-to-no impact areas.

Great Sand Dunes National Park & Preserve
Landscape Composition and Connectivity Resource Brief

CNHP

Importance

Connectivity both within GRSA and between GRSA and the surrounding landscape enables the operation of natural processes and ecosystem dynamics across the scale from small patch to landscape matrix. Over time, changes in composition and connectivity in the region could lead to changes in patterns of species movement and the operation of ecological processes, with a potential for directly impacting the condition of species populations at GRSA.

Indicators / Measures

- Ecosystem diversity
- Patch size distribution
- Connectivity

Reference Condition

Ecosystem diversity of GRSA is expected to be as good or better than the surrounding landscape. GRSA should contain large patches of characteristic ecosystems, and be well connected to the surrounding landscape. Current levels are presented as baseline.

Status and Trends

Overall, GRSA has ecosystem diversity slightly greater than that of the analysis area.

The three ecosystems characteristic of the park (Active and stabilized dune, Greasewood flats, and Semi-desert shrub-steppe) are all represented by patches in the upper quartile of patch size distribution in the vicinity of GRSA. Furthermore, the vicinity of GRSA also includes relatively large patches (in the upper half of the size distribution) of ecosystems characteristic of the Sangre de Cristo Mountains, with the exception of Spruce-fir. The connectivity analysis indicates that GRSA remains connected to native ecosystems in the larger landscape along the Sangre de Cristos, and is part of two large core areas. However, the reduced or absent connectivity across the floor of the San Luis Valley indicates moderate concern. Trend information is not available.

Great Sand Dunes National Park & Preserve
Hydrology Resource Brief

CNHP

Importance

The dunefield is a water-dependent resource, dependent on the functioning of a complex, interconnected local and regional hydrology. Surface flows in Sand Creek and Medano Creek carry sand away from the mountain front and around the perimeter of the dunes. The persistence of the dune field depends on groundwater levels in the shallow aquifer. A significant reduction in local groundwater levels would shorten the distance over which the flowing creeks are able to transport sand before their water infiltrates into the shallow unconfined aquifer, threatening the long-term viability of the dune field.

Indicators / Measures

- Surface water: timing & magnitude of runoff
- Groundwater: seasonal high and low elevations at boundary piezometers

Reference Condition

For surface water, the historical average annual hydrograph of discharge for area streams is the reference condition for timing and magnitude of seasonal flow patterns. Period of record flows are provided as a baseline of conditions for future comparison.

The reference condition for change in groundwater level is the base period interval (1-Jan-1999 to 31-Dec-2003) used in the GRSA groundwater model, which reflects conditions under which the dune system and other resources are able to persist.

Status and Trends

Although there is a suggestion of a regional decline in streamflows during the past few decades, there is insufficient evidence to support a decline due to water withdrawal under the contemporary configuration of surface and groundwater use. Surface hydrology is considered in a stable, but altered condition, until such time as additional data are available. In addition, all groundwater wells show a slight decline in groundwater elevation over the period of measurement, corresponding to a period of lower local and regional precipitation. The lack of adequate baseline period data constitutes uncertainty in the assessment.

Great Sand Dunes National Park & Preserve
Dune System Resource Brief

CNHP

Importance

The dune system consists of the unvegetated dunefield, the extensive sandsheet stabilized by vegetation, and the sabkha of carbonate-cemented sand which forms in places where sand is seasonally saturated by rising groundwater. Important considerations for this resource at GRSA include the size and stability of the dunefield, dune dynamics and stabilizing vegetation on the sandsheet, the sand transporting action of Medano and Sand Creeks, and the maintenance of near-surface water tables in the sabkha.

Indicators / Measures

- Wind direction and intensity
- Precipitation amounts and seasonality
- Size and distribution of dune system components

Reference Condition

Period of record data for key climatic drivers of the system are presented. The dune system should be considered stable if the relative proportions and landscape locations of active dunefield, sandsheet, and sabkha remain more-or-less as they have been through the history of the park and preserve, and if the climatic drivers remain in a similar pattern to that which has been historically documented.

Status and Trends

Period of record data at GRSA show a pattern of wind direction predominantly from the southwest for the strongest (daytime) winds, although night hours have a noticeable southeasterly component of lighter winds that was not explicitly identified in the 1970s. Wind intensity and direction continues to be sufficient for maintenance of the dune system. Dune movement is generally greater in periods of drought, which is presumed to reflect current conditions. As most recently mapped, the dune system components are in the following baseline proportions: dunefield covers about 7% of the dune system area, sandsheet accounts for the largest portion at about 60%, and the remaining 34% is sabkha. Trends are presumed stable.

Great Sand Dunes National Park & Preserve
Fire Resource Brief

NPS

Importance The National Park Service manages wildland fire to protect the public, communities and infrastructure, conserve natural and cultural resources, and restore and maintain ecological health. Wildland fire, whether due to natural or human causes, can have a landscape level influence on the ecosystems of the San Luis Valley and Sangre de Cristo Mountains. Past fire suppression efforts and other management activities have changed habitat composition in many areas of the western U.S., and thereby affected animal species that depend on them.

Indicators / Measures

- Fire extent and frequency – regional and local
- Proportion of each ecosystem group in fire condition classes

Reference Condition A baseline reference condition is considered to be no difference between GRSA and the larger landscape in relative frequency and extent of fire, and the majority of fire affected ecosystems in low to moderate departure from natural conditions.

Status and Trends The area within the GRSA fire management boundary has experienced similar patterns of fire extent and frequency in comparison with the surrounding landscape. Relative proportions of burned area are slightly higher within GRSA than in the surrounding landscape, but fire frequency in the recent past has not increased within the fire management boundary.

Ecosystems of the valley floor within GRSA are mostly in conditions indicating low or moderate departure from natural fire regimes. Some lower elevation forest and woodland types have substantial acreage in the high and moderate departure condition classes, but these do not represent substantial acreage within GRSA.

Great Sand Dunes National Park & Preserve
Forest Pests and Pathogens Resource Brief

NPS

Importance

GRSA now contains extensive acreage of forest ecosystems that are subject to damage by a variety of native pests, especially western spruce budworm. Infections of the introduced fungus that causes white pine blister rust also threaten the persistence of five-needle pines in the area. These factors could permanently alter the composition of GRSA forests and woodlands.

Indicators / Measures

- Natural patterns of forest damage within a historic range of variation.
- Presence of white pine blister rust, and levels of infection

Reference Condition

Damage levels due to native forest pests were evaluated qualitatively in relation to regionally documented ranges of historic variation. Because white pine blister rust is not a native pathogen, the reference condition is the absence of the disease. Since this condition may not be attainable, the infection levels presented here serve as a minimally disturbed baseline for future control efforts.

Status and Trends

Forest damage (including tree mortality) at GRSA is primarily due to western spruce budworm. Aspen defoliation and decline are also important causes of forest damage. Although historic damage levels for GRSA are essentially unknown, current damage levels appear to be within the range of historic variation documented in the region.

White pine blister rust is currently present in low levels, but is expected to spread and increase over time.

Great Sand Dunes National Park & Preserve
Native Ecosystems Resource Brief

CNHP

Importance

Due to its combination of landforms and wide elevational scope, GRSA supports an impressive variety of native ecosytems within a relatively small area. Twenty-nine ecosystem types are considered in seven groups (Alpine, Forests, Shrublands, Grasslands, Dunefield-Sandsheet-Sabkha, and two Wetland/Riparian types). These native ecosystems represent a resource of major vegetation types that if conserved and managed at appropriate scales would protect the majority of the plants and animals associated with them.

Indicators / Measures

- Representation and extent of regional native ecosystem types
- Condition of native ecosystem types
- Landscape context of native ecosystem types

Reference Condition

The assessment of native ecosystems at GRSA is based on the concept of viability specifications used for ranking occurrences of all types of elements of biodiversity under Natural Heritage methodology. Specifications summarize three factors: 1) size, 2) condition, and 3) landscape context, that contribute to the overall estimated viability of an ecosystem occurrence.

Status and Trends

All ecosystem groups score as either Resource is in Good Condition or as Warrants Moderate Concern, and GRSA receives an overall condition score in the Resource is in Good Condition category. Because trends information is not available for this resource, this constitutes uncertainty in the assessment. However, the overall condition of ecosystem groups is expected to change slowly, and we chose to represent the current trend as stable.

Great Sand Dunes National Park & Preserve
Endemic insects Resource Brief

NPS/Phyllis Pineda Bovin

Importance

Sandy habitat at GRSA supports eight endemic insect species (five beetles, one fly, a moth, and a camel cricket). These local and regional endemics have strong habitat associations and are largely found on active dunes, sandy blowouts, or shifting sands with sparse vegetation. The protection and preservation of these species is an important management objective for GRSA

Indicators / Measures

- Presence/absence of individuals
- Presence/extent of sparsely vegetated sandy habitat

Reference Condition

The documented presence of individuals of each species, and the presence of suitable habitat with sufficient extent to support them.

Status and Trends

Only one of the eight insect species was not reported during the most recent formal survey. Furthermore, park staff frequently encounter most endemic of the insect species during routine operations. The extent of sandy habitat is likely to be naturally variable under changing climatic conditions, but appears to be sufficient to support the endemic insect populations. Trend information is not available.

Great Sand Dunes National Park & Preserve
Amphibians and Reptiles Resource Brief

CNHP

Importance

Although impacts from human activities, especially from intensively cultivated agriculture have largely exterminated amphibians and reptiles in the larger landscape of the San Luis Valley, the vicinity of GRSA, retains large tracts of relatively undisturbed potential habitat for these animals. The presence of amphibian and reptile species at GRSA is an indication of undegraded habitat.

Indicators / Measures

- Presence/absence of individuals
- Presence of suitable habitat

Reference Condition

The documented presence of individuals of each species, and the presence of suitable habitat with sufficient extent to support them, for a subset of modeled species.

Status and Trends

Five of thirteen species were ranked good for presence; only one was ranked poor , or warranting significant concern. Five of six modeled amphibian species were ranked good for habitat presence, and one ranked of moderate concern. Habitat for reptile species is ranked either good or moderate. Confidence for the condition of this factor is low, therefore we chose to assume that habitat is present for all species, but at unknown extent for those ranked moderate. Trend information is lacking.

Great Sand Dunes National Park & Preserve
Other Species of Concern Resource Brief

CNHP/Georgia Doyle

Importance

Although there are no threatened or endangered plants known to be present within GRSA, there are a number of other rare, imperiled, or otherwise significant animal and plant species that are supported in the diverse habitats of GRSA. Four bird species, three mammal species, one fish, and one mollusk species are represented by element occurrence records The Rio Grande cutthroat trout is a candidate for listing under the U.S. Endangered Species Act. Eleven plant species of concern have been documented in or near GRSA.

Indicators / Measures

- Presence of individuals
- Presence/extent of suitable habitat for rare plant species

Reference Condition

Reference conditions are based on the documented presence of individuals of each species, and the presence of suitable habitat with sufficient extent to support them, for modeled rare plant species.

Status and Trends

The majority of species were ranked as good condition, therefore we consider that rare animal species as a group at GRSA are in good condition. The mollusk *Promenetus umbilicatellus* (umbilicate sprite) is the only species lacking recent documentation. Two of eleven rare plant species (*Draba grayana* and *Woodsia neomexicana*) lack recent documentation, all other plant species scored as in good condition. The generally low levels of disturbance within GRSA and vicinity increase the likelihood that even species not recently observed are in good condition.

Potentially suitable habitat for ten rare plant species is present within GRSA, and in many cases, represents a central portion of the distribution. The increasing protection for habitat within and near GRSA indicates improving condition for this resource.

Great Sand Dunes National Park & Preserve
Invasive / Exotic Plants and Aquatics Resource Brief

NPS/Phyllis Pineda Bovin

Importance

Vegetation structure and composition have a direct impact on wildlife habitat suitability. Invasion of non-native plant species is recognized as one of the most serious threats to National Park lands across the country, with approximately 5% of park lands being dominated by invasive plants. Non-native species can degrade habitat quality, displace native species, and alter natural processes.

Indicators / Measures

- Presence of species with high invasive potential
- Presence or dominance of other non-native species

Reference Condition

Complete absence of non-native species as a reference condition is not feasible for a unit with the history and extent of GRSA, therefore a baseline is conditions under which the integrity of park and preserve ecosystems remains essentially unimpaired, and natural processes that are affected by species composition are able to operate within the natural range of variation.

Status and Trends

A number of plant species with the potential to spread have been documented within the park and preserve, but native ecosystems are still functioning and not in immediate danger of alteration. Invasive aquatic species are absent or have been eradicated.

Non-native plant species are present, but not dominant in any native plant communities. Non-native aquatic species (trout) are present, but not invasive.

In the absence of detailed trend information, and after discussion with park staff, this resource is considered stable, reflecting ongoing control and eradication efforts.

Great Sand Dunes National Park & Preserve
Air Quality Resource Brief

CNHP

Importance

Air quality at GRSA is affected by many pollution sources outside park boundaries. Ecosystems within GRSA are at very high risk from nutrient enrichment, and at high risk from acidification. High elevation ecosystems in the preserve, especially subalpine lakes, are particularly sensitive to nitrogen and sulfur deposition, and receive more deposition than lower elevations due to greater amounts of snow and rain.

Indicators / Measures

- Visibility haze index
- Level of ozone
- Atmospheric wet deposition in total N and total S

Reference Condition

Reference conditions were provided by NPS-ARD, and reflect conditions that would be found in the absence of human-caused impairment or that are target conditions under applicable air quality programs.

Status and Trends

Eight plant species found within GRSA have been identified as ozone-sensitive, and all are appropriate for use as bioindicator species in the event of increased foliar ozone damage risk in the future. Because all three indicators are scored as Warrants Moderate Concern, GRSA receives an overall condition score in the Warrants Moderate Concern category. Good trend information was only available for visibility, which was improving. Because local trends were not available for the other two indicators, this constitutes uncertainty in the assessment, and, based on the information for the 5-year averages the resource trend is considered stable.

Great Sand Dunes National Park & Preserve
Night Sky Resource Brief

CNHP

Importance

National Parks are generally managed to preserve park resources and values, including natural visibility, both in daytime and at night. Visual impacts from light pollution may be perceived at long distances, impeding visibility and experience for park visitors. Artificial night lighting has also been shown to have physiological and behavioral consequences for many organisms.

Indicators / Measures

- Bortle Dark-Sky Scale
- Limiting magnitude
- Sky brightness (SQM)
- Anthropogenic Light Ratio (ALR)

Reference Condition

An ideal night sky condition would be the absence of any light pollution. Reference conditions were provided by NPS NSNSD, and reflect conditions that would be found in the absence of human-caused impairment.

Status and Trends

The Bortle Scale assessment was Class 3, indicating moderate quality, equivalent to a rural sky. The limiting magnitude estimation was 6.9 at both sites, which is comparable to the Class 3 Bortle Scale score. These two scores indicate a Resource in Good Condition assessment. The synthetic SQM measures are in the Warrants Moderate Concern range. The ALR score of 0.2 represents conditions 20% brighter than natural. This score is well under the threshold level for a Resource in Good Condition assessment.

With only a single indicator falling in the Warrants Moderate Concern range, and from the overall character of the night sky, it is clear that GRSA night sky conditions are in good condition. The human experience at GRSA would be one of being in a natural environment where natural features of the night sky are readily visible, and there is negligible impact to visual adaptation to dark conditions.

Great Sand Dunes National Park & Preserve
Soundscapes Resource Brief

CNHP

Importance

The ability to produce and detect sound is crucial to most wildlife species, and anthropogenic sounds can disrupt this essential communication. Noise pollution can also influence the composition of plant communities via its effects of animal pollinators and seed dispersers. Noise pollution also degrades visitor experience, detracting from the ability to experience quiet and sounds of nature.

Indicators / Measures

- Day/Night median dBA
- Percent time aircraft and other extrinsic noise audible
- Percent of time sound levels exceed thresholds.

Reference Condition

The natural ambient sound level (the environment of sound that exists in the absence of human-caused noise) is considered as the reference condition for areas within the park and preserve. Reference levels were provided by NPS NSNSD.

Status and Trends

Monitoring results indicated that human caused sounds increased the ambient sound levels above estimated natural levels by about 5 dB during daytime hours. Anthropogenic sound levels were essentially equivalent to natural ambient levels during the dark early morning hours (2am to 6am), and close to ambient for three or four hours prior to that. In general, GRSA appears to be a very quiet place. As far as can be determined from a single monitoring period, the natural soundscape of GRSA is in good condition, and stable. However, trend confidence is low.

Appendices

Appendix A: Team Members and Subject Matter Experts

Great Sand Dunes National Park and Preserve NRCA Project Team
Colorado Natural Areas Program Karin Decker, Conservation Ecologist (CSU/CNHP Principle Investigator) Michelle Fink, Landscape Ecologist
NPS - ROMN Mike Britten, ROMN Program Manager (GRSA NRCA Project coordinator) E. William (Billy) Schweiger, Network Ecologist Donna Shorrock, Network Ecologist Laura O'Gan, Network Data Manager **NPS – Great Sand Dunes National Park and Preserve** Art Hutchinson, Superintendent (former) Fred Bunch, Chief of Natural Resources Andrew Valdez, Geologist Phyllis Pineda Bovin, Biologist
NatureServe Pat Comer, Chief Terrestrial Ecologist Sound Science, LCC Bob Unnasch, Chief Scientist

Great Sand Dunes National Park and Preserve NRCA Subject Matter Experts
NPS James Harte, Hydrologist Water Resources Division Chad Moore, Night Skies Program Manager Jeremy White, Physical Scientist Natural Sounds & Night Skies Division **Colorado Natural Areas Program** Brad Lambert, Vertebrate Zoologist Susan Spackman-Panjabi, Senior Botanist Jill Handwerk, Botany Team Leader **USDA Forest Service** Kelly Sullivan Burns, Forest Pathologist Rocky Mountain Region Forest Health Protection **USGS** Erin Muths, Research Zoologist U.S. Geological Survey Fort Collins Science Center

Appendix B. Landscape Disturbance Index

In most cases, attempts to quantify the effects of anthropogenic disturbance are essentially the obverse of efforts to quantify biotic integrity. In recent decades researchers have focused on streamlining and standardizing such efforts by developing indices of biotic integrity or of disturbance that can be generated with geo-spatial or field-sampling rapid-assessment techniques. A variety of techniques have been used to depict and evaluate the intensity and extent of impact from anthropogenic sources on the landscape. In many instances, the impacts have been modeled with regard to their effects on composition, structure, or fragmentation of a landscape (reviewed by Cushman et al. 2008, Kindlmann and Burel 2008, Schindler et al. 2008), generating a plethora of landscape metrics. Other methods calculate a landscape-level index of impact within an “area of influence” around the disturbance or land use, applying some type of distance or area weighting.

Evidence for effects that reach beyond the boundaries of the footprint of an anthropogenic disturbance has been documented in a variety of studies. Road-zone effects have been especially well documented, showing effects for various taxa of anywhere from 100 to 1000 meters (Boarman and Sazaki 2006, Palomino and Carrascal 2007, Wilbert et al. 2008, Eigenbrod et al. 2009, Parris and Schneider 2008, and others). Other disturbance types are not as well studied, but there is evidence for effect-zones for both urban and exurban development (Odell and Knight 2001, Hansen et al. 2005, McDonald et al. 2009), energy development (BLM 1999, Wilbert et al. 2008, Nasen 2009, Lovich and Ennen 2011, Naugle 2011), and agriculture (Davis et al. 1993, de Jong et al. 2008). Due to the nature of the research, effect-zones are usually specified as applying to a particular taxa or guild. In addition, some species respond positively to anthropogenic disturbance. While it would be ideal to construct a disturbance effect model for every species or group of species within an area of interest, for practicality, we chose to generate a generalized landscape disturbance index (LDI).

Brown and Vivas (2005) computed a landscape development index based on the intensity of human activity and applied it to land uses within watersheds. Based on work that used benthic diatoms, and soil/water variables to characterize isolated marsh wetlands along a disturbance gradient (Lane and Brown 2006), Brown and Vivas (2005) assumed that a 100 m buffer was sufficient to capture effects as an area of influence for their development categories. Under the generally accepted premise that the magnitude of anthropogenic effects decreases with distance from the source of disturbance (Theobald et al. 1997),Tuffly and Comer (2005) used a distance-decay function of the form *Impact = (1/distance)*Weight of impact*, which reaches values close to zero within a few hundred meters, but without truncation leaves a small residual amount of disturbance as a background throughout the entire model. Later work recognized the need for either post-processing to relativize background values (Vance 2009), or truncation of a decay function at a set distance during model construction (Decker and Fink 2008, Vance 2009, Rondeau et al. 2011). Although Brown and Vivas (2005) detected no real difference between distance weighting and simple area weighting methods, we chose to use a distance based decay function to simulate an effect which is quite strong adjacent to the disturbance footprint but declines fairly quickly to a base level near zero, i.e., a sigmoid curve.

The distance-decay function represents a mathematical curve describing degree of influence over distance. A variety of curves can be used for distance decay models. The choice of curve for the distance decay function is determined by how the disturbance is believed to behave in the real world, i.e., does the effect drop sharply near the source but then fade gradually (log function), or perhaps maintain a noticeable effect for some distance away from the source before decreasing (e.g., sigmoid-curve, witch of Agnesi), or is the rate of decrease constant (i.e., linear)? Many potential curves are asymptotic at one or both ends, in which case the values can be artificially truncated at a distance thought to reflect the actual radius of the disturbance effect. Naturally the technique does not account for impacts which only have an effect in a limited direction from the impact (e.g., only downstream or downwind).

Curve type and impact values were developed and refined in discussions with partners engaged in conservation management. These discussions considered the relative impacts and apparent distance over which those impacts were believed to add to the disturbance of an otherwise intact landscape. Although there are few studies that quantify the effect over distance of various anthropogenic effects, wherever possible, we used studies from the literature to inform our choices of impact and distance of effect. Thus, for instance, an estimate of the average area of impact resulting from drilling a single oil or gas well was translated into an area around a point within which impact was expected to be significant. So, although our choice of curve type and impact values are generalized to nice round numbers, they are loosely based on observations documented in studies of the distance effects and impact areas of anthropogenic disturbances. Our disturbance categories have only a partial overlap with those identified in the landscape development intensity index of Brown and Vivas (2005), however, comparable categories in our LDI are in the same relative positions on the best to worse scale as those in the Brown and Vivas index.

During the development of the regional LDI used for the GRSA NRCA and similar work, we also investigated the relationship between an index of vegetation quality calculated on plot data from various sources, and the distance to each disturbance type. Six mappable impact types occurred within the vegetation mapping boundary (Table B1), affecting 154 of 600 (25.6%) vegetation plot points. Of these, 68 plots were within the effect zone of more than one impact. The primary disturbance types were untilled agriculture and local/primitive roads. Plot distance to both of these types had a clear correlation with mean C scores (Figure B1).

Table B1. Disturbance types and plots affected.

Impact	Plots Within Effect Zone	Mean C Intercept	R2
Development - Low Intensity (does not include park facilities)	3		
Agriculture - Tilled	5		
Agriculture - Untilled	157	4.2	0.63
Roads - Secondary	11		
Roads - Local & Primitive	119	4.7	0.31
Surface Mines - Inactive	3		

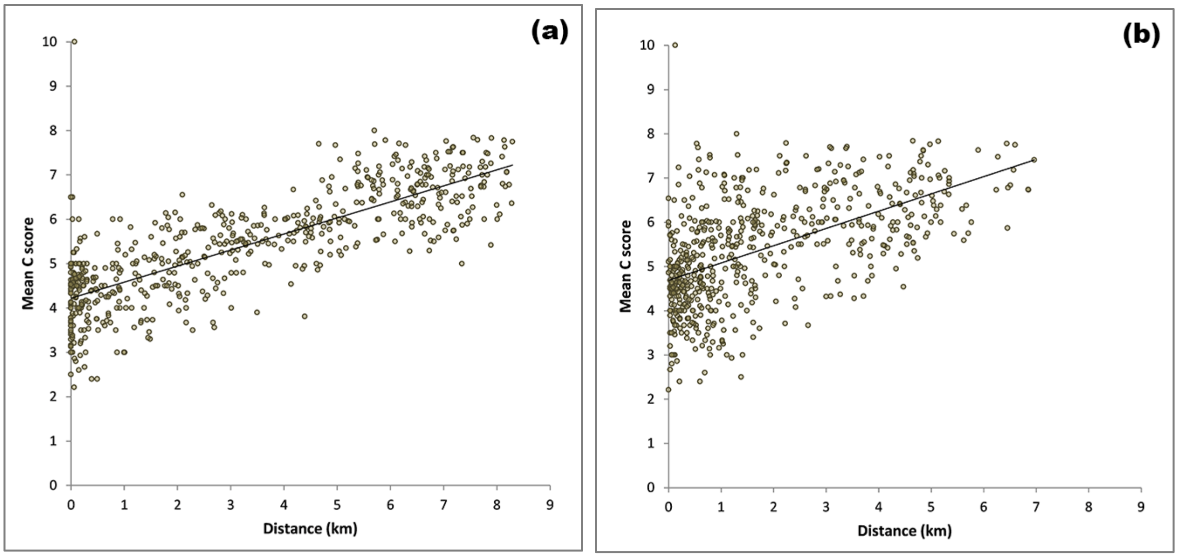


Figure B1. Mean C score of GRSA vegetation plots vs. distance from (a) untilled agriculture (b) local and primitive roads.

We chose to limit the distance beyond which our modeled disturbance would have an effect, even though some types of disturbance such as atmospheric deposition of particulate matter have effects documented at continental scales (Grantz et al. 2003). The curves used in our model are of the sigmoid function shown below:

$$y = \frac{1}{1 + \exp(b(\frac{x}{c} - a))} \times w$$

where:

a - shifts curve to right or left

b - determines spread of curve, or slope of the rapidly decreasing part of curve

c - scalar to adjust total distance of interest

x - distance in meters from impact

w - weight of impact (maximum value at 0 distance)

By adjusting the shift and spread of the curve (a and b), it can be tailored to the known or suspected behavior of specific impacts. Different values of a and b were used to derive four decay curves describing gradual, moderate, moderately abrupt, and abrupt distance decay behavior (Table B2). The inflection point of the curve marks the distance where the effect of the impact is reduced by half. These curves are asymptotic at both ends, therefore the results of the equation must be manually adjusted to equal the maximum weight at zero distance and minimum weight at a distance at which the weight becomes essentially zero ("cutoff distance").

Table B2. Defined distance decay curves.

Decay Function	a	b	Inflection pt. (m)	Cutoff Distance (m)	Equation
Abrupt	1	5	100	250	(1 / (1 + Exp(((Distance / 100) - 1) * 5))) * Weight
Moderate-Abrupt	2.5	2	300	600	(1 / (1 + Exp(((Distance / 100) - 2.5) * 2))) * Weight
Moderate	5	1	500	1,250	(1 / (1 + Exp((Distance / 100) - 5))) * Weight
Gradual	10	0.5	1,000	2,000	(1 / (1 + Exp(((Distance / 100) - 10) * 0.5))) * Weight

Each individual layer was assigned its own weight and decay function type (Table B3, Figure B2). Weights were scaled from 0 (no impact) to 100 (fully impacted). A fully impacted area is one where the entire natural/native surface of the area has been destroyed or replaced by man-made surfaces. As such, these weights may be viewed as representing a relative degree of impact from anthropogenic activities, although this should not be interpreted as literal proportion of aerial extent impacted. Some inputs were divided into subtypes, for instance roads were separated into primary, secondary, and local/primitive roads, each given their own weight and curve. After these impact subtypes were calculated, they were recombined by taking the maximum weight at each cell location, thereby preventing subtypes of the same impact from being counted multiple times. Once this was completed, the different impact layers were then additively combined to produce an overall landscape disturbance layer. The resulting levels of cumulative impact were then classified from no impact to very high impact (Table B4). Additional details of methods used are available in the landscape disturbance model metadata.

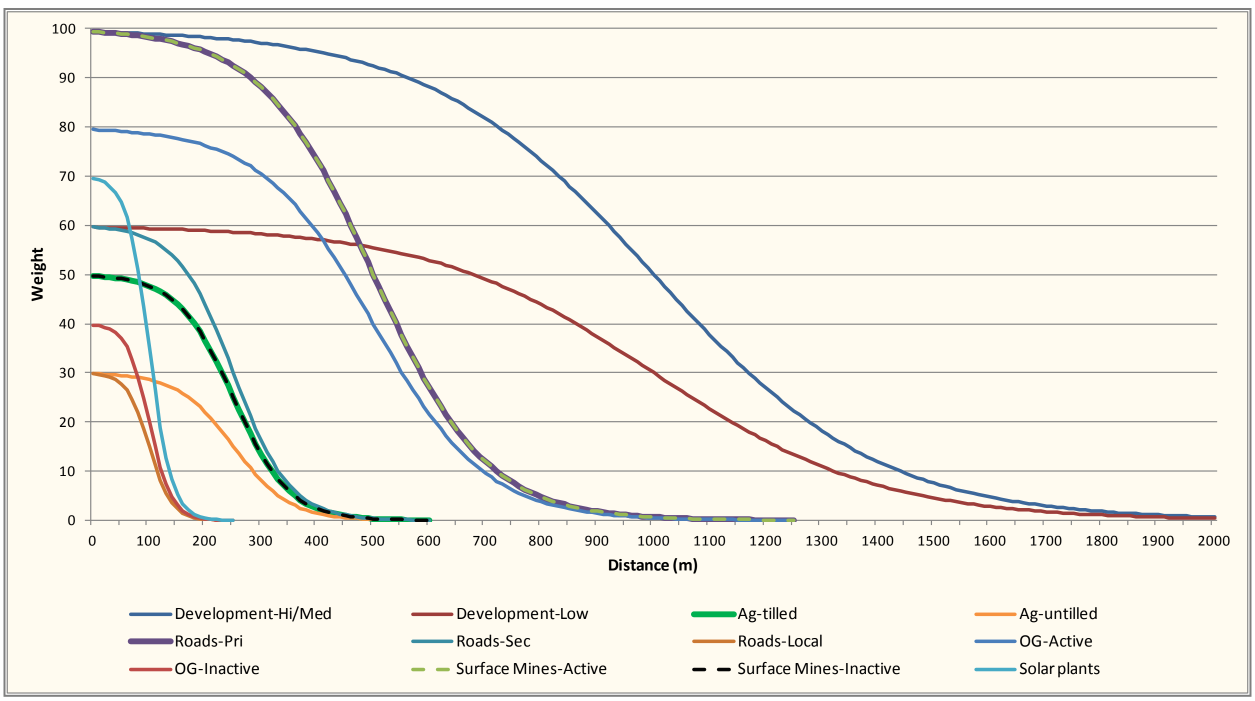


Figure B2. Graphic representation of distance decay curves for each input.

Table B3. Weights and curves used for each landscape disturbance input.

Impact	Subtype	Curve	Weight	Cutoff Distance (m)
Development	High/Medium Intensity	gradual	100	2,000
	Low Intensity	gradual	60	2,000
Agriculture	Tilled	moderate-abrupt	50	600
	Untilled	moderate-abrupt	30	600
Roads	Primary	moderate	100	1,250
	Secondary	moderate-abrupt	60	600
	Local & Primitive	abrupt	30	250
Oil & Gas Wells	Active	moderate	80	1,250
	Inactive	abrupt	40	250
Surface Mines	Active	moderate	100	1,250
	Inactive	moderate-abrupt	50	600
Solar plants		abrupt	70	250

Table B4. Classification of anthropogenic impact.

Impact Level	Impact Weight
None	0
Very Low	> 0 - 25
Moderate-Low	> 25 - 50
Moderate-High	> 50 - 75
High	> 75 - 100
Very High	> 100

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Appendix C: The Natural Heritage Network Ranking System

The Natural Heritage Methodology is used by Natural Heritage Programs throughout North, Central, and South America, forming an international database network. The 85 Natural Heritage Network data centers are located in each of the fifty U.S. states, eleven Canadian provinces and territories, and many countries in Latin America and the Caribbean. This network enables scientists to monitor the status of species from a state, national, and global perspective. Information collected by the Natural Heritage Programs can provide a means to protect species before the need for legal endangerment status arises. It can also enable conservationists and natural resource managers to make informed, objective decisions in prioritizing and focusing conservation efforts.

The Natural Heritage Ranking System

Key to the functioning of Natural Heritage Programs is the concept of setting priorities for gathering information and conducting inventories. The cornerstone of Natural Heritage inventories is the use of a ranking system to achieve the twin objectives of effectiveness and efficiency.

Ranking species and ecological communities according to their imperilment status provides guidance for where Natural Heritage Programs should focus their information-gathering activities. To determine the status of species within Colorado, CNHP gathers information on plants, animals, and plant communities. Each of these elements of natural diversity is assigned a rank that indicates its relative degree of imperilment on a five-point scale (for example, 1 = extremely rare/imperiled, 5 = abundant/secure). The primary criterion for ranking elements is the number of occurrences (in other words, the number of known distinct localities or populations). This factor is weighted more heavily than other factors because an element found in one place is more vulnerable to extinction than something found in twenty-one places. Also of importance are the size of the geographic range, the number of individuals, the trends in both population and distribution, identifiable threats, and the number of protected occurrences.

Element imperilment ranks are assigned both in terms of the element's degree of imperilment within Colorado (its State-rank or S-rank) and the element's imperilment over its entire range (its Global-rank or G-rank). Taken together, these two ranks indicate the degree of imperilment of an element. For example, the lynx, which is thought to be secure in northern North America but is known from less than five current locations in Colorado, is ranked G5 S1 (globally-secure, but critically imperiled in this state). The Rocky Mountain Columbine, which is known only in Colorado from about 30 locations, is ranked a G3 S3 (vulnerable both in the state and globally, since it only occurs in Colorado and then in small numbers). Further, a tiger beetle that is only known from one location in the world at GRSA is ranked G1 S1 (critically imperiled both in the state and globally, because it exists in a single location). CNHP actively collects, maps, and electronically processes specific occurrence information for animal and plant species considered extremely imperiled to vulnerable in the state (S1 - S3). Several factors, such as rarity, evolutionary distinctiveness, and endemism (specificity of habitat requirements), contribute to the conservation priority of each species. Certain species are “watchlisted,” meaning that specific occurrence data are collected and periodically analyzed to determine whether more active tracking is warranted. A complete description of each of the Natural Heritage ranks is provided in Table C1.

Table C1. Definition of Natural Heritage Imperilment Ranks

Rank*	Explanation
G/S1	Critically imperiled globally/state because of rarity (5 or fewer occurrences in the world/state; or 1,000 or fewer individuals), or because some factor of its biology makes it especially vulnerable to extinction.
G/S2	Imperiled globally/state because of rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout its range.
G/S3	Vulnerable through its range or found locally in a restricted range (21 to 100 occurrences, or 3,000 to 10,000 individuals).
G/S4	Apparently secure globally/state, though it may be quite rare in parts of its range, especially at the periphery. Usually more than 100 occurrences and 10,000 individuals.
G/S5	Demonstrably secure globally/state, though it may be quite rare in parts of its range, especially at the periphery.
G/SX	Presumed extinct globally, or extirpated within the state.
G#?	Indicates uncertainty about an assigned global rank.
G/SU	Unable to assign rank due to lack of available information.
GQ	Indicates uncertainty about taxonomic status.
G/SH	Historically known, but usually not verified for an extended period of time.
G#T#	Trinomial rank (T) is used for subspecies or varieties. These taxa are ranked on the same criteria as G1-G5.
S#B	Refers to the breeding season imperilment of elements that are not residents.
S#N	Refers to the non-breeding season imperilment of elements that are not permanent residents. Where no consistent location can be discerned for migrants or non-breeding populations, a rank of SZN is used.
SZ	Migrant whose occurrences are too irregular, transitory, and/or dispersed to be reliably identified, mapped, and protected.
SA	Accidental in the state.
SR	Reported to occur in the state but unverified.
S?	Unranked. Some evidence that species may be imperiled, but awaiting formal rarity ranking.

*Where two numbers appear in a state or global rank (for example, S2S3), the actual rank of the element is uncertain, but falls within the stated range.

This single rank system works readily for all species except those that are migratory. Those animals that migrate may spend only a portion of their life cycles within the state. In these cases, it is necessary to distinguish between breeding, non-breeding, and resident species. As noted in Table 1, ranks followed by a "B," for example S1B, indicate that the rank applies only to the status of breeding occurrences. Similarly, ranks followed by an "N," for example S4N, refer to non-breeding status, typically during migration and winter. Elements without this notation are believed to be year-round residents within the state.

Legal Designations for Rare Species

Natural Heritage imperilment ranks should not be interpreted as legal designations. Although most species protected under state or federal endangered species laws are extremely rare, not all rare species receive legal protection. Legal status is designated by either the U.S. Fish and Wildlife Service under the Endangered Species Act or, in Colorado by the Department of Natural Resources, Colorado Parks and Wildlife division under Colorado Statutes 33-2-105 Article 2. In addition, the U.S. Forest Service recognizes some species as "Sensitive," as does the Bureau of Land Management. Table C2 defines the special status assigned by these agencies and provides a key to abbreviations used by CNHP.

Table C2. Federal and State Agency Special Designations for Rare Species

Acronym	Definition
1. U.S. Fish and Wildlife Service (58 Federal Register 51147, 1993) and (61 Federal Register 7598, 1996)	
LE	*Listed Endangered*: defined as a species, subspecies, or variety in danger of extinction throughout all or a significant portion of its range.
LT	*Listed Threatened:* defined as a species, subspecies, or variety likely to become endangered in the foreseeable future throughout all or a significant portion of its range.
P	*Proposed:* taxa formally proposed for listing as Endangered or Threatened (a proposal has been published in the Federal Register, but not a final rule).
C	*Candidate:* taxa for which substantial biological information exists on file to support proposals to list them as endangered or threatened, but no proposal has been published yet in the Federal Register.
PDL	*Proposed for delisting*.
XN	*Nonessential experimental population*.
2. U.S. Forest Service (Forest Service Manual 2670.5) (noted by the Forest Service as S")	
FS	*Sensitive:* those plant and animal species identified by the Regional Forester for which population viability is a concern as evidenced by: Significant current or predicted downward trends in population numbers or density. Significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution.
3. Bureau of Land Management (BLM Manual 6840.06D) (noted by BLM as "S")	
BLM	*Sensitive:* those species found on public lands designated by a State Director that could easily become endangered or extinct in a state. The protection provided for sensitive species is the same as that provided for C (candidate) species.
4. State Status: Colorado Parks and Wildlife (CPW) has developed categories of imperilment for non-game species. The categories being used and the associated CNHP codes are provided below.	
E	*Endangered:* those species or subspecies of native wildlife whose prospects for survival or recruitment within this state are in jeopardy, as determined by the Commission.

Table C2 (continued). Federal and State Agency Special Designations for Rare Species

Acronym	Definition
4. State Status (continued): Colorado Parks and Wildlife (CPW) has developed categories of imperilment for non-game species. The categories being used and the associated CNHP codes are provided below.	
T	*Threatened:* those species or subspecies of native wildlife which, as determined by the Commission, are not in immediate jeopardy of extinction but are vulnerable because they exist in such small numbers, are so extremely restricted in their range, or are experiencing such low recruitment or survival that they may become extinct.
SC	*Special Concern:* those species or subspecies of native wildlife that have been removed from the state threatened or endangered list within the last five years; are proposed for federal listing (or are a federal listing "candidate species") and are not already state listed; have experienced, based on the best available data, a downward trend in numbers or distribution lasting at least five years that may lead to an endangered or threatened status; or are otherwise determined to be vulnerable in Colorado.

Element Occurrences and Their Ranking

Actual locations of elements, whether they are single organisms, populations, or plant communities, are referred to as element occurrences. The element occurrence is considered the most fundamental unit of conservation interest and is at the heart of the Natural Heritage Methodology. To prioritize element occurrences for a given species, an element occurrence rank (EO-Rank) is assigned according to the ecological quality of the occurrences whenever sufficient information is available. This ranking system is designed to indicate which occurrences are the healthiest and ecologically the most viable, thus focusing conservation efforts where they will be most successful. The EO-Rank is based on three factors:

Size – a measure of the area or abundance of the element's occurrence. This factor takes into account aspects such as area of occupancy, population abundance, population density, population fluctuation, and minimum dynamic area (which is the area needed to ensure survival or re-establishment of an element after natural disturbance). This factor for an occurrence is evaluated relative to other known, and/or presumed viable, examples.

Condition/Quality – an integrated measure of the composition, structure, and biotic interactions that characterize the occurrence. This includes measures such as reproduction, age structure, biological composition (such as the presence of exotic versus native species), structure (for example, canopy, understory, and ground cover in a forest community), and biotic interactions (such as levels of competition, predation, and disease).

Landscape Context – an integrated measure of two factors: the dominant environmental regimes and processes that establish and maintain the element, and connectivity. Dominant environmental regimes and processes include herbivory, hydrologic and water chemistry regimes (surface and groundwater), geomorphic processes, climatic regimes (temperature and precipitation), fire regimes, and many kinds of natural disturbances. Connectivity includes aspects such as a species having access to habitats and resources needed for life cycle completion, fragmentation of ecological communities and systems, and the ability of the species to respond to environmental change through dispersal, migration, or re-colonization.

Each of these factors is rated on a scale of A through D, with A representing an excellent rank and D representing a poor rank. These ranks for each factor are then averaged to determine an appropriate EO-Rank for the occurrence. If not enough information is available to rank an element occurrence, an EO-Rank of E is assigned. EO-Ranks and their definitions are summarized in Table C3.

Table C3. Element Occurrence Ranks and their Definitions

Rank	Definition
A	Excellent viability.
B	Good viability
C	Fair viability.
D	Poor viability.
H	Historic: known from historical record, but not verified for an extended period of time.
X	Extirpated (extinct within the state).
E	Extant: the occurrence does exist but not enough information is available to rank.
F	Failed to find: the occurrence could not be relocated.

Appendix D: Species Habitat Modeling Methods

Species Habitat Modeling

Species distribution or habitat modeling is one of many tools available to assist land managers in the complex process of regulating and prioritizing different land-use scenarios. Developing a predictive model of the potential distribution of a particular species can involve several different techniques, and be reported under a variety of names. All such models, however, are based on the ecological principle that the presence of a species on the landscape is controlled by a variety of biotic and abiotic factors, in the context of biogeographic and evolutionary history. Because we rarely, if ever, have complete and accurate knowledge of these factors and history, we can only seek to predict or discover suitable habitat by using characteristics of known occurrences of the taxon in question.

The modeling process is further constrained by our inability to measure habitat characteristics accurately on a continuous spatial scale. As a result, modeling factors are usually an approximation of the environmental factors that control species distribution, using available data that is probably only a surrogate for the actual controlling factors. In the context of our study, species distribution modeling is a process that uses a sample of a real distribution (known locations or element occurrences) to build a model (estimate) of suitable environmental conditions (and, by implication, unsuitable conditions), and map that model across a study area.

It is important to regard these models as hypotheses intended to be field tested, and not as definitive maps of suitable habitat. A variety of life-history and biogeographic factors may preclude the presence of the target element in areas of predicted suitable habitat. Likewise, errors or lack of precision in modeling assumptions, input data, or procedures may incorrectly predict suitable habitat where none exists. In addition, users should be aware that the true resolution of these distribution models is only as fine as the coarsest layer of input data. It is not appropriate to base land management decisions of 1-1000 m scale entirely on this type of analysis without additional field verification.

We used two different types of modeling approach: deductive and inductive. Deductive modeling is essentially knowledge-driven; it is often the best approach when we have limited data on exact occurrence locations, but have some information about habitat requirements of the species. In this case, we build our model directly from information about the species. For example, only areas within a certain elevation range, within a particular vegetation or soil type. This can work well for most taxa, but it may be difficult to find data layers that are good representations of critical habitat factors. With the inductive modeling approach, the output is data-driven. These modeling techniques use selected statistical functions to build a model that fits the occurrence data points onto the available environmental variables. For the analysis presented in this document, we used the maximum entropy inductive technique.

Maximum Entropy Modeling

In order to more accurately reflect the ecological factors that determine species distributions, we decided to model target species on a statewide basis rather than restrict the model to the study area. Time constraints led us to select the maximum entropy (Maxent) modeling procedure (Phillips et al.

2004, 2006) as a technique because it can generate a large number of species models quickly, and because it can use presence-only data. This procedure has been widely used in species distribution modeling and performs well in comparison with other methods (Elith et al. 2011).

The Maxent procedure is based on the concept of information entropy, which can be regarded as a measure of the information contained in a set of propositions (e.g., that species A occurs at only at elevations between 8,000 and 9,000 ft) in the context of some known data, called testable information (e.g., the elevation at actual known locations of species A). The most informative distribution would occur when one of the propositions was known to be true (i.e., we know absolutely that species A cannot be found at other elevations). In this case, the information entropy would be equal to zero. The least informative distribution would occur when there is no reason to favor any one of the propositions over the others (e.g., we have no real evidence that species A isn't found at all elevations). In that case, the only reasonable probability distribution would be uniform, and the information entropy would be equal to its maximum possible value.

In modeling species distributions with Maxent, we deliberately choose to use the distribution with the maximum entropy allowed by our information, that is, the most uninformative distribution possible given what we actually do know. To choose a distribution with lower entropy would be to assume information we do not possess; to choose one with a higher entropy would violate the constraints of the information we do possess. Thus the maximum entropy distribution is the most reasonable choice.

As with most inductive modeling, we use raster data that represents environmental conditions, i.e., elevation, precipitation, soil type, and so forth. Included data can represent any environmental conditions that seem biologically meaningful for the target species, and which is available for the study area. This data are combined with mapped known locations of the species, and the values of each input environmental parameter for each point location are identified and used as input data for the Maxent modeling procedure. Ideally, species distribution models are parameterized with environmental data that are known to be highly predictive of conditions determining the ability of a species to persist. Unfortunately, for many species we lack even basic life-history information that could guide input selection. Even when extremely detailed information about important microhabitat factors is available, these factors are generally not mapped or otherwise spatially represented at a scale that is equivalent to that experienced by the organism. Consequently, models represent a best-guess scenario in which we know that our data are incomplete and of insufficiently fine resolution.

The Maxent program estimates (from the environmental covariate data of the documented locations, and from the covariate data of 10,000 randomly selected background points within the study area) a distribution that is consistent with the known occurrence data. This estimate is also as close as possible to the means from the background points, i.e., it has the largest entropy. That is, the species distribution is estimated by minimizing the environmental distance between the occupied points and background points, subject to constraining the means of estimated occupied factors to be close to observed mean. The constraints ensure that the mean for a variable in the estimated distribution is close to the mean across the locations with occurrences. A model is fit on transformations of the covariates, and the raw solution is transformed to logistic output that is used to produce a probability surface map that more-or-less represents areas of potentially suitable habitat.

Literature Cited

Elith, J., S.J. Phillips, T. Hastie, M. Dudik, Y.E. Chee, and C.J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17:43-57.

Phillips, S. J., M. Dudik, and R.E. Schapire. 2004. A maximum entropy approach to species distribution modeling. Pages 655-662 in Proceedings of the 21st International Conference on Machine Learning. ACM Press, New York .

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

Dataset Details

Annual Growing Degree Days

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org
Other citation details:	Annual Growing Degree-days
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet Annual Growing degree-days for Colorado (The summation for a year of the daily average air temperatures for the period that are greater than 0.0 °C. Units are degree-days). Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Annual Precipitation

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org
Other citation details:	Annual Total Precipitation
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet total annual precipitation (centimeters) for Colorado. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Annual Precipitation Frequency ("Wet Days")

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org

Other citation details: Annual Precipitation Frequency
Source scale denominator: 1 km resolution raster
Source contribution: Habitat model environmental input.

Daymet Annual Precipitation Frequency for Colorado (proportion of days in a year with any precipitation, range 0 to 1). Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

April Minimum Temperature

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online links: http:\\www.daymet.org
Other citation details: Monthly Minimum Temperature; April
Source scale denominator: 1 km resolution raster
Source contribution: Habitat model environmental input.

Daymet Monthly Minimum Temperature in April for Colorado. Units are degrees Celsius. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Aspect

Derived from U.S. Geological Survey. 2006. 30m Digital Elevation Model for Colorado.

Source scale denominator: 30 m resolution raster
Source contribution: Habitat model environmental input.
The Elevation raster was used to create an Aspect raster, which was then used to create two separate rasters representing northness and eastness.
northness = cos(aspect)
eastness = sin(aspect)

Values range from -1 to +1. Northness will take values close to 1 if the aspect is generally northward, close to -1 if the aspect is southward, and close to 0 if the aspect is either east or west. Eastness behaves similarly, except that values close to 1 represent east-facing slopes.

For more information on method used, see: http://ordination.okstate.edu/envvar.htm

CNHP EORs

The Colorado Natural Heritage Program, Colorado State University. May 2012. Colorado Biodiversity Tracking and Conservation System Element Occurrence Records.

Source scale denominator: 24,000
Source contribution: Known species occurrence input training and testing points.

CNHP Observations

The Colorado Natural Heritage Program, Colorado State University. May 2012. Colorado Natural Heritage Program Rare Species Observations.

Source scale denominator: 24,000
Source contribution: Known species observations input training and testing points.

Depth to Bedrock

Miller, D.A. and R.A. White. 1998. A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling.

Online links:	http://www.essc.psu.edu/soil_info/index.cgi?soil_data&conus
Other citation details:	Data derived from Natural Resources Conservation Service (NRCS) State Soil Geographic database (STATSGO).
Source scale denominator:	12,000 - 63,360
Source contribution:	Environmental Input

Depth to bedrock (field ROCKDEPM) is a single value per STATSGO polygon. Units are centimeters. Note that a value of 152 really means >= 152 cm and a value of 0 is really NoData (occurs on Water polygons only).

Tabular data were joined to NRCS STATSGO dataset (ArcInfo coverage) for Colorado and exported as a 30m raster.

Distance to Water

Derived from U.S. Geological Survey. 05/2010 (last update). High Resolution National Hydrography Dataset.

Online link:	http://nhd.usgs.gov/index.html
Other citation details:	NHDFlowline NHDWaterbody NHDPoint
Source scale denominator:	12,000 - 24,000
Source contribution:	Habitat model environmental input.

USGS High Resolution National Hydrography Dataset (NHD) for Colorado was queried for permanent water (polygon, line, and point). Results were converted to 30m raster and a distance raster calculated. Queries used:

NHDFlowline: ("FType" = 460 OR "FType" = 558) AND (("FCode" = 46000 OR "FCode" = 46006) OR ("GNIS_Name" IS NOT Null))

NHDWaterbody: "FCode" = 39000 OR "FCode" = 39004 OR "FCode" = 39009 OR "FCode" = 39010 OR "FCode" = 39011 OR "FCode" = 39012 OR "FCode" = 43600 OR "FCode" = 43617 OR "FCode" = 43618 OR "FCode" = 43621

NHDPoint: "FType" = 458

Distance to Wetland
Derived from United States Forest Service. 2006. LANDFIRE Current Vegetation for Colorado
and
U.S. Geological Survey. 05/2010 (last update). High Resolution National Hydrography Dataset.

Online links: http://landfire.cr.usgs.gov/viewer/viewer.html
http://nhd.usgs.gov/index.html

Source scale denominator: 12,000 - 24,000
Source contribution: Habitat model environmental input.

There is not a complete statewide dataset for wetland or riparian areas. Using available partial datasets (NWI, CDOW riparian) may just bias to mapped areas. Used NHD & LandFire as described below, although this is known to be an imperfect solution.

USGS High Resolution National Hydrography Dataset (NHD) for Colorado and USFS LandFire Current Vegetation were queried for wetland and riparian areas. Results were converted to 30m raster and a distance raster calculated. Queries used:

NHDWaterbody: "FType" = 361 OR "FType" = 466 OR "FCode" = 39001 OR "FCode" = 39005 OR "FCode" = 39006

LandFire Current Veg: "SYSTMGRPNA" LIKE '%Riparian%' OR "SYSTMGRPNA" LIKE '%Wet%'

Elevation
U.S. Geological Survey. 2006. 30m Digital Elevation Model for Colorado.

Online link: http://seamless.usgs.gov/website/seamless/viewer.php
Source scale denominator: 30 m resolution raster
Source contribution: Habitat model environmental input.

Geology
RS/GIS Laboratory, College of Natural Resources, Utah State University, USGS GAP Analysis Program. 09/17/2004. 1:500,000 Scale Geology for the Southwestern U.S.

Online links: http://earth.gis.usu.edu/swgap/
http://fws-nmcfwru.nmsu.edu/swregap/default.htm
Source scale denominator: 500,000
Source contribution: Habitat model environmental input - categorical.

Original vector data were rasterized and clipped to Colorado.

Landform
RS/GIS Laboratory, College of Natural Resources, Utah State University and USGS GAP Analysis Program. 09/15/2004. Ten Class DEM Derived Landform for the Southwest United States.

Online link: http://earth.gis.usu.edu/swgap/

Source scale denominator:	30 m resolution raster
Source contribution:	Habitat model environmental input - categorical.

Local Relief

Derived from U.S. Geological Survey. 2006. 30m Digital Elevation Model for Colorado.

Source scale denominator:	30 m resolution raster
Source contribution:	Habitat model environmental input.

A measure of surface roughness. Created from 30m DEM for Colorado by using FocalRange command:

FOCALRANGE(coelev30, Circle, 16, DATA)

May Minimum Temperature

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online links:	http:\\www.daymet.org
Other citation details:	Monthly Minimum Temperature; May
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet Monthly Minimum Temperature in May for Colorado. Units are degrees Celsius. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Number of Frost Days

Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org
Other citation details:	Annual average number of frost days
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet number of days in a year when the daily minimum air temperature is less than or equal to 0.0 °C for Colorado. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Slope

Derived from U.S. Geological Survey. 2006. 30m Digital Elevation Model for Colorado.

Source scale denominator:	30 m resolution raster
Source contribution:	Habitat model environmental input.

Degrees slope derived from USGS 30m DEM.

Soil pH

Derived from Miller, D.A. and R.A. White. 1998. A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling.

Online link:	http://www.essc.psu.edu/soil_info/index.cgi?soil_data&conus
Other citation details:	Data derived from Natural Resources Conservation Service (NRCS) State Soil Geographic database (STATSGO).
Source scale denominator:	12,000 - 63,360
Source contribution:	Habitat model environmental input.

Soil pH values are supplied for each of 11 standard soil levels, down to 2.5m. Values of 0 are really NoData. Non-zero pH values were averaged from layers 1 - 6 for this project. Note - a mathematical mean is not technically the appropriate way to lump multiple pH values, but we are restricted by how the data were originally recorded. Surface pH alone was not seen as sufficient information, so we averaged the values of the first 6 layers as a proxy for actual total pH down to 60cm soil depth.

Tabular data were joined to NRCS STATSGO dataset (ArcInfo coverage) for Colorado and exported as a 30m raster.

Soil Texture

Derived from Miller, D.A. and R.A. White. 1998. A Conterminous United States Multi-Layer Soil Characteristics Data Set for Regional Climate and Hydrology Modeling.

Online link:	http://www.essc.psu.edu/soil_info/index.cgi?soil_data&conus
Other citation details:	Data derived from Natural Resources Conservation Service (NRCS) State Soil Geographic database (STATSGO).
Source scale denominator:	12,000 - 63,360
Source contribution:	Habitat model environmental input - categorical.

Soil texture classes are supplied for each of 11 standard soil levels, down to 2.5m. For this modeling, we focused on the first 6 layers (to 60 cm). Because these data are categorical, we used the mode (majority). A mode over 6 inputs creates too many ties to be useful, so values for layers 1- 5 only were used instead.

Tabular data were joined to NRCS STATSGO dataset (ArcInfo coverage) for Colorado and exported as a 30m raster.

Spring Precipitation

Derived from Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org
Other citation details:	Monthly Total Precipitation
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet total precipitation (centimeters) for March, April, & May for Colorado were totaled to represent average spring precipitation. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Spring Snow Depth

Derived from National Operational Hydrologic Remote Sensing Center. 2004 – 2011. Snow Data Assimilation System (SNODAS) Data Products at NSIDC, 2004 - 2011 snow depth.

Online link:
http://nsidc.org/data/docs/noaa/g02158_snodas_snow_cover_model/index.html

Other citation details:	Boulder, Colorado USA: National Snow and Ice Data Center.
Source scale denominator:	30 arc seconds resolution raster
Source contribution:	Habitat model environmental input.

SNODAS snow depth (mm) data for March, April, and May were averaged over the years 2004 - 2011. Data for each month was treated as a separate input into the model.

Outputs were projected, downsampled to 30 m, and snapped to be consistent with all other inputs.

Summer Precipitation

Derived from Peter E. Thornton, National Center for Atmospheric Research. 2002. Daymet: Climatological Summaries for the Conterminous United States, 1980-1997.

Online link:	http:\\www.daymet.org
Other citation details:	Monthly Total Precipitation
Source scale denominator:	1 km resolution raster
Source contribution:	Habitat model environmental input.

Daymet total precipitation (centimeters) for June, July, & August for Colorado were totaled to represent average summer precipitation. Daymet represents an average from 1980 - 1997, at 1 kilometer resolution. Raster was downsampled to 30m, re-projected and snapped to be compatible with other environmental inputs.

Vegetation type

RS/GIS Laboratory, College of Natural Resources, Utah State University and USGS GAP Analysis Program. 09/15/2004. Southwest Regional GAP Analysis Project Landcover.

Online link:	http://fws-nmcfwru.nmsu.edu/swregap/default.htm
Source scale denominator:	30 m resolution raster
Source contribution:	Environmental Input – categorical.

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