

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
Fort Collins, Colorado



Mojave Inventory and Monitoring Network Phase II Report

Natural Resource Report NPS/MOJN/NRR—2006/XXX



ON THE COVER

Mojave Network parks, clockwise from top, DEVA, MOJA, PARA, JOTR, LAME, GRBA, and MANZ.
Digital images: courtesy Mojave Network staff.

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Natural Resource Report NPS/MOJN/NRR—2006/XXX

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Scope of Phase II Report

The Mojave Network (MOJN) Vital Signs Monitoring Plan is being developed over a multi-year period following specific guidance from the NPS Washington Office (WASO) (NPS 2003a). Networks are required to document monitoring planning progress in three distinct phases and to follow a standardized reporting outline. Each phase of the report requires completion of specific portions of the outline.

The Phase II Report includes Chapter One (Introduction and Background), Chapter Two (Conceptual Models) and Chapter 3 (Vital Signs) of the monitoring plan. Other chapters will be developed for the Phase III Report, the first full version of the MOJN Monitoring Plan. This document presents the MOJN framework and approach to planning for vital signs monitoring and sets the stage upon which the program will be developed. Specifically, this report:

- introduces network monitoring goals and describes the process we will use to select key resources and monitoring questions;
- summarizes existing information concerning park natural resources and identifies the most significant resources and resource threats for each park across the network;
- introduces the ecological context of the Mojave and Great Basin Deserts and provides conceptual models of significant network ecosystems.
- summarizes the process used to identify, prioritize, and initially select network vital signs.
- introduces vital signs identified and initially selected and associated justification, monitoring questions, and/or monitoring objectives.

Three-phase planning process for Vital Signs development:

Planning Phase	Goals and Tasks	MOJN Deadlines
Phase I	Program Background, Description of Important Resources and Threats, Data Mining Results, and Conceptual Model Development	September 2005
Phase II	Vital Signs Prioritization, Selection, and Rationale	September 2006
Phase III Initial Draft	Monitoring Design/Monitoring Plan	December 2007
Phase III Peer-review	Monitoring Design/Monitoring Plan	December 2008

Executive Summary

Knowing the condition of natural resources in national parks is fundamental to the National Park Service's ability to manage park resources "unimpaired for the enjoyment of future generations". The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. The effort was undertaken to ensure that the approximately 270 park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. The national strategy consists of a framework having three major components: 1) completion of basic resource inventories; 2) creation of experimental prototype monitoring programs; and 3) implementation of ecological monitoring.

Parks with significant natural resources have been grouped into 32 monitoring networks linked by geography and shared natural resource characteristics. The network organization will facilitate collaboration, information sharing, and economies of scale in natural resource monitoring. Parks within each of the 32 networks work together and share funding and professional staff to plan, design, and implement an integrated long-term monitoring program. The Mojave Network (MOJN) is made up of 7 National Park Service units located in Arizona, California, and Nevada: Death Valley National Park, Great Basin National Park, Joshua Tree National Park, Lake Mead National Recreation Area, Manzanar National Historic Site, Mojave National Preserve, and Parashant National Monument.

The complex task of developing ecological monitoring requires a front-end investment in planning and design to ensure that monitoring will meet the most critical information needs and produce ecologically relevant and scientifically credible data that are accessible to managers in a timely manner. Network monitoring programs are being developed over a four-year timeframe with specific objectives and reporting requirements for each of three planning phases. This document is the second of three scheduled reports. Its purpose is to: 1) outline MOJN monitoring goals and the planning process we will use to develop the monitoring program; 2) summarize existing information concerning park natural resources and identify the most significant resources, resource concerns and issues across the network; and 3) introduce the ecological context and provide a conceptual model framework for Mojave-Great Basin ecosystems.

Over the next year, MOJN staff, park managers and scientists, and collaborators from the scientific community will be engaged in writing protocol development summaries, data 'mining' activities, and the documentation and analysis of existing monitoring datasets. The network also hopes to initiate work on aspects of implementation such as sampling design, data management, budget, etc.

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Many people contributed their ideas and hard work toward the development of the MOJN monitoring program and the preparation of this report. The resource management and other staff of the MOJN parks contributed their time and efforts, through the MOJN Technical Committee, MOJN Curation Committee, and MOJN Water Resources Committee. The MOJN Technical Committee consists of Gretchen Baker, Linda Greene, Debra Hughson, Tom Leatherman, Kent Turner, Larry Whalon, Tod Williams, David Ek, Paul DePrey, and Kari Yanskey, to whom the MOJN network is indebted.

We thank the MOJN Board of Directors (JT Reynolds, Cindy Nielsen, Curt Sauer, William K. Dickinson, Tom Leatherman, Penny Latham, Jeff Bradybaugh, Dennis Shramm, Angela Evenden) for their support, advice and advocacy. We trust that through their involvement, the program will grow to be integrated into park management and relevant to resource-related decisions.

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We thank Lake Mead National Recreation Area and Pacific West Regional Office for all their administrative and technical support for the MOJN staff.

Thanks to Penny Latham, Pacific West Region I&M Coordinator, for guiding the MOJN through this intermediate step. We thank, John Gross, Washington Office I&M Ecologist. You both have facilitated and focused our efforts and provided an encouraging voice.

And finally, we greatly appreciate the leadership provided by Steve Fancy, NPS National Monitoring Leader. It is largely through his continuing dedication and guidance that the National Park Service monitoring program is becoming a reality.

Chapter 1 Introduction and Background

1.1 Mojave Network Overview

The Mojave Network (MOJN) is one of 32 National Park Service inventory and monitoring networks developing Vital Signs Monitoring Plans to assess the condition of park ecosystems. The MOJN is composed of seven units managed by the National Park Service (NPS) in Arizona, California, and Nevada (Table 1-1, Figure 1-1, and Figure 1-2). This network included Parashant National Monument (PARA) a unique entity that it is managed jointly by the NPS and Bureau of Land Management (BLM) (Table 1-1). The majority of network parks are within the Great Basin-Mojave Desert region, which forms a broad wedge between the Sierra Nevada, the Transverse ranges, the Southern Rocky Mountains, and the Columbia and Colorado plateaus (Brussard et al. 1998). Network parks are often characterized by significant topographic relief and elevation gradients (Table 1-1, elevation range). These elevation gradients influence temperature regimes (though the interaction of air density, solar radiation, precipitation, and slope), soil development and ultimately the distribution of plant and animal communities across the region. The biota of MOJN parks are diverse and contain elements of neighboring ecosystems, including the Sonoran Desert (JOTR, MOJA, LAME), the Southern California Mountains (JOTR, MOJA, DEVA), the Great Basin (GRBA), and the Colorado Plateau (PARA). Biological diversity across the network is concentrated primarily in riparian habitats (e.g. springs, oases, stream corridors), montane islands, and specialized habitats (e.g. sand dunes) (Brussard et al. 1998). Network parks contain a variety of regionally, nationally, and globally significant resources. Appendix A contains a general overview of each network park.

Table 1-1. Basic characteristics of MOJN park units.

Park Name	Abbreviation	Hectares	Elevation Range (m)
Death Valley National Park	DEVA	1,374,420	-86 to 3,368
Great Basin National Park	GRBA	31,194	1,615 to 3,981
Joshua Tree National Park	JOTR	321,327	0 to 1,772
Lake Mead National Recreation Area	LAME	521,346 ^a	152 to 1,719
Manzanar National Historical Site	MANZ	329	1,158
Mojave National Preserve	MOJA	619,923	274 to 2,438
Parashant National Monument	PARA	424,242 ^b	366 to 2,447
Total		3,292,732	-86 to 3,981

^a Excludes 84,358 hectares of NPS-owned land currently within LAME boundary that is now part of PARA; Total park acreage for LAME including NPS-owned land within PARA is 605,704 hectares.

^b Total size of PARA includes 84,358 hectares of NPS-owned land, 327,288 hectares of BLM-managed lands, and 12,595 hectares of non-federal lands.



Overview of Parks in the Mojave Network

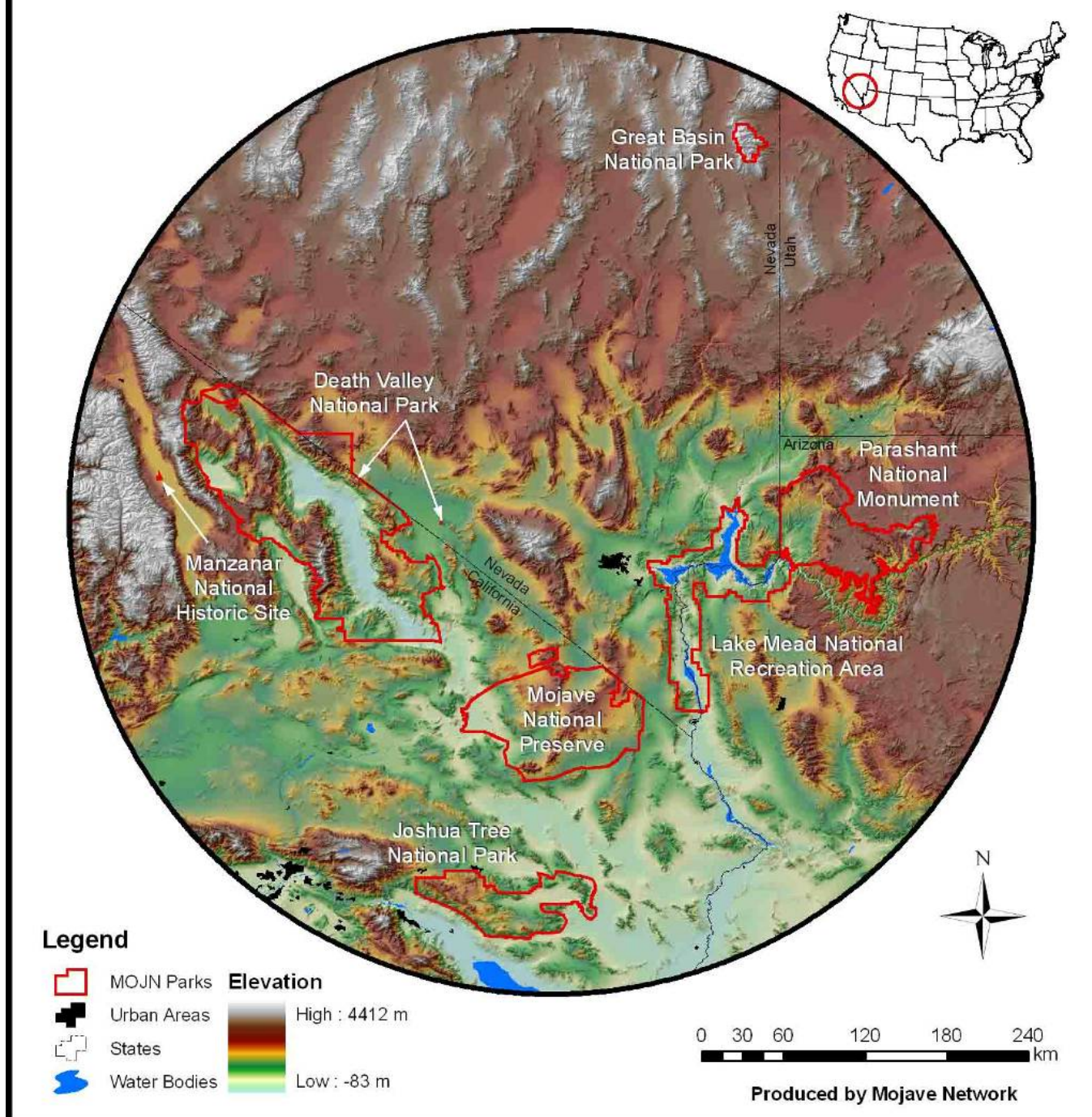


Figure 1-1. Parks included in the Mojave Inventory and Monitoring Network.



Land Ownership across the Mojave Network

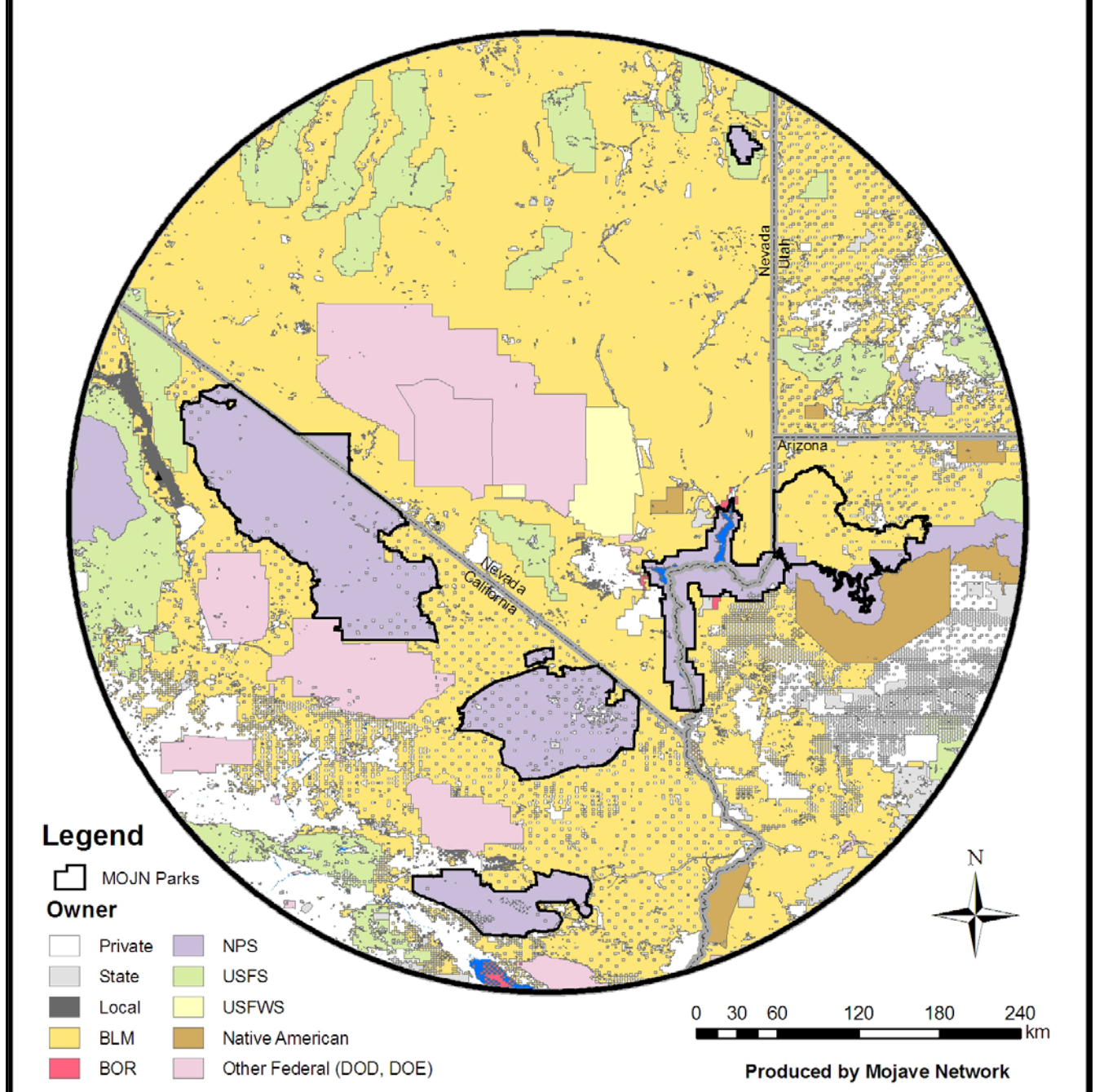


Figure 1-2. Land ownership across the Mojave Network.

The enabling legislation of an individual park provides insight into the natural and cultural resources and resource values that it was created to preserve. Along with national legislation, policy and guidance, a park's enabling legislation provides justification and, in some cases, specific guidance for the direction and emphasis of resource management programs, including inventory and monitoring. Appendix B contains a description of the enabling legislation, other related legislation, mission, purpose, and management goals for MOJN parks.

MOJN parks are surrounded by a significant amount of public land (Figure 1-2). The quality of the surrounding landscape in which national park units are embedded is vital to the long-term integrity of the units themselves. Attributes of the surrounding landscapes contribute to both abiotic and biotic dynamics of national parks (Saunders et al. 1991, Meffe and Carroll 1997) and are major determinants of both short-term and long-term protection effectiveness (Schonewald-Cox 1988).

1.1.1 Death Valley National Park

Death Valley National Park (DEVA) lies in the extreme western portion of the Basin and Range physiographic province (Figure 1-3). Two principal mountain ranges embrace DEVA, the Panamint Range on the west and the Armagosa Range on the east. Relief is dramatic, from the highest point at Telescope Peak (3,368 meters above sea level-a.s.l.) to the lowest point at Badwater (-86 meters below sea level). DEVA is renowned for its exposed, complex and diverse geology and tectonics, including one of only two active rift faults known in the world. Additionally, the park contains five major dune systems representing all dune types and one of the only places on earth where this variety of dune types occur in such close proximity.



Figure 1-3. DEVA. Photo D. Miller.

1.1.2 Great Basin National Park

Great Basin National Park (GRBA) is the only National Park wholly within the Great Basin physiographic region (Figure 1-4). GRBA lies in the South Snake Range in east-central Nevada and is essentially a mountain park with more than 2,800 hectares (ha) above 3,050 meters (m) in elevation. Due in part to its distance from urban centers, GRBA contains many relatively pristine natural resources. Biological diversity is perhaps the most notable attribute of GRBA due to the elevation, temperature, and moisture gradients in the South Snake Range. Ten perennial stream systems and 5 alpine lakes support significantly greater biological productivity than surrounding, more arid areas and have great local and regional ecological significance due to the scarcity of water in the South Snake Range.



Figure 1-4. GRBA. Photo J. Arnott.

1.1.3 Joshua Tree National Park

Joshua Tree National Park (JOTR) lies at the eastern terminus of the Transverse Ranges physiographic province, along the east-west oriented Little San Bernardino Mountains (Figure 1-5). The southern park boundary follows the base of these mountains along the northern perimeter of the Coachella Valley, and the northern park boundary is defined by the Morongo Basin. A unique diversity of desert flora is represented within JOTR as a consequence of a compressed transition zone between the Mojave and Sonoran Deserts. Over 700 plant species have been documented at JOTR. The original impetus for the creation of JOTR was the wholesale uprooting of native desert vegetation that occurred in the 1920's. The highlands of JOTR form a peninsula that sustains many floral and faunal elements of the southern California mountain ranges. Several endemic coastal species have evolved due to the relative isolation of this peninsula and selective pressures of the desert environment (NPS 1995).



Figure 1-5. JOTR. Photo P. Latham.

1.1.4 Lake Mead National Recreation Area

Lake Mead National Recreation Area (LAME) encompasses 229 kilometers of the Colorado River in northwestern Arizona and southern Nevada (Figure 1-6). The recreation area is centered on two artificial lakes, Lake Mead and Lake Mojave. This park is located within the Basin and Range physiographic province. Mountain ranges to the north include the Black Mountain and the Muddy Mountains. Mountain ranges to the south (west of the Colorado River and Lake Mohave) are Eldorado and Newberry Mountain. The park has approximately 75,000 ha of designated wilderness and thousands of additional hectares proposed as such.



Figure 1-6. LAME. NPS Photo.

1.1.5 Manzanar National Historic Site

Manzanar National Historic Site (MANZ) is located in the Owens Valley of southern California and encompasses 329 ha at an elevation of approximately 1,159 m above sea level (Figure 1-7). The park is shielded from moist ocean air masses by the Sierras and predominantly experiences a high desert type climate. Natural resource diversity is highest along Bairs Creek, the primary natural watercourse, which flows west to east through the Park toward the Owens River. This creek is intermittent, carrying substantial flows during periods of spring and summer runoff, but tapering off to minimal or no flow during fall and winter months. Natural vegetation at MANZ is primarily Great Basin sagebrush scrub, characterized by low shrubs such as sagebrush, saltbush (*Atriplex polycarpa*), and rabbitbrush (*Chrysothamnus nauseosus*), and a variety of forbs, cacti, and grasses.



Figure 1-7. MANZ. NPS Photo.

1.1.6 Mojave National Preserve

Mojave National Preserve (MOJA) is characterized by isolated mountain ranges and ridges separated by alluvium-filled, irregular large valleys (Figure 1-8). Dividing MOJA in half is the northeast trending Providence-Mid Hills-New York Mountain ranges. Elevation at MOJA ranges from 275 meters a.s.l. to 2,439 m a.s.l. MOJA has a hot desert climate. Winter temperatures range from 1 to 16 °C, and summer temperatures range from 25 to 43 °C. Precipitation occurs primarily in the form of rain, averaging 21.8 cm per year (NPS 2000b). MOJA encompasses a vast expanse of desert land set among a landscape of mountain ranges, sand dunes, great mesas and extinct volcanoes (NPS 2000b). Represented within these desert lands are a combination of Great Basin, Sonoran, and Mojave Desert ecosystems. Numerous natural resources at MOJA have regional, national, or global significance and serve as the basis for management.



Figure 1-8. MOJA. Photo D. Miller.

1.1.7 Parashant National Monument

The Parashant National Monument (PARA) was created by presidential proclamation on January 11, 2000 (Figure 1-9). The unit encompasses approximately 410,000 ha of land that will be jointly managed by the NPS and Bureau of Land Management (BLM). The NPS will retain primary authority over the Shivwits Plateau, approximately 87,414 ha of land within the boundaries of LAME. The monument is at the junction of two physiographic ecoregions: the Mojave Desert and the Colorado Plateau. The western margin of the Shivwits Plateau marks the boundary between the Sonoran/Mojave/Great Basin floristic provinces to the west and south and the Colorado Plateau province to the northeast. The intersection of these biomes is a distinctive feature of this park (Stevens 2001).



Figure 1-9. PARA. NPS Photo.

1.2 Purpose

The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. The effort was undertaken to ensure that the approximately 270 park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. The national strategy consists of a framework having three major components: (1) completion of basic resource inventories upon which monitoring efforts can be based; (2) creation of experimental Prototype Monitoring Programs to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters ("vital signs") in all natural resource parks (NPS 2005a)

1.2.1 Justification for Monitoring

Knowing the condition of natural resources in national parks is fundamental to the Service's ability to manage park resources "unimpaired for the enjoyment of future generations" (NPS 1916). NPS managers across the country are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources as a foundation for making decisions, working with other agencies, and the public for the benefit of those resources.

For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas to assess the efficacy of management practices and restoration efforts and to provide early warning of impending threats. The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because most parks are open systems, with threats such as air and water pollution, or invasive species, originating outside of the park's boundaries. An ecosystem approach is further needed because no single spatial or temporal scale is appropriate for all system components and processes; the appropriate scale for understanding and effectively managing a resource might be at the species, population, community, or landscape level, and in some cases may require a regional, national or international effort to understand and manage the resource. National parks are part of larger ecosystems and must be managed in that context.

Monitoring is a central component of natural resource stewardship in the NPS, and in conjunction with natural resource inventories and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1-10). Ecological monitoring establishes reference conditions for natural resources from which future changes can be detected. Site-specific information provided through natural resource monitoring is needed to understand and identify change in complex, variable, and imperfectly understood ecosystems and to determine whether observed changes are within historic levels of variability or may indicate unwanted influences. Thus, monitoring data help define the typical limits of variation in park resources and when put into a landscape context, monitoring provides the basis for determining meaningful change in ecosystems. Monitoring results may also be used to determine what constitutes impairment and to identify the need to initiate or change management practices. Understanding the dynamic nature of park ecosystems and the consequences of human

activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

The intent of the NPS Inventory and Monitoring Program is to track 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 or resource significance, known as “vital signs.” This subset of resources and processes is part of the total suite of natural resources that park managers are directed to preserve “unimpaired for future generations” (NPS 1916). In situations where natural areas have been so highly altered that physical, chemical, and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

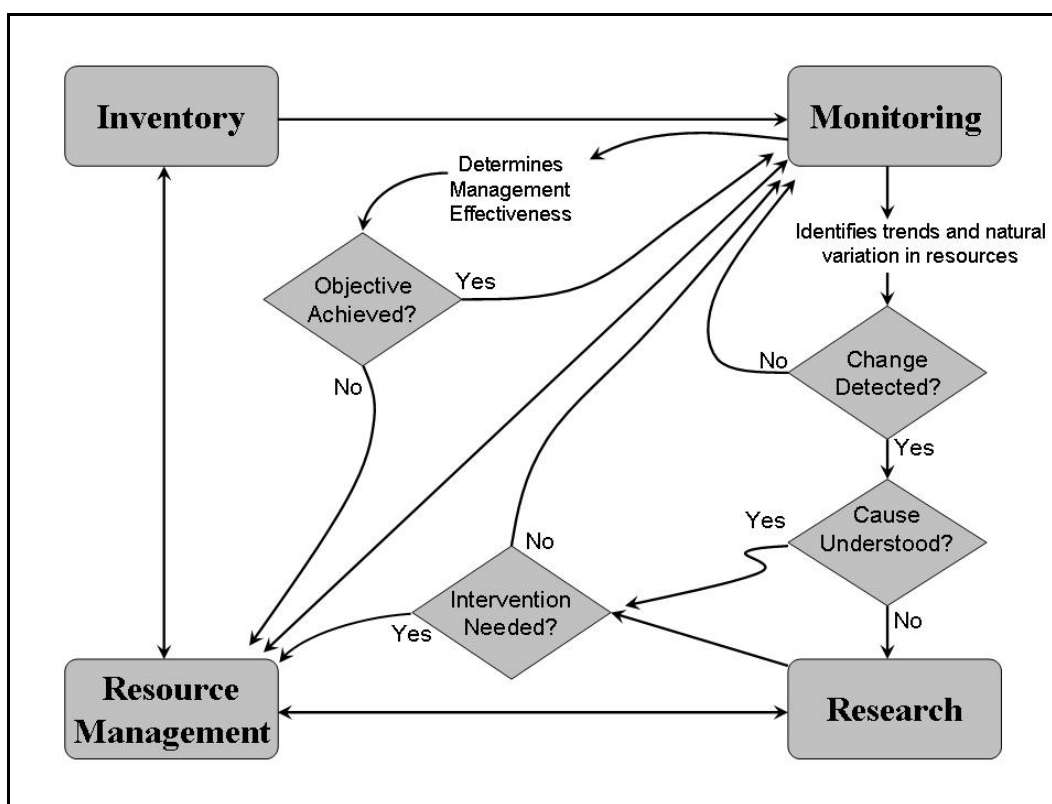


Figure 1-10. Relationships between inventories, monitoring, research, and natural resource management activities in national parks (modified from Jenkins et al. 2002).

1.2.2 Legislation, Policy, and Guidance

National Park managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission of leaving these resources “unimpaired for the enjoyment of future generations” (NPS 1916). Congress strengthened the National Park Service’s protective function, and provided language important to recent decisions about resource impairment, when it amended the Organic Act in 1978 to state that “the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established...”.

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. Section 5934 of the Act requires the Secretary of the Interior to develop a program of “inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources”. The Act charges the Secretary of the Interior to “assure the full and proper utilization of the results of scientific studies for park management decisions”. A summary of federal legislation and policy related to the inventory and monitoring efforts can be found in Appendix C.

The 2001 NPS Management Policies updated previous policy and specifically directed that “natural systems in the National Park System, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions”.

1.2.2.1 Government Performance and Results Act (GPRA)

It is particularly important to note the Government Performance and Results Act (GPRA), because of its central role in agency operations and its relationship to the monitoring program. The National Park Service has developed a national strategic plan identifying key goals to be met (NPS 2005b). The Vital Signs Monitoring Program reports directly to two GPRA goals identified for network parks (NPS 2005b) (Table 1-2, categories 1a & 1b).

In addition to the goals above, the Vital Signs Monitoring Program provides data and information systems needed to report to several other GPRA goals. For example, for new Department of Interior Land Health goals parks will use a combination of quantitative trend information from vital signs monitoring and other efforts, and qualitative assessments based on the best available scientific information and expert opinion, to report on the condition of resources within each land type (e.g. uplands, wetlands) and resource category (e.g. air, water)(NPS 2005a). A list of the national GPRA goals relevant to MOJN parks is provided in Table 1-2. In addition to the national strategic goals, each park unit has a five-year plan that includes specific park GPRA goals. Many of these park specific goals are directly related to natural resource monitoring needs. The source for the preceding information on justification for monitoring and legislation, policy, and guidance can be located online (NPS 2005a).

Table 1-2. GPRA goals specific to parks^a and relevant to development of a monitoring plan for the MOJN.

GPRA Goal	Goal #	DEVA	GRBA	JOTR	LAME	MANZ	MOJA
<i>Category 1a: Natural and cultural resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem context.</i>							
Disturbed Lands Restored	Ia1A	X	X	X	X		X
Exotic Plant Species	Ia1B	X	X	X	X		X
Land Health – Wetlands ^b	Ia1C		X				
Land Health – Riparian and Stream Areas ^b	Ia1D		X				
Land Health – Upland ^b	Ia1E		X				
Land Health – Mined Lands ^b	Ia1G		X		X		
Threatened and Endangered Species	Ia2	X	X	X	X		X
Species of Management Concern	Ia(0)2B		X	X	X		X
Exotic Animals	Ia2C	X	X		X		X
Air Quality and Wilderness Values	Ia3	X	X	X			
Surface Water Quality	Ia4	X	X	X	X		X
Water Quantity	Ia4B						X
Cultural Landscapes on the CLI	Ia7	X	X			X	X
Paleontological Resources	Ia9	X		X	X		X
<i>Category 1b: The National Park Service contributes to knowledge about natural and cultural resources and associated values; management decisions about resources and visitors are based on adequate scholarly and scientific information.</i>							
Park Natural Resource Data Sets	Ib01	X	X	X	X	X	X
Cultural Landscapes Baseline	Ib2B	X	X	X	X	X	X
Vital Signs Identified	Ib3A	X	X	X	X	X	X
Vital Signs Monitored	Ib3B	X	X	X	X	X	X

^a PARA not included because still developing park strategic and planning documents.

^b Goal targets will be established in 2006 after parks have completed baseline and status determinations. It is expected that several Mojave Network park units will adopt one or more of the land health goals.

1.2.2.2 National Park Service Mandates for Water Quality

The NPS Water Resources Division provides explicit guidance and funding for the water quality component of a network's monitoring program. Design and implementation of water quality monitoring is fully integrated with the network vital signs monitoring design process (including staffing, planning, design, etc.) to facilitate integration within the context of a comprehensive network monitoring program. Historically, availability of water quality data for the parks has been inconsistent due to the variety of agency and state efforts and protocols. The NPS goal is to rely on its own uniform monitoring data and use it to protect water resources. Monitoring of water quality also is supported through legislation, policy, and guidance described above,

including the 1916 Organic Act (NPS 1916), National Parks Omnibus Management Act (NPS 1998), and Natural Resource Challenge (NPS 1999a).

More explicit direction regarding monitoring and protection of water resources is provided through the NPS Strategic Plan 2005 to 2008 (NPS 2005b) which sets the following GPRA goal for the NPS system to meet by September 2008:

- 90% of lake, reservoir, estuarine, and marine areas managed by the National Park Service will meet State and Federal water quality standards as defined by the Clean Water Act.

Previous GPRA water quality goals targeted “swimmable beaches.” The strategic plan extended that goal to preventing the deterioration of the highest quality waters and improving the quality of the most degraded NPS waters. Each network, as part of the Vital Signs Monitoring Program, is required to:

1. Determine priorities for impaired water and pristine water monitoring;
2. Define site-specific monitoring objectives; and
3. Develop detailed water quality monitoring plans.

Planning and design for water quality monitoring will be addressed as a component of water resource monitoring within the MOJN. National GPRA goals related to water resources and relevant to MOJN parks are provided in Table 1-2. More holistic planning and design for water resource monitoring in the MOJN will include all water-related vital signs and will facilitate integration with the MOJN Vital Signs Monitoring Program. Detailed guidance for water quality monitoring developed by the NPS Water Resources Division is available at: <http://science.nature.nps.gov/im/monitor/vsmTG.htm#TGWater>.

1.2.3 Goals of Vital Signs Monitoring in the Mojave Network

The goals and objectives we define for monitoring frame our expectations and drive subsequent steps in the conceptual design and protocol development process. Ultimately, monitoring data are intended to detect long-term environmental change, provide insights into the ecological consequences of change and help decision-makers determine if observed changes indicate a needed change in management practices.

The Servicewide I&M Program has developed long-term goals to comply with legal requirements, fully implement NPS policy and to provide park managers with the data they need to understand and manage park resources. The Servicewide and MOJN goals for vital signs monitoring are listed below. Clearly articulated goals and objectives help define all aspects of a program including the choice of vital signs to be monitored. In the MOJN, objectives will be developed for each individual vital sign selected for monitoring.

Based on network monitoring goals, individual vital signs will be selected that address the most important attributes of ecosystems and/or resources that are of high importance for park management. Following recommendations by Noss (1990) and others, the MOJN aims to select

vital signs across a range of spatial and temporal scales and across multiple levels of ecological hierarchy, from the genetic to the landscape level. The program will include effects-oriented monitoring to detect changes in the status or condition of selected resources, stressor-oriented monitoring to meet certain legal mandates (e.g. Clean Air Act), and effectiveness monitoring by parks to measure progress toward meeting performance goals (NRC 1995, Noon et al. 1999). These goals also acknowledge the importance of seeking an understanding of inherent ecosystem variability in order to interpret human-caused change, and recognize the potential role of NPS ecosystems as reference sites for more impaired systems.

Service-wide and MOJN vital signs monitoring goals:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress toward performance goals.

1.3 General Ecological Overview

MOJN network parks encompass over 3.2 million ha of land and include vertical relief that ranges from the lowest point in North America in DEVA (-86 m a.s.l.) to the alpine peaks of GRBA (3,981 m a.s.l.). In this section we describe key abiotic and biotic characteristics of the MOJN as a preface to conceptual models presented in Chapter 2 to be more comprehensible. More detailed information for each subsection of this section can be found in Appendix D.

1.3.1 Ecoregions

In recent years, the idea of ecoregions has emerged as the most useful land classification system for supporting sustainable resource management practices (Bailey 1995, 1998). The ecosystem concept underlies the ecoregion system of land classification because it effectively brings together the biological and physical worlds into a framework by which natural systems can be described, evaluated, and managed (Rowe 1992).

The National Hierarchical Framework of Ecological Units developed by the USDA Forest Service (ECOMAP 1993, McNab and Avers 1994, Bailey 1995) provides a useful means of integrating factors such as regional physiography and climate to assess broad-scale differences and similarities among MOJN parks. The four levels of ecological units, in decreasing spatial scale, are *Domain*, *Division*, *Province*, and *Section*. Park units within the MOJN belong to five provinces within the Dry Domain (Figure 1-11). Units in the hierarchy are designed on the basis

of similarity for: 1) potential natural communities, 2) soils, 3) hydrologic function, 4) topography and landforms, 5) lithology, 6) climate, 7) air quality, and 8) ecological processes such as nutrient cycling and natural disturbance regimes (Cleland et al. 1997).

1.3.2 Regional Climate and the Role of Topography

Bailey (1995, 1998) describes climate as operating at the broadest spatial and temporal scales, and thus serving as a prime controlling factor for ecosystem distribution. Climate in the MOJN is one of the most extreme and variable in the world. The significant diurnal variation in temperature controls the structure and function of ecosystems in the MOJN (Bailey 1995). An understanding of both current (20th century) climate patterns and climate history is important to understanding and interpreting change and patterns in ecosystem attributes.

Desert conditions prevail across the MOJN because this region is in the rain shadow created by the Sierra Nevada and the Transverse Ranges of California. As air masses leaving coastal California meet the mountain ranges, they rise and cool, and atmospheric moisture condenses and precipitates. East of the mountains, moisture-deficient air masses descend and warm (the rain shadow). The rain and snow that precipitates on the mountains ultimately enters watersheds, some of which empty in desert basins.

The effect of the rain shadow, in combination with other regional factors, manifests itself by creating a moisture gradient with drier conditions prevailing in the west. However, summer and fall monsoons increase total annual precipitation to the eastern parts of the MOJN. In the west, precipitation mostly results from regional winter storms originating over the North Pacific Ocean. Toward the east, there is increasing likelihood of summer precipitation resulting from localized convective storms or the remains of large tropical depressions moving northward from the Gulf of California and the tropical Pacific Ocean. During winter, several gradients related to freezing temperatures are strong determinants of desert ecosystems (Figure 1-12). In general, winter temperatures decrease with increasing elevation and increasing latitude in the Great Basin and Mojave Deserts.

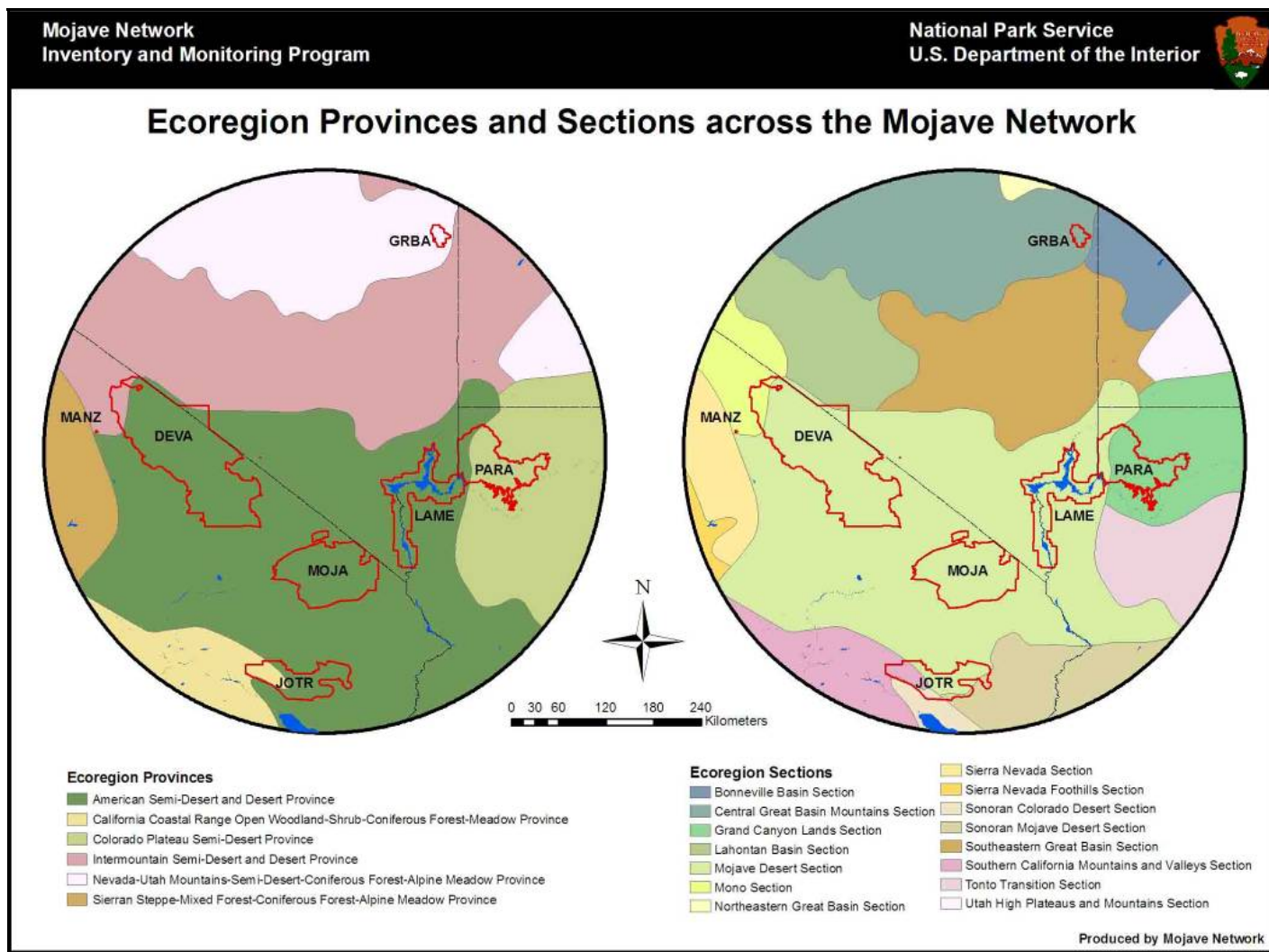


Figure 1-11. Ecoregion provinces and sections across the MOJN. Ecoregions boundaries are not abrupt and may encompass wide areas (park boundaries- red outlines).

Climate is locally influenced by topography. Winter precipitation is strongly orographic (e.g. related to increase in elevation due to mountains), increasing from approximately 100 mm at lower elevation sites to more than 500 mm near the tops of some Mojave Desert mountain ranges. Average temperature decreases approximately 6°C for every 1,000 m increase in elevation (Ricklefs 1990). Thus, topography directly influences the amount and timing of precipitation across large spatial gradients (across basins and ranges) and more proximal elevation gradients (e.g. on a single mountainside). The variation in temperature combined with topography results in high variability of potential evapotranspiration (e. g. water vapor resulting from evaporation from the ground and open waters, plus that resulting as a by-product of plant physiological processes) and soil-moisture storage. Patterns of plant distributions related to these environmental variables were formalized in a conceptual model over one hundred years ago (Merriam 1890) and are further elaborated on in the flora section of this document.

Closed basins, which are characteristic of the Basin and Range physiographic province often experience temperature inversions. During nighttime, cold air descends from the surrounding mountains and accumulates in valleys, creating an atmospheric inversion of cold air under warmer air. Temperatures frequently increase with increasing elevation above valleys and then decrease toward the tops of mountain ranges. This temperature inversion can affect the elevational distribution of plants, but may disappear toward the northern Great Basin due to strong winter storms that mix the air more thoroughly and disrupt the inversions (Grayson 1993). At more local scales, cold-air drainage along deeply incised washes causes colder temperatures than nearby higher ground. In the Mojave Desert, some species, such as brittlebush (*Encelia farinosa*) may have responded to the freezing temperatures within the washes with different genotypes that occur on hillslopes versus those adjacent to washes.

Within basin and range topography, local microclimate is also dependent on slope and aspect. For example, at any given elevation, a northeast-facing slope will likely have more effective moisture than a comparable southwest-facing slope. Steep slopes (>45%) further complicate plant and animal distributions. Higher angles of slope reduce the stability of surfaces, resulting in highly unstable talus or bare bedrock that is unsuitable for most plant species. An even finer resolution and more ephemeral effect of local topography and regional climate is the canyon effect. This effect occurs when rising warm air is funneled within a canyon and in turn creates strong upslope winds. At night, denser cool air rushes back down the bottoms of canyons. The diurnal temperature fluctuations induced by this air movement creates opportunities for plants to exceed their normal elevational limits.



Major Climatic Trends Across the Mojave Network

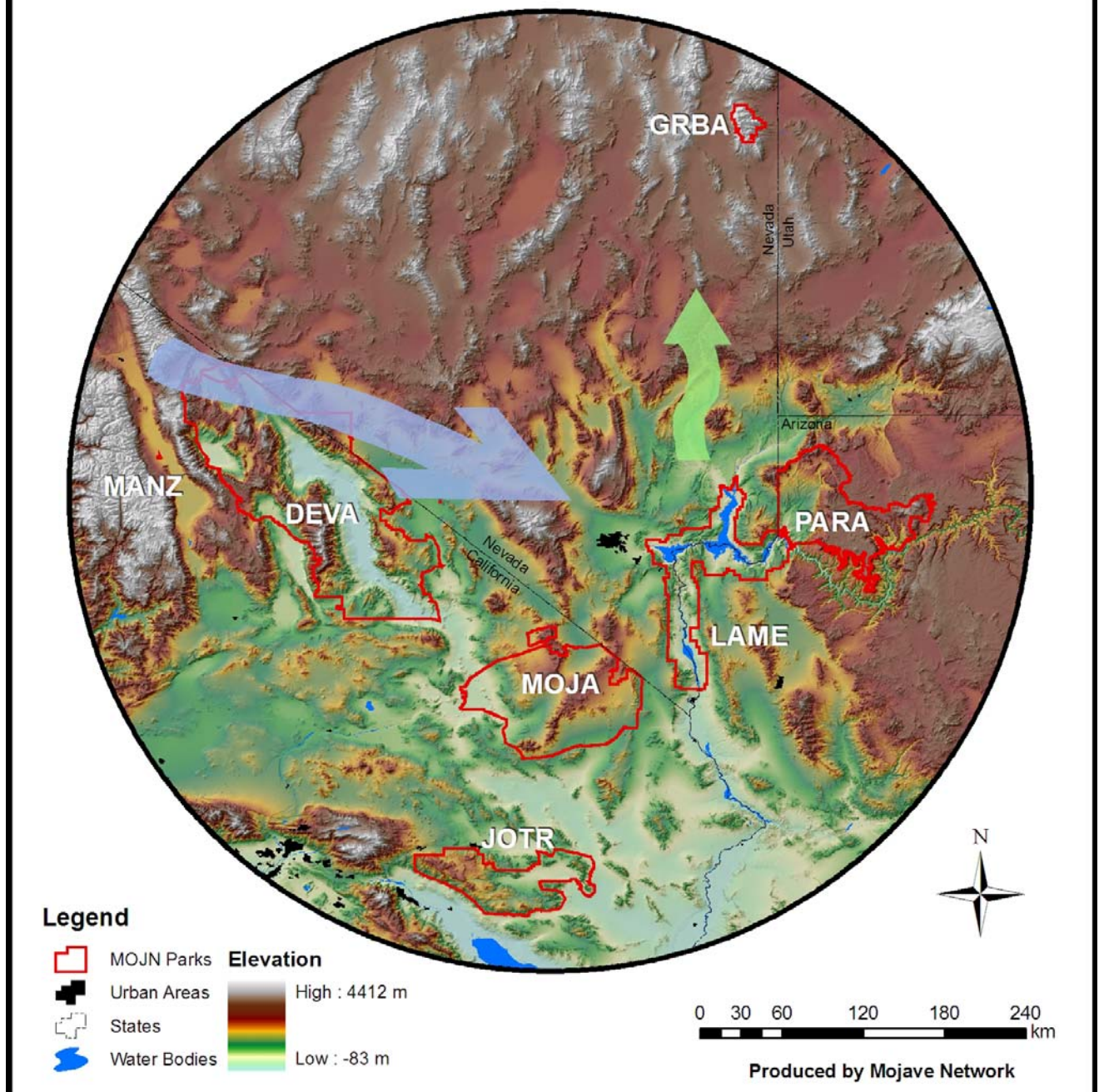


Figure 1-12. Regional view of major climatic trends. The green arrow shows increasing latitude and increasing average elevation northward in the Great Basin which results in cooler and wetter conditions. The blue arrow represents increasing precipitation across the Mojave Desert and a greater tendency for more summer precipitation along this gradient.

1.3.3 Air Resources

Air quality in the MOJN ranges from some of the best to the worst in the United States. In 2004, the American Lung Association State of the Air Report declared San Bernadino County, CA (including areas within or adjacent to JOTR and MOJA) to have the unhealthiest air in the nation (American Lung Association 2004). Recent data indicates that JOTR, MANZ, and MOJA are at high risk for foliar injury to plants from elevated ozone levels (NPS 2004a). In contrast, the best visibility in the contiguous United States occurs in an area centered near GRBA.

The most specific guidance related to air quality in national parks is provided in the Clean Air Act Amendments of 1977 and 1990, which established the Prevention of Significant Deterioration Program and designated certain areas, generally national parks and wilderness areas, as class I areas. These areas receive special protection from additional pollution and federal land managers have an “affirmative responsibility” to protect class I areas from adverse effects of air pollution. JOTR is the only unit in the network within a class I area. Other park units are considered class II areas, still receiving protection under the Clean Air Act, but to a lesser degree and allowing limited amounts of new emissions. Air quality in the network is affected primarily by pollution sources in California, Arizona, and Nevada, although more distant sources can also affect the area. Los Angeles, the San Joaquin Valley, and Las Vegas are major source areas, with significant emissions from mobile (e.g., cars, trucks, off-road vehicles), stationary (e.g., power plants and industry), and area sources (e.g., agriculture, fires, and road dust). With airflow from the south to southwest, GRBA is also impacted by the urban plume from Las Vegas and Los Angeles. Infrequently, airflow from the northeast during low pressure periods also may bring pollutants to GRBA from the direction of Salt Lake City, UT (DuBois and Green 2005). Although most of the park units in the network are some distance from cities and pollution sources, many experience poor air quality from pollutants such as ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxics (Table 1-3). A more detailed description of the air resources and issues of MOJN parks are found in Appendixes E and F.

Table 1-3. Air quality pollutants in the MOJN and associated sources of emission.

Component	Source
Sulfate	coal/oil fired power plants, refining and smelting activities
Nitrate	automobiles, combustion sources
OMC (Organic matter carbon)	biogenics (natural emissions), smoke, industrial solvents
LAC (light-absorbing carbon)	diesel exhaust, smoke
Soil	wind-blown dust, agricultural activities, off-road traffic
Particulate Pollution	dust, smoke, pollen
Rayleigh (Rayleigh scattering)	natural gases in the atmosphere

1.3.4 Geology and Geomorphology

The United States has been divided into physiographic or geomorphic regions based on common topography, rock types and structure, and geologic and geomorphic history. Fenneman and Johnson (1946) present a regional geologic classification system based on division, province and section (subdivision). MOJN park units are located in 2 physiographic provinces and 4 physiographic sections (Table 1-4).

The Basin and Range province is the largest in the United States and extends from southeastern Oregon and southern Idaho through Nevada and eastern California, southern Arizona, and New Mexico into western Texas. It is characterized by uplifted and tilted mountain ranges consisting primarily of thick Paleozoic and Mesozoic rocks separated by broad, elongate, alluvium-filled valleys. The overall structure of these mountain ranges and valleys is generally northwest-southeast. Most of the province is characterized by dramatic relief as exhibited at DEVA from the highest point at Telescope Peak (3,368 m a.s.l.) to the lowest point at Badwater (86 m below sea level). Topographic relief creates powerful elevation gradients that determine temperature regimes which in turn strongly influence the distribution of plant and animal communities across the region.

The Colorado Plateau province is bordered to the north and east by the Rocky Mountains and to the south and west by escarpments that divide it from the Basin and Range province. The Colorado Plateau is a high standing crustal block of relatively undeformed rocks and is characterized by large-textured forms developed on a great thickness of nearly horizontal Paleozoic, Mesozoic and Tertiary formations. Extensive areas of bare rock cover the Plateau's surface. A more detailed description of geologic and soil resources in the MOJN are found in Appendixes G and H.

Table 1-4. Physiographic provinces and sections within the MOJN.

Physiographic Province(s)	Physiographic Section(s)	Park
Basin and Range	Basin and Range	DEVA
		MANZ
		GRBA
	Sonoran Desert	LAME
		MOJA
		JOTR
Colorado Plateau	Salton Trough	
	Grand Canyon	PARA

1.3.5 Hydrology

Aquatic and associated riparian resources represent a very small portion of total land cover in the MOJN (excluding LAME), however they are disproportionately important from ecological

perspective (e.g. biodiversity, biological productivity, etc.). Infrequent precipitation and long periods of drought are defining characteristics of the MOJN (Whitford 2002).

Surface water resources in network parks include both lotic (flowing) and lentic (non-flowing) environments. Major lotic environments include the Colorado, Virgin, and Muddy Rivers. Other lotic environments include perennial streams and springs, and seasonal and ephemeral springs, streams, and seeps. Lentic (non-flowing water) environments in the MOJN include lakes and ponds, playas, and oases/springs as well as floodplains. Surface waters in parks are important for a variety of reasons including ecological significance, importance as a supply of drinking water, and association with important cultural sites. A variety of man-made structures exist across the desert landscape to provide artificial sources of surface water (e.g. guzzlers) for domestic livestock and wildlife. Of particular importance are the surface waters within GRBA which include 425 perennial springs and seeps, six alpine lakes, and ten perennial streams.

Lake Mead and Lake Mohave will not be incorporated into the conceptual models presented in Chapter 2. However, LAME encompasses two reservoirs formed by the Colorado River: Lake Mead and Lake Mojave. These two reservoirs have a surface area of 77,490 ha and are responsible for providing 90% of Southern Nevada's water supply. Largely due to recent drought conditions, lake levels dropped 27 m between 2000 and 2004. Lake levels have fluctuated without a clear trend since 2004. However, water management officials predict that lake levels will continue to drop if weather and water use predictions are correct (Allen 2003).

Ground-water hydrology (discharge at springs, seeps, and storage in ground-water aquifers) is controlled by factors affecting recharge through the unsaturated zone. Much of the present-day recharge in the MOJN is discharged to the atmosphere by evapotranspiration from the plants, the soil, or open water (lakes, reservoirs, spring pools, and wet playas). In the absence of any human development, the ground-water systems in the MOJN are in dynamic equilibrium with long-term climatic patterns. Rain and snow provide recharge to the ground-water system, which is balanced by an equal amount of discharge plus short-term changes in ground-water storage. Storage is depleted during periods of drought and replenished during wet periods. Over the long term, however, the system remains roughly in balance.

Additional information is provided in Appendix I on water resources in individual network parks, baseline water quality data inventory and analysis, clean water action plans (CWAP), water quality standards for states in the MOJN, and water monitoring projects in the MOJN.

1.3.6 Flora

The Mojave Desert has the highest frequency of endemic species in the western United States (McLaughlin 1989), which is indicative of its high value within the national park system. Vegetation in this region may be separated among several functional groups and between riparian and xerophytic species (Johnson 1976). Riparian species occur in the relatively rare situation with perennial surface water and/or high ground water. Xerophytic species occur on uplands and can be separated into annual, biennial, and perennial species. Most desert plants exhibit general adaptations to hot environments such as small leaf size and reduced stomata

number and size. Adaptive specializations that further improve the probability of survival include rooting patterns, stem photosynthesis, succulence, seed production and germination strategies, and different photosynthetic pathways (Whitford 2002). Annual, perennial, and biennial species tend to exhibit different adaptive specializations such as fine, shallow root systems in annual species and deep root systems frequently with some root near the soil surface exhibited by many perennial species. Understanding these functional differences between annual, perennial, and biennial species can help in predicting and interpreting plant response to stressors such as climate change.

Current vegetation in MOJN parks are a result of species evolution and migration in response to departures from normal climatic conditions (Thompson and Anderson 2000). Over time, more than one method has been used to categorize MOJN vegetation, making the biogeography of MOJN flora more complex and difficult to understand. The MOJN is in the Madrean floristic region (subkingdom) which is further sub-divided into three distinct floristic provinces; the California, Sonoran, and the Great Basin Provinces (Takhtajan 1986). To further complicate categorizing MOJN flora, McLoughlin (1989) indicates that GRBA shows a higher correlation with the Rocky Mountain floristic element. Using a unique methodology set forth by Olson et al. (2001) the MOJN falls into four distinct ecoregions: Colorado Plateau Shrublands, Great Basin-Shrub Steppe, Mojave Desert, and Sonoran Desert. The boundaries between these ecoregions, floristic provinces, floristic element, and biomes are imprecise and often encompass wide zones of transitions that include small areas that differ from their assigned classification (Olson et al. 2001). Appendix J contains a listing of the existing vegetation alliances and associations within the Mojave-Great Basin Desert region (compiled for MOJN by the Association for Biodiversity Information).

1.3.7 Fauna

Invertebrates and microorganisms are important inhabitants in desert ecosystems because of their roles in a wide range of functional groups, including predators, parasites, granivores, herbivores, pollinators and decomposers. Invertebrates comprise approximately 95% of all animals on earth (Mason 1995) and similarly comprise most of the animal biomass in deserts.

Microorganisms play an often unnoticed role in the function of desert ecosystems. They must be specially adapted to the harsh desert environment. Cyanobacteria are exclusively the endolithic primary producers in the desert due to their ability to adjust to extreme temperatures and low amounts of moisture (Atlas and Bartha 1998). Cyanobacteria fix atmospheric nitrogen into amino acids, helping to enrich the soil with nitrogen for plant growth. Fungi facilitate the decomposition of dead organic material, also making nutrients available for plants.

Until recently aquatic invertebrates were mostly overlooked due to the low amounts of free surface water in the Great Basin and Mojave Deserts. Unfortunately, significant numbers of aquatic invertebrates most likely exist in this region, but have not been described. As with terrestrial invertebrates, aquatic invertebrate communities experience the environment on a much smaller temporal and spatial scale than larger animals. Due to this characteristic, aquatic invertebrates can function as water quality monitors or indicators (Brussard et al. 1998). Many

aquatic invertebrates can be found in arid land springs that are scattered across the Mojave and Great Basin desert region. Springs are small wetlands supported by ground water that discharges onto the land. Each spring is distinctive due to its unique combination of water chemistry, discharge, temperature, elevation, morphology, and disturbance. Springs are becoming increasingly important and are referred to as biodiversity hotspots because they support a large proportion of the aquatic and riparian species in desert regions (Desert Research Institute 2005).

A variety of vertebrate species are found in the Great Basin, Mojave, and Sonoran Deserts. Vertebrates may be categorized taxonomically or by functional categories (based on how they acquire nutrients, the ecosystem services they provide, or processes that they participate in). Animals may be categorized based on their foraging method and may fall into one of the following groups: herbivores, granivores, carnivores, omnivores, and scavengers. Herbivores are some of the most readily apparent desert inhabitants and are represented broadly by cervids (mule deer), bovids (bighorn sheep), equids (horses), and artiodactyls (pronghorn). Granivores consume seeds for a significant portion of their diet and include kangaroo rats and many small birds (Pulliam and Brand 1975, Reichman 1977). Frugivores and seed dispersers are not particularly abundant in hot desert habitats, but more types are found in the Great Basin Desert because of the greater availability of fruits. One interesting frugivore found in hot deserts is a small bird known as the silky flycatcher or phainopepla (*Phainopepla* spp.) Phainopepla spend part of their lives feeding on the viscous fruit of a parasitic plant known as mistletoe (*Phoradendron* spp.). Nectarivores and pollinators include several types of birds that glean a large portion of their sustenance by gathering nectar from flowers. These species are largely summer residents in the Great Basin, but may inhabit the desert year round in the Sonoran and Mojave Deserts. Carnivores consume animal matter for a large part of their diets. Carnivores include the felines (mountain lion, bobcats), canines (coyote and foxes), mustelids (short-tailed weasels), raptors (hawks, owls and eagles), and rapacious songbirds such as the loggerhead shrike. Omnivores and scavengers are an interesting group of animals that are largely generalists. This group includes some mustelids (striped and spotted skunks), the ringtail (*Bassariscus* spp.) and avian species such as ravens. The classic scavenger of the desert is the turkey vulture (*Cathartes aura*).

1.3.8 Resources of Special Ecological Significance

Cave and karst systems are sensitive to many environmental factors including changes in hydrology (e.g. lowered water table), changes in water quality, atmospheric changes (e.g. CO₂, temperature), and altered geologic processes (e.g. erosion). Caves are generally stable environments when compared with surface ecosystems, often showing remarkable consistency in temperature and humidity (daily, seasonal, and annual). Unique, cool microclimates near cave mouths may be important for several plant and animal species. Caves in the MOJN are mostly dry, hydrologically inactive caves. Whereas Great Basin National Park has many wet active caves, Mojave National Preserve and Parashant National Monument have only one. For example Lehman Cave, one of the primary reasons for establishment of GRBA, is famous throughout the world for an unusual concentration of cave formations and abundance of shields (NPS 1992a).

Sand dunes are generally composed of well-sorted fine- to medium-grained sand. The sorting results in deep water infiltration and rapid evaporation of shallow moisture, and hence relatively short periods of near-surface water availability. Dunes are inhabited by distinctive plants that are able to colonize unstable materials, and this plant cover is crucial to dune stability. Plant cover less than 14% generally results in dune migration (Wiggs et al. 1995). Vegetation and biologic crust cover have been shown to vary with the effective moisture function ($P-E_p$), where P is precipitation and E_p is potential evapotranspiration. This function plus mean wind speed determine dune stability reasonably well (Woodruff and Armbrust 1968). Destabilized dunes and sheets can undergo blow-out, which can rapidly destabilize areas in a chain-reaction effect and migrate into areas that have not experienced eolian activity. DEVA, contains five major dune systems representing all dune types.

Playas are complex valley bottom systems that typically serve as terminal water flow and sediment deposition sites. However, a few playas are flow-through systems with exiting washes (e.g. Silurian Lake, Soda Lake). Playas can be broken into two fundamental types, wet and dry. Wet playas have shallow groundwater and undergo ground-water discharge, resulting in abundant salts, soft and sometimes unstable surfaces, and possible adjacent springs (e.g. Bristol Lake, Searles Lake, Death Valley floor, Soda Lake). Dry playas have deeper water tables and are periodically inundated by surface water, but have much less salt buildup than wet playas (e.g. Ivanpah Lake, Dale Lake, Racetrack Playa). Dry playas undergo deposition by distal piedmont alluvial processes, by shallow ephemeral lakes, and by eolian dust and sand. The resulting deposits of the playa and its fringing zones are highly variable mixed-process environments and typically defy categorization. Playas can be found throughout the MOJN, with numerous playas occurring at DEVA, JOTR, LAME, and MOJA.

The terms biotic soil crusts, microbiotic crusts, cryptobiotic crusts or cryptogamic soils (cryptogams) all refer to a diverse community of cyanobacteria, bacteria, lichen, mosses and metabolic by-products that are cemented into a semi-permeable soil surface. The biomass and species richness of biological soil crusts increase as precipitation quantity increases and precipitation temperature decreases. The lichen and moss components of the crusts are most prevalent at locations dominated by winter precipitation, whereas warm season precipitation seems to be a limiting factor for the distribution of these organisms (J. Belnap, *personal communication*). Intact biological soil crusts protect soils from both wind and water erosion, relative to bare soil, thus providing soil stabilization (Belnap 2003a, Warren 2003). Biological soil crusts are susceptible to trampling from large animals (including feral equids, livestock and recreationists) and disturbances from vehicles. Biological soil crusts can be found in all network parks.

Riparian communities are supported along water major watercourses and lakeshores and are associated with isolated springs, seeps, ponds, and streams. A significant number of species of special concern also are associated with aquatic and riparian habitat within network parks (Appendix K). Although riparian areas comprise one of the most dramatically altered community types over the last 150 years in the western United States, they remain the most biologically diverse. More than 75% of the species in the Mojave-Great Basin region are strongly associated with riparian vegetation, including 80% of birds and 70% of butterflies (Brussard et al. 1998). Additionally, a significant number of species of special concern are associated with riparian

habitat (e.g. southwestern willow flycatcher [*Empidonax traillii*] and least Bell's vireo [*Vireo bellii pusillus*]). Because of the isolated nature of surface water resources in the MOJN, these sites, particularly springs, tend to exhibit a high rate of endemism. Obligate riparian bird species may be particularly good indicators of change in riparian communities, the most threatened habitat in the MOJN. Obligate riparian bird species are those who locate >90% of their nests in riparian vegetation or those for which >90% of their abundance occurs in riparian vegetation during the breeding season, such as the least Bell's vireo.

1.4 Cultural Resources

The MOJN has a rich and fascinating cultural history. Cultural landscapes are important in maintaining our national, regional, and local identity by revealing human origins and development through their form, features, and the way they were used. A cultural landscape is defined as “a geographic area, including both cultural and natural resources and the wildlife and domestic animals therein, associated with a historic event, activity, or person or exhibiting other cultural or aesthetic values.” Types of cultural landscapes found within MOJN parks are historic vernacular landscapes, historic sites, and ethnographic landscapes (Table 1-5). Most cultural landscapes are dependent on natural resources and it is interconnected natural systems with dynamic properties that differentiate cultural landscapes from other cultural resources (Birnbaum 2005).

Cultural landscapes within MOJN parks reflect a diverse human history ranging from the Pleistocene Era to present day. Prehistoric occupation of network parks dates from the Paleo Indian period (12,000 B.C. to 9,000 B.C.) through the Shoshonean period (A.D. 1300 to present) (NPS 1995, NPS 2001a). Prehistoric inhabitants were hunters and gatherers and included the Pinto Culture in southern portions and Fremont Culture in the northern portions of the network. The Timbisha Shoshone Tribe continues, into present day to inhabit portions of DEVA and works collaboratively with the NPS to manage resources. Lands within MOJA served as an east-west transportation corridor across the eastern Mojave Desert since prehistoric times. The first Euro-American exploration of the Great Basin-Mojave Desert Region began in the late 1700's and is evidenced by the presence of wagon roads, railroads, and other early transportation routes. Variants of the Mojave Indian Trail, used by Native Americans for centuries, were followed by explorers, mountain men, and traders beginning in the late 1820's, establishing what would become the Old Spanish Trail (NPS 2000).

Euro-American settlement in the network occurred in the mid-late 1800's. The primary 'industries' of early, and in many cases current, settlements were associated with ranching, agriculture, and mining. The 1920's and 1930's brought the advancement of the automobile, construction of new roads, and homesteaders to the Great Basin-Mojave Desert area. The location of early settlements was generally directly related to the availability of water resources. The post-World War II era brought the greatest changes to the Mojave Desert landscape with establishment of military training and testing sites (e.g. Edwards Air Force Base, Nellis Air Force Base) encompassing over 2.5 million ha. Initiation of military training exercises began in the 1940's, and above ground testing of nuclear weapons occurred between 1951 and 1963 (Wilkerson 2004).

Table 1-5. Cultural landscape types found within the MOJN.

Cultural Landscape Type	Description	Mojave Network Examples (Park Code)
Historic Vernacular	A landscape that evolved through use by the people whose activities or occupancy shaped that landscape. Through social or cultural attitudes often individual, family or a community, the landscape reflects the physical, biological, and cultural character of those everyday lives. Function plays a significant role in vernacular landscapes. They can be a single property such as a farm or a collection of properties such as a district of historic farms along a river valley.	• Scotty’s Castle (DEVA) • Lower Vine Ranch (DEVA) • CCC-era national monument administration structures (DEVA) • Osceola ditch (GRBA) • Lehman Orchard (GRBA) • Keys Ranch Area (JOTR) • Lost Horse Mine Ranch Area (JOTR) • Kelso Depot Historic District (MOJA) • Zzyzx Depot Historic District (MOJA) • Mojave Road (MOJA) • Greater Waring Ranch (PARA) • Tassi Ranch (PARA)
Historic Site	A landscape significant for its association with a historic event, activity, or person.	• Internment camp associated with the relocation of Japanese- Americans during World War II (MANZ)
Ethnographic	A landscape containing a variety of natural and cultural resources that associated people define as heritage resources.	• Contemporary Timbisha Shoshone Village (DEVA) • Prehistoric burial grounds and burial caves (GRBA) • Spirit Mountain Traditional Cultural Property (LAME) • Sugarloaf Mountain Goldstrike Canyon Traditional Cultural Property (LAME)

MANZ represents the most notable historic site within the MOJN. Between 1942 and 1945, this 329 ha site was occupied by 10,000 Japanese American internees. Prior to their arrival the site had been largely denuded of vegetation, except for a few fruit orchards. During their confinement, internees engaged in extensive landscaping and development of “victory gardens” in available space. Additionally, this site contained significant support facilities including a hospital complex, auditorium, residential barracks, schools, stores, road network, agricultural plots, etc. Of 10 centers established during World War II for similar purpose, MANZ is the best preserved (NPS 1996). This entire site is considered a cultural landscape and principles for managing the area as a landscape are being established. Today thousands of visitors come to see and recreate in these landscapes, preserved and memorialized in MOJN parks.

Cultural landscapes are an important component of the parks of the MOJN. While cultural landscapes represent a relatively small proportion of total land area in the network, they are disproportionately important to park mission and visitor experience. These landscapes are affected by natural forces, development (e.g. commercial, residential), vandalism, and neglect. Few cultural landscapes in network parks have been formally designated or nominated through the regional inventory and assessment process coordinated out of the NPS Pacific West regional office, and the majority of parks lack baseline data and planning documents related to important

cultural and ethnographic resources. As the regional inventory and assessment process continues, many of these landscapes, sites, and features are hoped to be formally designated in the future.

Cultural landscapes are important to the MOJN monitoring program in a number of ways. First, these landscapes and features are highly influential on park ecosystems. Visitation and NPS management is concentrated on these cultural landscapes, particularly those associated with surface water resources. Spring sites associated with cultural landscapes tend to be highly altered areas and often serve as a starting point for non-native plant and animal invasion (e.g. american bullfrogs [*Rana catesbeiana*], tamarisk [(*Tamarix spp.*)], thus affecting the structure and function of surrounding ecosystems. Additionally, natural forces such as floods and wind that may alter or destroy important elements of the cultural landscape also pose a significant threat to preservation of natural resources. Lastly, cultural landscapes function as discreet ecosystems, and therefore represent an important focus for monitoring. The MOJN monitoring program considers cultural landscapes to be distinct systems that exhibit unique and important ecosystem processes and that interact with surrounding ecosystems in profoundly important ways. Within this context, the MOJN seeks to explicitly incorporate cultural landscapes into the vital signs monitoring program.

1.5 Natural Resource Threats and Management Concerns

Parks in the MOJN share many similar natural resource threats and issues originating from both inside and outside park boundaries. Threats or stresses originating from outside park boundaries can, and are, significantly modifying biodiversity and other valued components of park ecosystems (National Parks Conservation Association 1979, Garratt 1984, Machlis and Tichnell 1985, Sinclair 1998). In 1980, greater than 50% of threats reported across the National Park Service system were from external sources. Development on adjacent lands, air pollution, urban encroachment, roads, and railroads were most frequently cited (NPS 1980). More recently, land use change (Hansen and Rotella 2002), fragmentation (Ambrose and Bratton 1990), and human population density (Newmark et al. 1994) have been documented as threats to individual parks. It has been hypothesized that only protected areas with adequate expanses of surrounding habitat and linkages to other protected areas will be able to support current levels of biodiversity into the future (Hansen et al. 2001).

An essential step in the process of selecting vital signs is the gathering of park specific information on key natural resources, natural resource threats, and the significant concerns and issues facing parks in the management of those resources. In order to narrow the focus, ensure relevance to network parks, and increase efficiencies in the planning process, priorities must be established among focal resources and resource concerns. Network staff used several sources of information to summarize priority resource threats and management concerns in network parks including General Management Plans, Resource Management Plans, Strategic Plans, and interviews with park staff. Resource managers identified stressors/threats to park resources. Those considered a high priority at the network-level were invasive species, water quantity alteration, land use change/development, and air quality degradation. Additional threats considered a high priority in at least 2 individual parks but not at a network-level were altered

disturbance regime, recreation/visitation, and soil alteration. Livestock grazing also is briefly discussed due the significant and broad scale historic impacts of this activity within network parks and relevance to present day species composition and distribution. Appendix L provides a summary of threats and management concerns for all Level 2 vital signs.

1.5.1 Invasive Species

Deserts are considered one of the least invaded ecosystems by plants, possibly due to naturally low levels of soil nitrogen (Brooks and Esque 2003). However, at least 66 non-native plant species have been identified in two or more park units within the MOJN (Appendix M). Of most concern across the network are invasive annual grasses and tamarisk. Invasive annual grasses are widespread and abundant in the Mojave Desert. By one estimate, alien annuals comprised 9-13% of all annual plant species, and 4 alien species (foxtail brome [*Bromus madritensis rubens*], Mediterranean grass [*Schismus barbatus*], Arabian schismus [*S. arabicus*], stork's bill [*Erodium cicutarium*]) comprised 66% of all annual plant biomass in one wet year (Brooks 1998, 2000).

Only 7 non-native vertebrate species have been identified in two or more park units, including, several common bird species (e.g European starling [*Sturnus vulgaris*], brown-headed cowbird [*Molothrus ater*], house sparrow [*Passer domesticus*]), feral burro (*Equus asinus*), and feral horse (*Equus caballus*) (Appendix M). Non-native fauna were considered less important than non-native invasive plants. Nonetheless, a significant amount of staff time has been, and continues to be, dedicated to the management of these non-native fauna (e.g. feral burro).

Park management concerns are primarily related to invasive, non-native plant species and include: (1) the ability of invasive, non-native plant species to compete with native plant communities for limited resources, reducing native plant density, biomass, and diversity (Brooks 2000); (2) potential impacts of non-native plant species on native fauna, particularly special status species (e.g. desert tortoise [*Gopherus agassizii*]), through the alteration of native plant communities (e.g. food source, shelter); (3) potential for permanent alteration of ecosystem processes, such as fire, which are critical to maintaining ecosystem structure and function; and (4) potential impacts of invasive species, such as tamarisk, on groundwater and surface water resources. As an example, change in fire regime in some network parks has been directly linked to the spread of invasive grasses. These grasses form a continuous layer of fine fuels in an environment historically characterized by few fine fuels and patchy fuel distribution. In 1999 nearly 5,666 ha (14,000 ac) burned at JOTR, including many large Joshua tree (*Yucca brevifolia*) stands. Repeated burning in the future and the inability of desert plant communities to recover from repeated burns may result in a permanent shift from shrubland habitats to alien annual grasslands in some network parks (Brooks 1999b). Permanent alteration of the fire process and native shrubland plant communities has significant implications for the desert tortoise. Increased fire frequency and intensity may cause direct tortoise mortality through burning or smoke inhalation (in or out of burrow), particularly during the spring (active season for tortoises), and may alter the nutritional quality of available forage (Boarman 2002). *Schismus* spp. is an invasive grass species often eaten by tortoises (Esque 1994), and nutritional analyses indicate that its consumption results in depletion of nitrogen, phosphorus, and water in tortoises, ultimately leading to weight losses (Avery 1998, Nagy et al. 1998, Hazard et al. 2001).

Tamarisk has invaded almost all watercourses and other wetland habitats throughout the Southwest, taking over more than 400,000 ha of wetland habitat. These habitats in the MOJN are considered hotspots of biodiversity and support a significant number of special status species as well as frequently being culturally significant. A single, large tamarisk can transpire up to 1,150 liters of water per day. In areas where watercourses are small or intermittent this species can severely limit the available water or even dry up a water source. Reduction in water quantity at critical desert springs poses a significant threat to biotic communities (Eastman 2002)

1.5.2 Water Quantity Alteration

The importance of water to desert ecology cannot be overstated. Available water is critical for desert survival and areas associated with surface waters are often focal points for biodiversity and important in the management of special status species as evidenced by the fact that 67% of Federally Endangered species in the network are desert fishes. This point is illustrated by the *Cappaert* decision, a case involving the Devils Hole Pupfish (*Cyprinodon diabolis*) and water quality alteration that made it all the way to the Supreme Court in the 1970's (Ek, *personal communication*). The availability of surface water is directly related to the availability of subsurface or groundwater (although this relationship is poorly understood) which is slowly recharged through precipitation events and which feeds scattered springs and wetland habitats across network parks. In places around Las Vegas, groundwater levels have declined 90 m since 1907 due to humans demands (Bawden et al. 2003). Continued up-gradient pumping of groundwater may potentially lower the water table and dry up critical surface water resources within MOJN parks. Primary threats to surface and subsurface water quantity identified by park managers are groundwater withdrawal by surrounding communities/commercial use, diversion of surface waters (e.g. through pipeline), and hydrophyllic, non-native plant species such as tamarisk

Park management concerns related to alteration of water quantity are primarily focused on the future ability of parks to protect this critical resource in the face of burgeoning population growth. Reductions in already scarce water resources will impede our ability to understand the the complex relationship between groundwater withdrawal and available surface water, loss of biodiversity, potential extinction of aquatic and riparian dependent species, and impacts to other fauna (e.g. bighorn sheep [*Ovis Canadensis*]).

1.5.3 Land Use Change/Development

The landscape of the MOJN parks has been significantly altered through historic and current patterns of land use and continues to be threatened by competing human interests. The most significant alterations are in areas associated with water (e.g. obtaining drinking water for population growth versus preservation of desert spring systems). The landscape at MANZ has been most intensely altered through human impacts, including occupation by a high population density over a short period of time and activities associated with this occupation. Land use in its broadest sense encompasses a myriad of human activities occurring within and outside park

boundaries such as: 1) physical alteration of the landscape surface (e.g. road-building, construction of buildings, agriculture and grazing, 2) modifications of plant and animal communities (e.g. introduction of predators such as cats and dogs, introduction of invasive plants and animals, and habitat fragmentation), and 3) multiplicative effects such as enhanced dust generation from gravel roads and effects of visitation. As human population continues to increase in areas surrounding parks the associated impacts of urbanization such as air pollution, increased groundwater withdrawal, nitrogen deposition, noise/light pollution, introduction of invasive species, etc. on fragile desert resources are expected to increase. Since WWII, human population across the desert southwest has increased from approximately 8 million to over 40 million human inhabitants today (Wilkerson 2004). In Clark County, Nevada, human population increased 8200% between 1940 and 2000 and now had over 1.3 million inhabitants by 1995 (U.S. Census Bureau 2005).

1.5.4 Air Quality Degradation

Threats to air quality in and around network parks are primarily associated with urbanization adjacent to park units and include both point and non-point sources. Air quality in the network is affected primarily by regional air pollution sources in California, Arizona, and Nevada, although more distant sources can also affect the area. Network parks experience poor air quality primarily from pollutants such as ozone, nitrogen oxides, sulfur dioxide, volatile organic compounds, particulate matter, and toxics. Specific sources of air quality degradation identified by park managers within and outside park boundaries included increased fire frequency in areas not naturally prone to fires, off-road vehicular traffic, mining activities (particulates), congeneration power plants, landfills, vehicular emissions, and watercraft emissions (nitrogen and sulfur deposition, ozone, toxins). Potential future threats to air quality were primarily related to proposed commercial development on lands adjacent to parks (e.g. Eagle Mountain Landfill).

Park management concerns related to declining air quality are associated with potential or actual negative impacts to visitor experience and human health, impacts on selected park resources (e.g. petroglyphs), and alteration of ecological processes (e.g. nutrient cycling) critical to maintaining ecosystem structure and function and achieving park management goals. Maintenance of viewsheds and night sky vistas is a key management goal for several network parks, and reduced visibility may have a significant negative impact on the visitor experience. Some park resources are sensitive to specific pollutants. For example, alpine lakes at GRBA, which have a very low buffering capability and whose ecology (e.g. soil and water chemistry, species composition, predator-prey relations, etc.) could be significantly altered through deposition of 'acid rain', a by-product of emission of sulfur and nitrogen compounds into the atmosphere.

The greatest concern among network parks relates to the potential landscape-scale changes in abiotic and biotic resources associated with increasing levels of nitrogen deposition in and around network parks. Stable isotope studies near JOTR indicate that soil nitrogen increases in and around the park are due to increased atmospheric deposition and that these changes have occurred rapidly since the 1950's (NPS 2004b). Nitrogen is a limiting factor in desert soils and widespread deposition of nitrogen compounds acts to fertilize desert soils and alter key ecosystem processes such as nutrient cycling and competitive relationships between native and

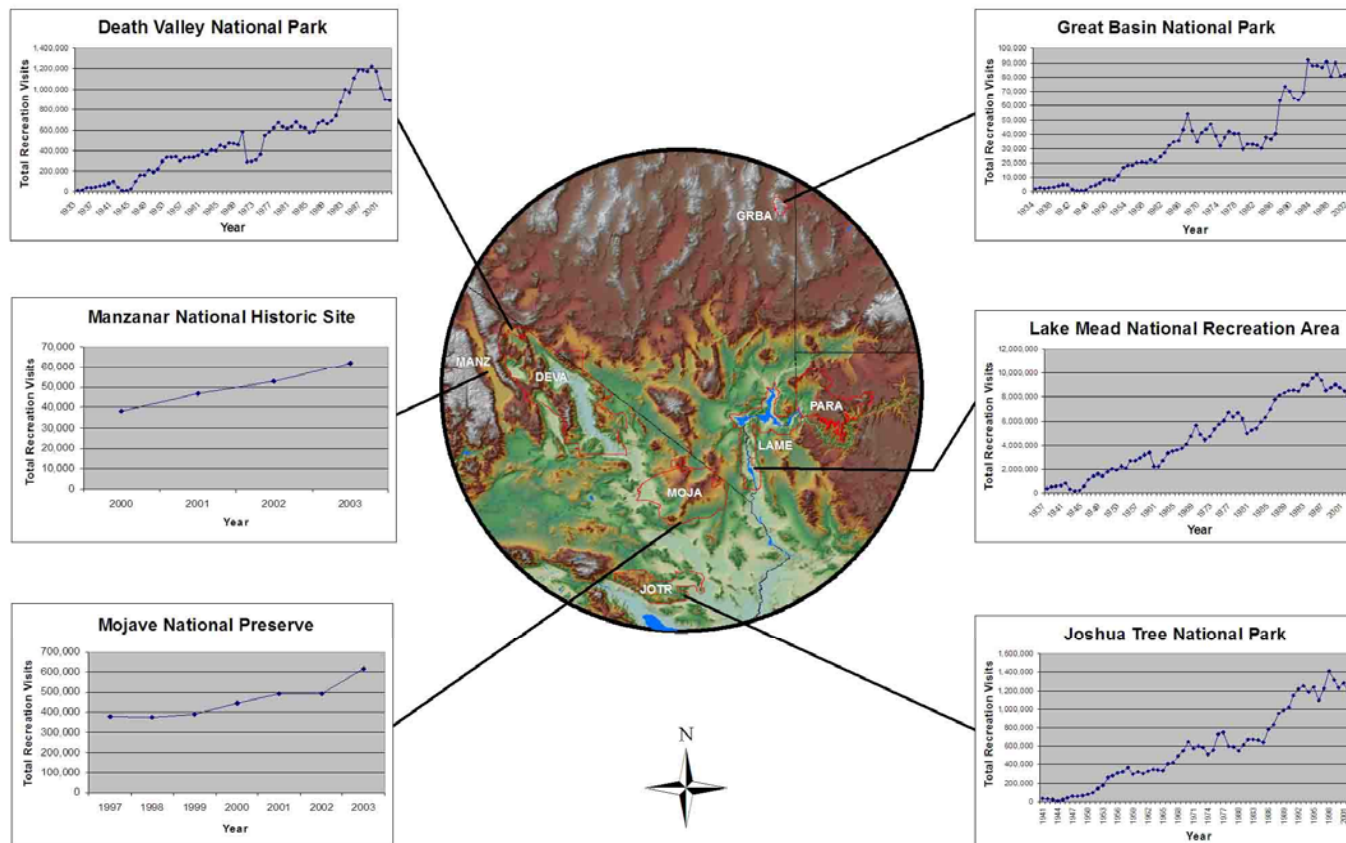
non-native plant species. Soil nutrients (particularly soil nitrogen) are one of the determinants of habitat invasibility in the MOJN (Brooks 1999a). There is evidence to suggest that invasive plant species benefit from increased soil nitrogen and are likely to continue to spread and thrive in areas subject to increased atmospheric nitrogen deposition.

1.5.5 Recreation/Visitation

Increased human population (described under section 1.5.3) surrounding parks is reflected in an increasing trend in park visitation. The longest period of record for visitation exists at DEVA and indicates an increase from 9,970 visitors in 1933 to 890,375 visitors in 2003. In 2003, four of six network parks (DEVA, JOTR, LAME, MOJA) were in the top 30% of NPS units (N=353) with the highest percent of total visitors (Figure 1-13). LAME experiences the highest visitation in the network and, in 2003, ranked 5th in the nation with 7,915,581 recreation visits. The highest visitation was 9,838,702 total recreation visits at LAME in 1995 (NPS 2005c) (Appendix N). Natural resources within parks are impacted not only by land use and development outside park boundaries, but also by increased visitation within parks. Direct effects of increased park visitation include soil compaction in sensitive riparian habitats, light pollution (e.g. headlights), illegal collecting, and introduction and spread of invasive plant and animal species. Indirect effects of increased visitation are related to the potential need for additional park infrastructure and staff to manage visitation and provide a quality visitor experience. Ultimately, the need to provide high quality visitor services may lead to changes in land use, possible development within park boundaries, and negative impacts to park resources (e.g. increased number of developed roads, increased number of bathrooms, interpretive buildings, and increased water consumption).



Visitation Trends in Mojave Network Parks (except Parashant NM)



Produced by Mojave Network

Figure 1-13. Visitation Trends in the Mojave Network Parks.

1.5.6 Soil Alteration

Soil is the basic element affecting the structure and processes of arid and most terrestrial ecosystems (Whitford 2002). In arid systems, any disturbance or other alteration to the top soil layer (top 3-20 mm) where nutrients and living organisms are concentrated is of particular concern. Generally, threats to soil resources in MOJN parks include any change that may unnaturally accelerate geomorphic processes (e.g. change in rate of erosion and deposition, rate of stabilization, sand/dust mobilization) or significantly alter the physical or chemical properties of soils (e.g. compaction, contamination) and ability of soils to function. Specific threats to soils identified in network parks include atmospheric deposition of nutrients, accelerated climate change, grazing, altered fire regime, mining activities, roads, road maintenance, commercial operations (e.g. railroad) and recreational activities. Concerns expressed by park managers vary depending on the specific threat but relate primarily to the potential impacts of degraded soil quality on desert ecosystems. Specific concerns identified include:

1. The potential for altered soil nutrient cycling leading to broad scale changes in plant communities (e.g. spread of invasive annual grasses)
2. Increased atmospheric particulates (e.g. dust) leading to alteration of soil pedogenesis processes
3. Compaction of soils in high visitor use areas (e.g. trails, riparian habitats) and in association with activities such as grazing and off-highway vehicle use leading to long-term changes in soil-water-plant interactions, runoff, and rate of soil erosion
4. Alteration in the location and/or rate of soil erosion leading to changes in surface hydrology, loss of cultural resources, alteration in plant distribution, etc.
5. Destruction of biological soil crusts and associated changes in soil stability and rate of erosion
6. Development of hydrophobic soils in association with more intense, stand replacing fires (altered fire regime)
7. Potential contamination of soils and water (e.g. cyanide, lead, mercury, arsenic, uranium) associated with mining and other commercial activities in parks.

Park management needs to focus on long term prevention rather than restoration efforts when dealing with desert soils. Currently there is a need to better understand soil changes over time. Preventing damage is critical because of the sensitivity of desert soils to disturbance and time required for recovery. A single footprint may have long-lasting impacts in desert environments that are not easily repaired because living organisms and nutrients are only in the soil surface. Biological soil crust recovery after a single footstep is estimated to take up to 20 years in areas of higher rainfall and up to 250 years on dryer sites (Belnap 2001). Recovery time for plant communities on sites that have been repeatedly disturbed may be much longer. Webb et al. (1983) estimated recovery of plant communities in the Western Mojave Desert to potentially take centuries in areas subject to off-road vehicle use. Soils are further discussed in Appendix H.

1.5.7 Altered Disturbance Regime

Natural disturbance regimes that are of primary interest in the MOJN are drought, fire, and flood events. Although these disturbances are considered part of and critical to the maintenance of natural ecological processes, they may also be considered ecosystem stressors or threats when the natural disturbance regime is altered by human activities. Changes in disturbance regime that concern park managers generally involve change in frequency (e.g. fire frequency), intensity (e.g. flood events), or duration (e.g. drought events). Examples of specific threats to natural disturbance regimes in network parks include: (1) spread of invasive annual grasses leading to increased fuel continuity and increasing fire frequency and intensity; (2) historic and current fire suppression activities (in and around parks) leading to increased fuel loading and changes in plant community structure and composition that increase the frequency and intensity of fires; and (3) climate change that may alter the amount or pattern of precipitation leading to extended drought periods or increased frequency and intensity of floods.

It should be noted that across the Mojave and Great Basin Deserts and Colorado Plateau, the impacts and importance of change in, for example, fire regimes may be very different. To maintain species composition and distribution of native plant communities, management efforts in the Great Basin and Colorado Plateau have been focused on restoring the natural fire regime after 100 years of fire suppression. In contrast, the Mojave Desert is poorly adapted to fire and fires of any size have been historically infrequent. Prevention of fires and/or fire suppression is the goal of management in this system where increased fire frequency may move natural systems beyond their ability to recover naturally. Park managers also are concerned that the insufficient information on natural disturbance regimes and the response of park ecosystems to disturbance to guide future management and determine thresholds for management action.

1.5.8 Grazing

Livestock grazing is a common use of lands throughout western states and on a majority of federal lands (Fleischner 1994) and has occurred at a broad scale and varied intensity for over 150 years in the MOJN. Limited livestock grazing continues presently in DEVA, GRBA, LAME, MOJA, and PARA. However, several parks are in the process of removing this activity from NPS lands. Few studies have extensively documented the impacts of grazing on park ecosystems or natural recovery time after removal of grazing in the Mojave Desert and Colorado Plateau. However, research from other areas of the Southwest indicates that livestock grazing can impact the species composition, function, and structure of ecosystems (Fleischner 1994). Grazing directly alters the composition of plant communities through differential selection of plant species by grazing animals and the sensitivity of these species to grazing and trampling. These changes combined with soil disturbance and seed dissemination by livestock further modify species composition by facilitating the invasion of exotic species.

Ecosystem functions that are disrupted by livestock grazing (primarily cattle) include nutrient cycling and succession (Fleischner 1994). In arid systems, such as on the Colorado Plateau and adjacent ecoregions, soils contribute a vital role in nutrient cycling (Rychert and Skujine 1974), soil stability (Bailey et al. 1973, Harper and Marble 1988), water infiltration (Loope and Gifford

1972, Brotherson and Rushforth 1983), and water retention (Lange et al. 1998). Fragile desert soils, particularly biological soil crusts are highly sensitive to trampling impacts. Surface disturbances such as trampling can decrease biological soil crust cover (Jeffries and Klopatek 1987) and reduce or eliminate nutrient cycling (Belnap 2003a). The loss of nitrogen cycling can have a corresponding impact on the nitrogen content of dominant plant species (Harper and Pendleton 1993). Livestock grazing patterns and surface disturbance may arrest succession or irreversibly shift a habitat to another state (Fleischner 1994). Two studies of riparian habitat in Arizona found that cottonwoods were not regenerating on grazed sites (Carothers et al. 1974, Glinski 1977). Under a continuous grazing regime, this could ultimately impact canopy cover and stand replacement (Glinski 1977).

Of particular concern to park managers are the impacts of grazing on riparian habitats. As stated previously, riparian habitat in the MOJN supports a high level of biotic diversity (Carothers et al. 1974, Snyder and Miller 1992) and is potentially the most threatened habitat across network parks. Livestock grazing has been identified as a primary threat to this ecosystem (Leopold 1924, Carothers 1977, Mosconi and Hutto 1982, Szaro 1989, Chaney et al. 1990) in part because the animals actively seek riparian zones for water and shelter (Roath and Krueger 1982, Van Vuren 1982, Windell et al. 1986). As summarized by Fleischner (1994), “Riparian vegetation is altered by livestock in several ways:

1. Compaction of soil, which increases runoff and decreases water availability to plants
2. Herbage removal, which allows soil temperatures to rise, thereby increasing evaporation
3. Physical damage to vegetation by rubbing, trampling, and browsing
4. Altering the growth form of plants by removing terminal buds and stimulating lateral branching”

Bahre (1991) found that the legacy impacts of grazing included degradation of riparian habitat from erosion, loss of palatable plant species, spread of exotic species, and altered age structure of tree species. Although some studies concluded that complete removal of grazing from riparian systems can result in relatively rapid recovery (2+ years) of aquatic components (Warren and Anderson 1987, Fleischer 1994,), the wooded component may require extended recovery times (Knopf and Cannon 1982, Szaro and Pase 1983).

At the local and regional level, grazing and trampling also has long-term, moderate to severe adverse effects on water quality by increasing erosion within stream corridors and around springs, which then increases sedimentation and stream temperature. Increased sedimentation with accumulations of urine and fecal matter changes water chemistry. Over a long period of time, changes in water chemistry in combination with trampling (livestock, hikers, and motorized vehicles) can destroy the micro- and macrobiotic communities that define a healthy riparian system (Marion and Merriam 1985, Cole and Bayfield 1993). The impacts discussed above collectively contribute to the degradation of ecosystems at a local and regional scale, thus impairing systems on adjacent NPS lands.

1.6 Summary of Past and Current Monitoring

An understanding of current and previous monitoring in and around network parks is an important foundation for development of the MOJN vital signs monitoring program. Documentation and review of existing work allows the network to identify where monitoring is adequate, where additional inventory, monitoring, or protocol development is needed, which monitoring studies can be built upon and expanded, and what studies to abandon. Monitoring activities within network parks falls into 2 general categories: 1) monitoring being conducted only within park boundaries; and 2) monitoring being conducted within parks that is part of a larger (e.g. state-wide, regional, national) monitoring program attempting to make inferences beyond park boundaries. Regional or broader-scale monitoring within parks may or may not significantly involve park staff. Current and historic monitoring activities within network parks is described in Appendix O. Monitoring that is occurring at a larger regional to national scale in and around network parks is described in Appendix P.

1.6.1 Past and Current Monitoring in and Around Mojave Network Parks

Park Resource Management Plans and the NPS Natural Resource Inventory and Monitoring Guidelines (NPS-75) guide current monitoring activities at the network parks (NPS 1992b). Monitoring of vital signs identified through park and network level vital signs scoping workshops should be complementary to existing monitoring programs already in place in network parks. The existence of current and past monitoring or data that may serve as the basis for long-term monitoring in parks related to high priority or initially ‘selected’ MOJN vital signs is indicated in Table 1-6. Historic and current monitoring activities occurring within network parks have been initially documented in the NPS I&M program Dataset Catalog database. Existing monitoring involving park staff related to focal species and communities varies by park unit. Generally monitoring conducted by or in cooperation with park staff is geared toward reporting to various (GPRA) management goals and often is focused on special status species non-native plant and animal species, and riparian communities. A summary of vital signs scoping workshops can be found in Appendix R and Appendix Q.

Table 1-6. Availability of historic (H)(> 5 years ago) or current (C) monitoring data related to funded vital signs for MOJN, listed in priority.

MOJN Vital Sign	DEVA	GRBA	JOTR	LAME	MANZ	MOJA	PARA
Weather and climate – basic meteorology	H/C	H/C	H/C	C		H/C	
Vegetation change	C ^e	C	C ^e	C ^e		C ^e	
Invasive/Exotic Plants ^a				C			
Surface water dynamics	H/C	C		C			
Groundwater dynamics and chemistry	H/C		H/C				
Air quality – visibility and particulates	H/C	H/C	H/C				
Air chemistry – ozone	H/C	H/C	H/C	H/C			
Air chemistry – wet and dry deposition	H/C	H/C	H/C				
Soil chemistry and nutrient cycling			C				
Soil hydrologic function							
Soil erosion and deposition				C ^d			
Soil disturbance				C ^d			
Biological soil crust dynamics							
Surface water chemistry	H/C	C		H/C			
Fire and fuel dynamics	H/C	H/C	H/C	H/C		H/C	H/C
Landscape dynamics							
At-risk populations				C			
Riparian Birds	C ^c	C ^c	H/C ^c	H/C ^{b,c}		C ^c	
Reptile communities							
Small mammal communities							

^a All parks report the number of acres of invasive species ‘contained’ related to GPRA Goal Ia1B.

^b Associated with spring restoration.

^c Landbird monitoring primarily conducted in parks through the Great Basin Bird Observatory, Point Reyes Bird Observatory, U. S. Geological Survey (N. Am. Breeding Bird Survey), or state wildlife agencies (NV raptor surveys) – some focus on riparian habitats. LAME is the only network park with a MAPS (Monitoring Avian Productivity and Survivorship Program) station.

^d Represents a project approved for funding titled, “Monitoring protocols for soil stability at Lake Mead National Recreation Area” – see description below.

^e A total of 921 long-term vegetation monitoring plots associated with the U. S. Forest Service, Forest Inventory and Analysis program are contained within DEVA (N=553), JOTR (N=127), and MOJA (N=241) and it is assumed some plots are located within LAME. It is unknown how many of these plots have associated data.

1.6.1.1 Air Quality Monitoring

The most significant network-wide monitoring being conducted is related to air quality and weather. DEVA, GRBA, and JOTR have long-term, on-site, air quality monitoring stations supported by the NPS. Types of monitoring at these sites include ozone monitoring through the NPS Gaseous Pollutant Monitoring Network (GPMN), wet deposition monitoring of atmospheric pollutants by the National Atmospheric Deposition Program (NADP), dry deposition monitoring of atmospheric pollutants by the Clean Air Status and Trends Network (CASTNet), and visibility monitoring through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (Figure 1-14). Additional information related to air quality monitoring and the monitoring history associated with NPS-administered sites in individual network park is available in Appendix E.



Active Air Quality Monitoring in Mojave Network Parks

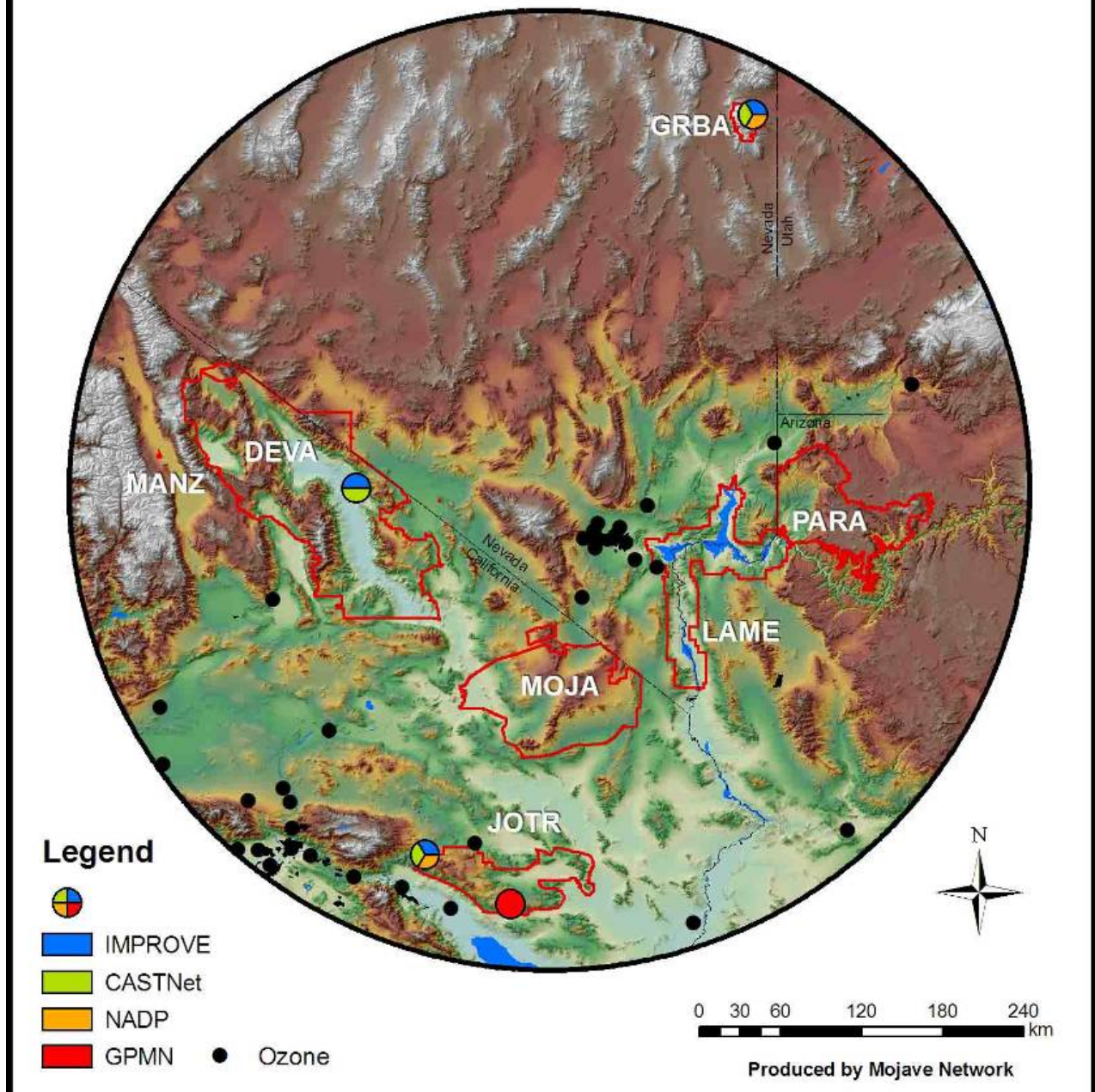


Figure 1-14. Air quality monitoring in the Mojave Network Parks (GPMN=NPS Gaseous Pollutant Monitoring Network for ozone; NADP= National Atmospheric Deposition Program; CASTNet= Clean Air Status and Trends Network; IMPROVE=Interagency Monitoring of Protected Visual Environments; Ozone=ozone monitoring by States).

1.6.1.2 Water Resources Monitoring in Mojave Network Parks

Prior to the MOJN Water Resources Monitoring Workshop in April 2005, a survey of water monitoring projects was conducted for the parks in the MOJN primarily through interviews with key personnel. Information regarding on-going water (quality and quantity) monitoring projects being conducted within parks is provided in Appendix I.

Water monitoring in most MOJN parks is generally limited. In stark contrast, Lake Mead is one of the most intensively monitored lakes in the country (B. Moore, *personal communication*) due to its importance as a regional source of drinking water, recreational value, and designation as critical habitat for several special status fish species. In addition to identification of existing water-related monitoring in network parks the MOJN developed and prioritized monitoring objectives for water-related vital signs at the 2005 MOJN Water Resources Monitoring Workshop. Monitoring objectives are presented in Chapter 3.

Each state has developed its own list of Outstanding National Resource Waters (ONRW) under EPA guidance. Officially, there are no ONRW in the MOJN, however, GBRA has water bodies that have received a Class A designation by the state of Nevada (Table 1-7). Nevada defines Class A waters as waters or portions of waters located in areas of little human habitation, no industrial development or intensive agriculture and where the watershed is relatively undisturbed by man's activity.

Table 1-7. State of Nevada Class A waters within the MOJN (Nevada Division of Environmental Protection 2005).

Park	Water Body Name	Description
GRBA	Baker Creek	From its origin to the national forest boundary.
	Lehman Creek	From its origin to the national forest boundary.
	Pine Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E.
	Ridge Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E.

Under Section 305(b) of the Clean Water Act, each state is required to conduct water quality surveys to determine the overall health of the waters of the state, including whether or not designated uses are being met. States report to the EPA every two years. When impaired water bodies are identified through 305(b) assessments, they are included in 303(d) lists for ranking of priority sites and Total Maximum Daily Load (TMDL) development in order to limit discharges of specific pollutants to that water body (Ledder 2003). LAME is the only network park that contains waters designated as 303(d) (Table 1-8).

Table 1-8. California and Nevada 303(d) Listed Water Bodies Within and Adjacent to Parks in the MOJN.

Waterbody ID	Waterbody	Reach Description	Size	Units	Existing TMDL's	Pollutant/Stressor of Concern	In Park
Nevada's 303(d) List of Impaired Waterbodies							
NV13-CL-06	Las Vegas Wash	Telephone Line Rd to Lake Mead	5.12	miles	Total ammonia, total phosphorus	Iron (total) Total suspended solids	Yes (portions)
NV13-CL-09	Virgin River	Mesquite to Lake Mead	25.7	miles	Draft TMDL Boron	Boron (total) Iron (total) Temperature Total phosphorus	Yes (portions)
NV13-CL-12	Muddy River	Glendale to Lake Mead	25.1	miles	None	Boron (total) Iron (total) Temperature	Yes (portions)
<i>Nevada's List of Waterbodies with Exceedances of RMHQs (Requirements to Maintain Higher Quality Water)</i>							
NV13-CL-04	Lake Mead/Las Vegas Bay	Las Vegas Bay	3,840	acres		chlorophyll <i>a</i>	Yes; Data collected by Las Vegas Wash Discharger Monitoring Network
Nevada's List of Waterbodies Warranting Further Investigation							
NV13-CL-01	Colorado River	Lake Mohave Inlet to CA stateline				Temperature	Yes (portions)
NV13-CL-02	Colorado River	Hoover Dam to Lake Mohave Inlet				Temperature	Yes
NV13-CL-06	Las Vegas Wash	Telephone Line Rd to Lake Mead				Selenium (total)	Yes (portions)
NV13-CL-09	Virgin River	Mesquite to Lake Mead				Selenium (total)	Yes (portions)
<i>California's 303(d) List of Impaired Water Bodies: None exist in or adjacent to MOJN parks.</i>							

Chapter 2 Conceptual Ecological Models

2.1 Introduction

Conceptual models are critical elements in the design of scientifically credible monitoring programs for the management of ecological systems. Models provide a way to organize information pertaining to the complex natural systems. An ecological conceptual model is a visual or narrative summary that describes current understanding of ecosystem components, identifies important processes, and illustrates connections between indicators and ecological states or processes. Developing conceptual models helps explain how physical, chemical, and biological elements of a monitoring program interact, promotes integration and communication among scientists and managers from different disciplines, and informs on the choice of indicators (Gross 2003). The conceptual models for the MOJN do not attempt to explain all possible relationships or identify all possible components of the ecosystems, but instead they simplify reality by presenting information most relevant to understanding and preserving natural resources within the Mojave and Great Basin Deserts (Margoluis and Salafsky 1998). The models inform the selection of indicators and design of monitoring protocols and provide a basis for interpreting monitoring data.

2.1.1 Purpose

The objectives of the MOJN conceptual models are to:

- Formalize current understanding of ecosystem functioning and structure (cumulative, holistic, multi-scale) in the MOJN.
- Identify major system drivers and stressors, the system attributes most affected by these drivers, and the dynamics of these features.
- Identify and articulate relations between attributes of interest and indicators.
- Aid in defining relevant spatial and temporal scales for monitoring.
- Aid in the development, interpretation, and presentation of monitoring data.
- Serve as a means of communicating a common understanding of the connections between management decisions and natural systems to NPS and others (DeAngelis et al. 2003).

2.1.2 Approach

A wealth of conceptual models exists for semi-arid and arid parts of the American West, so we adapted many models for the MOJN. For cases of unique vegetation and desert processes, we have developed new models that are specific to the MOJN. In addition, because water is such an important limiting factor for desert life, we have emphasized its role in models. Several parks in the Network contain ecological systems with components of nearby Great Basin Desert, Sonoran Desert, Sierran, and the Colorado Plateau ecoregions (Figure 1-11). Where we address these

1 parks, we added material to illustrate variations in the models required to accurately describe
2 these somewhat different systems.

3
4 Our general approach is to take the limitation of a key resource, water, in the Mojave and Great
5 Basin Deserts as the basis for describing many processes that structure the desert communities.
6 The processes that partition water to make it available for biota control the amount of water,
7 when water is available, and its quality. As a result, many models are driven by soil moisture
8 dynamics, by groundwater levels, and by stream flow regime; within these models, plants and
9 animals adapted to these water conditions are described.

10
11 No single model form describes an entire system adequately. Model generality is needed to
12 characterize broad-scale influences and relations among park resources. Model specificity is
13 required to identify detailed relationships and components in the system that can be effectively
14 monitored and subsequently managed. The models presented here and in Appendix S omit many
15 details in order to emphasize the landscape-level features of the ecosystem and the most
16 fundamental ecosystem processes and drivers. The overall conceptual model describes factors
17 and processes controlling the structure and function of ecosystems, and component submodels
18 describe key aspects of ecological dynamics with particular implications for vital signs
19 monitoring.

20
21 Contemporary ecological theory suggests that conservation should emphasize the maintenance of
22 *ecosystem processes* because ecological systems and their components are inherently dynamic
23 both in space and time and thus cannot be conserved as static entities (Pickett et al. 1992,
24 Christensen et al. 1996). The process-based perspective described for ecological systems is
25 equally important to other levels of organization including populations, species, and landscapes.
26 Linkages among ecological systems are realized by the flow of materials, energy, and organisms
27 in spatially structured landscape mosaics (Turner et al. 2001). Thus landscape-level
28 considerations are encompassed in the system and are emphasized in our models, and the models
29 are commonly expressed in geographical terms.

31 **2.1.3 Hierarchy of Models**

32
33 We have developed a series of models that underlie a highest level, general framework model
34 (Figure 2-1). The framework model illustrates fundamental ideas about ecosystem sustainability,
35 describing the interactive controls on an ecosystem and how broad-scale drivers such as climate
36 and human disturbance influence the ecosystem. Nested under the framework model are system-
37 specific models. At this level, the system models describe the major system components and
38 indicate the principal processes connecting system components. These models illustrate in
39 general ways the human drivers that perturb the system from its reference range of variability. At
40 the system level, models attempt to represent all major parts of the system. More detailed system
41 control models describe parts of the systems that are specific with respect to processes,
42 interactions, and components, and are therefore key for vital signs and monitoring. They are
43 broken down in some cases as detailed models to more specifically describe effects of drivers,
44 such as climate change or invasive grasses, on the subsystem.

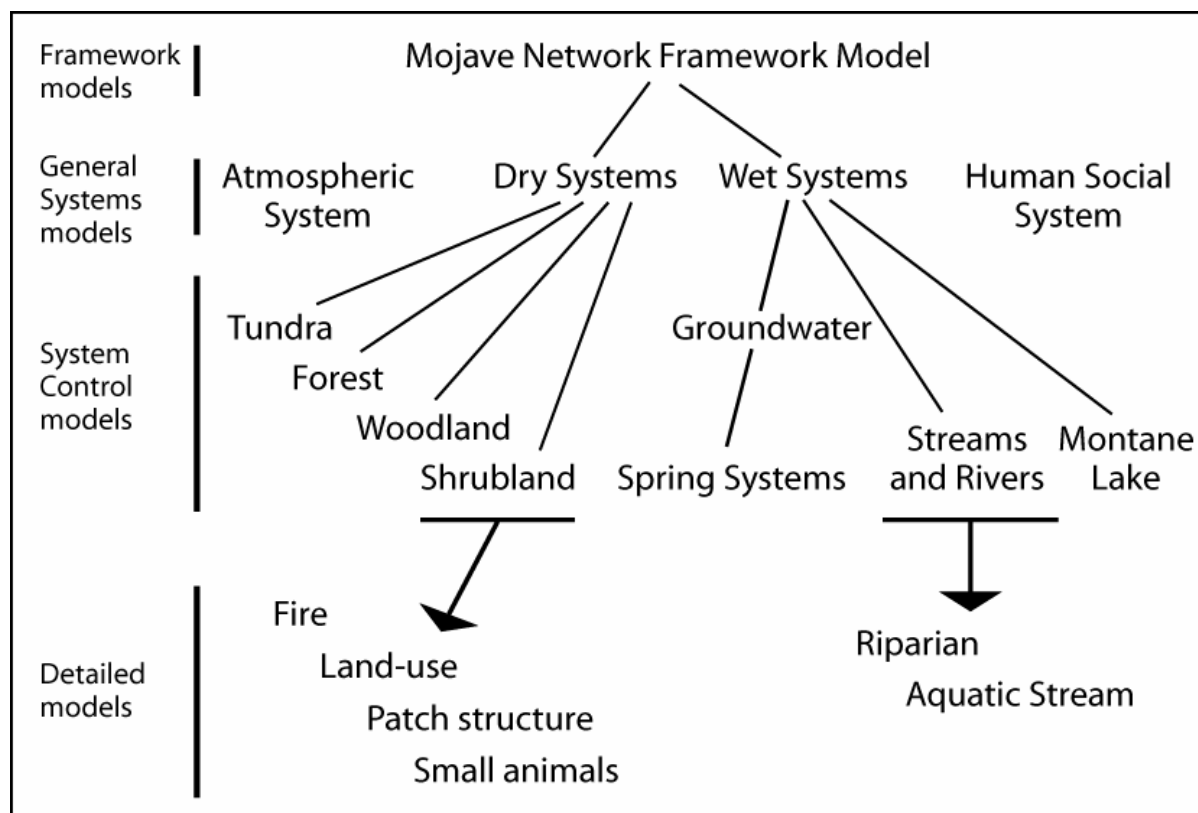


Figure 2-1. Hierarchy of models from framework description of ecosystem, to system and control models that introduce more specificity, to detailed models that represent specific subsystems and their response to drivers, and that inform in detail on monitoring strategies.

2.2 Background

2.2.1 Ecosystem Description

The MOJN is typified by wooded, rocky mountains, shrub-covered rocky piedmonts, and sparsely vegetated playas or broad valley bottoms. The mountains create elevation gradients that strongly influence ecosystem attributes because precipitation, temperature, and effective moisture availability follow the elevation gradients (see summary of climate, Chapter 1). West of the MOJN lies a nearly continuous chain of high mountains that create a rain shadow. Parks of the MOJN occur in three distinctive desert ecosystems and some of the parks are close to and influenced by other ecosystems (Figure 1-11). The Great Basin, Mojave, and Sonoran desert ecosystems are contiguous, grading from north to south across the Network. To the east lies the Colorado Plateau, and to the west lie the Sierra Nevada.

The Mojave Desert is the smallest of North American deserts and considered by some to be transitional between the Sonoran and Great Basin Deserts because it is intermediate on a climatic

1 and elevation gradient from south to north. The Mojave Desert ecosystem exhibits a northward
2 gradient of decreasing temperature caused by decreasing solar insolation and increasing average
3 elevation. DEVA lies near the northern boundary of the Mojave Desert, where many Great Basin
4 species are found at higher elevation and in northern parts of the park. MOJA lies in the south-
5 central Mojave Desert and has fairly strong floristic influences from the Sonoran Desert near its
6 southern boundaries. JOTR also fringes on the Sonoran Desert along its south margin, as well as
7 the Southern California Mountains ecosystem. LAME lies along the northeast boundary of the
8 Mojave Desert and is represented by the Colorado Plateau ecosystem on the high plateaus at its
9 eastern edge. Adjacent to LAME on the north is PARA with low elevations represented by
10 classic Mojave desertscrub, and upper elevations represented by Colorado Plateau vegetation.
11 MANZ lies at the northwest extreme of the Mojave Desert, adjoining the Great Basin ecosystem
12 and lying below the Sierran montane area. Although the Mojave Desert is primarily a rocky,
13 mountainous desert, sand dunes and sheets exist in several places, including dunes within DEVA
14 and MOJA. Dunes constitute unique environments, commonly with endemic plants and animals
15 that are specially adapted. Dunes are briefly described in Chapter 1 and also in Appendix D.

17 GRBA is distinguished from all the other parks in the network because it exists entirely in a cold
18 desert and because the land surface is almost entirely mountainous with little representative
19 valley habitat. The Great Basin Desert receives more than half of its precipitation as snow
20 (MacMahon 1979). Freezing conditions change soil behavior and require different adaptations by
21 organisms. Lehman Cave at GRBA represents an ecosystem that is unusual in deserts in that it is
22 high humidity and cool. Caves are briefly described in Chapter 1 and also in Appendix D.

24 The essential feature of these desert regions from an ecological point of view is the scarcity of
25 water. Water can be fresh or saline, and in saturated or unsaturated conditions. The fundamental
26 hypothesis underlying this conceptualization of the region is that health and sustainability of
27 arid-land ecosystems are dependent on maintaining the capacity of these systems to capture and
28 retain water and nutrients (Whitford 2002). Water availability is controlled by climate inputs,
29 which are partitioned by runoff, infiltration, and recharge to make water available in saturated
30 conditions (such as lakes, streams, and springs) and unsaturated conditions (such as soil
31 moisture). Each of these categories is further divided by how much and where water is available,
32 its duration, and its quality; for example, drylands can be described on a xeric to mesic gradient
33 that corresponds with effective soil moisture from valley bottoms to mountain tops. The
34 framework ecosystem model emphasizes the partitioning of water as the driver for plant and
35 animal community structure and composition.

37 Although water availability in space, time, and abundance provides a primary
38 limitation/facilitation for desert biota, water limitation sets the stage for complex interactions
39 among organisms that ultimately shape biotic communities. Pulses of water and nutrient
40 availability against a background of temperature fluctuations in deserts create a diversity of
41 niches that shape communities by facilitating species coexistence (Chesson et al. 2004).
42 Some of the primary processes that shape desert communities include: competition, herbivory
43 and granivory, various symbiotic relationships (e.g. mutualism, and commensalisms), predation,
44 parasitism, decomposition and other relationships affect the flow of energy and nutrients. These
45 processes are linked by microbes, plants, and animals in non-linear relations that are difficult to
46 quantify deterministically. Microbes are influenced strongly by the availability of moisture, but

once water is available, microbes sequester nutrients, such as nitrogen, and are primary factors in the decomposition of vegetative matter and thereby cycle nutrients making them available for higher organisms. Furthermore, biological soil crusts build soils (Belnap and Gillette 1998) by trapping dust and fixing nitrogen, and influence the nutrient availability for plants and for animals that feed on the plants (DeFalco et al. 2001). Plant-plant relationships are diverse and particularly interesting to consider because of the similarity of plant requirements as a taxonomic group. Competition occurs among desert plants when one individual or one species has the ability to usurp required resources to the detriment of another individual or species. Competition may occur between perennial and annual plants species or within each of those groups. Parasitism among plants is not common, but more readily apparent than most parasitic relations among animals. Among plant parasites, perhaps the most well known are the epiphytic mistletoe plants. There are particular mistletoe species that infest mesquite and acacia trees, willow and cottonwood trees, oaks, and junipers. Mistletoe berries are important food sources for some migratory birds and is part of a symbiotic relationship with the endemic phainopepla. The birds eat mistletoe berries and nest in the plants and in return the phainopepla disperses the berries of the mistletoe, depositing the pre-packaged seeds in their gelatinous coating that sticks to the tree branches to establish new plants.

2.2.2 Drivers

Drivers are defined as major external driving forces that have large-scale influences on natural systems. Drivers can be natural or anthropogenic, and encompass stressors (physical, chemical, and biological perturbations to a system that cause significant change in ecological components, patterns, and processes in natural systems) as we use the term. As part of the Vital Signs process, the MOJN identified major resource threats (Chapter 1.5) as invasive species, water availability, land use change, air quality degradation, recreation and visitation, soil alteration, altered disturbance regime, and livestock grazing. These constitute a list of important ecosystem drivers, to which can be added: Climate change and variability, disease and parasites, pollution, and resource extraction.

Perturbations to the ecosystems occur at the regional scale by such processes as change in climate, air pollution (which especially impacts JOTR), invasive species, and water diversion and consumption. More local perturbations range widely in type and effect; examples are increases or changes in land use adjacent to and within parks, disturbed stream flow regime by water diversions, compacted soils from recreational use, altered fire regimes, and illegal dumping. Climate change is perhaps the most difficult driver to predict; it is creating longer growing seasons, reduced snowpack and early snow melt periods (see Appendix D), and may cause ecotone movement. The general ecosystem model illustrates how to conceptualize these impacts, and more detailed models provide specificity for understanding and monitoring the impacts. These drivers are tied to vital signs identified by the MOJN (Table 2-1) and used in conceptual models throughout this report.

Table 2-1. High-priority vital signs of the MOJN conceptual models. Numbers refer to vital signs shown in models shown in Figures 2-5 and 2-6.

	Top Vital Signs	Conceptual Models	Location
1	Air Quality - Ozone	Atmospheric model	Chapter 2 and Appendix S
2	Air Quality - Wet and Dry Deposition	Atmospheric model	Chapter 2 and Appendix S
3	Air Quality - Visibility and Particulate Matter	Atmospheric model	Chapter 2 and Appendix S
4	Weather and Climate - Basic Meteorology	Atmospheric model	Chapter 2 and Appendix S
5	Soil Quality - Erosion and Deposition	Land-use model	Appendix S
6	Soil Quality - Soil Disturbance	Land-use and patch structure models	Appendix S
7	Soil Quality - Chemistry and Nutrient Cycling	Patch structure model	Appendix S
8	Soil Quality - Hydrologic Function	Patch structure model	Appendix S
9	Soil Quality - Biological Soil Crust Dynamics	Shrublands model	Appendix S
10	Groundwater Dynamics and Chemistry	Groundwater model	Appendix S
11	Surface Water Dynamics	Groundwater, Spring, and Alpine stream models	Appendix S
12	Surface Water Chemistry	Groundwater, Spring, and Alpine stream models	Appendix S
13	Invasive/Exotic Plants	Shrublands and Fire models	Appendix S
14	Vegetation Change	Shrublands, Land-use, and Fire models	Appendix S
15	Reptile Communities	Reptile model	Appendix S
16	Riparian Birds	Spring and Alpine stream models	Appendix S
17	Small Mammal Communities	Small mammal model	Appendix S
18	At-Risk Populations	All models	Appendix S
19	Fire and Fuel Dynamics	Fire model	Appendix S
20	Landscape Dynamics	Dry systems, Wet systems models	Chapter 2 and Appendix S

2.2.3 Scaling

High-priority vital signs in the MOJN respond to drivers that vary across space and time (Figure 2-2). An important goal toward understanding scaling is to differentiate the effects of intrinsic variability from those resulting from human-induced patterns of change (Osenberg et al. 1994, Noon et al 1999, Miller and Thomas 2004). Characterizing intrinsic variability in the recent and distant past using historical ecology (Swetnam et al. 1999) may help identify anomalous processes and conditions caused by human effects and provides a framework for predicting future outcomes. By interpreting trends in resource condition against historic variability, landscape-level effects of human perturbations are most evident. The scales of temporal and spatial variability can be difficult to incorporate into models of ecological systems. Many of

these spatial and temporal scales are not explicit in the conceptual models we present but must be considered in vital sign and monitoring design.

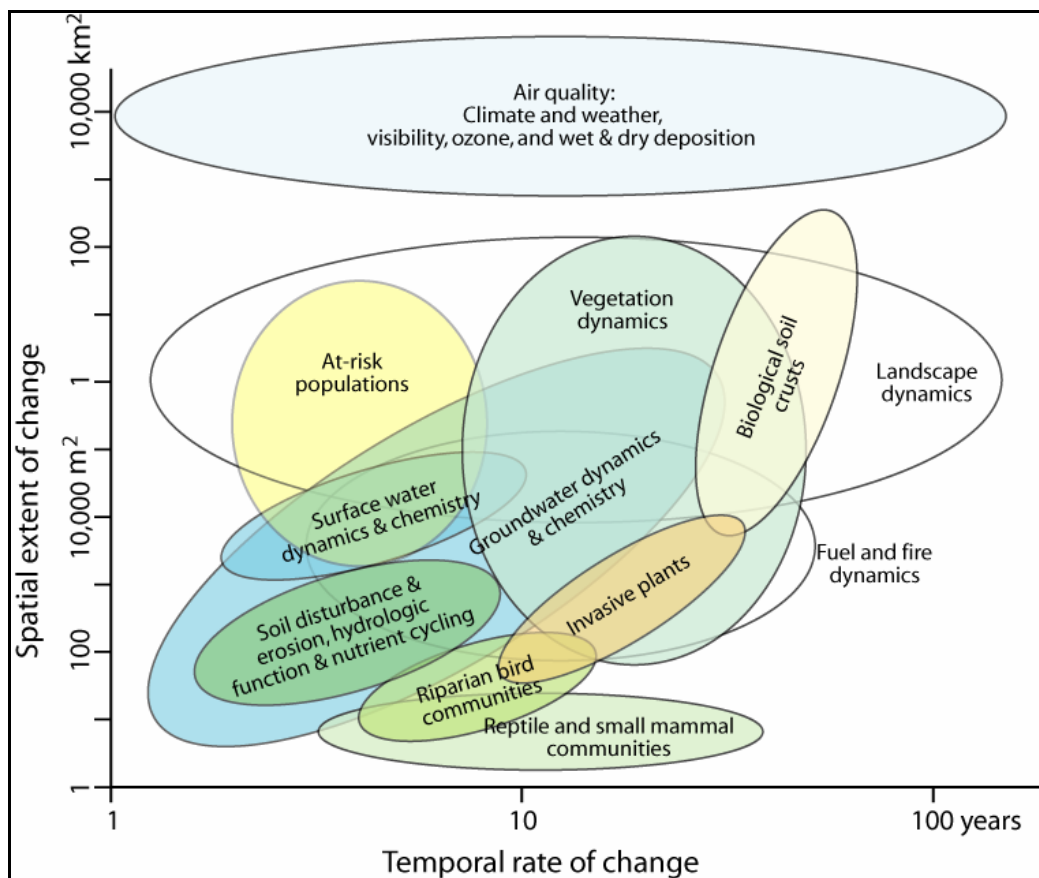


Figure 2-2. High-priority vital signs of the MOJN organized by spatial extent and predicted rate of change in Mojave and Great Basin Desert ecosystems, using approximate log scales on both axes.

Ecosystem components (e.g. plants, animals, soils) respond to different scales such as different lengths of drought or intensities of rainfall, so scales and variability are fundamental to predicting ecological response. In addition, ecological processes and components can vary spatially in complexly interacting ways.

2.3 Framework Ecosystem Model

State factors that structure ecosystems are global climate, time, topography, parent material and a variety of potential biota; these factors in turn affect regional atmospheric resources and conditions, disturbance regimes, soil/water relations, and biological functional groups (Chapin et al. 1996). Water plays an especially pivotal role in ecological models for arid and semi-arid environments (Whitford 2002). The water budget is largely a function of climate, recent weather, topography, geology (soils and bedrock), and vegetation. Particularly important for most aspects

of the ecosystems in the MOJN are the near-surface soil moisture dynamics in which the available moisture is driven by spatial and temporal interactions with climate, vegetation, and soil (Noy-Meir 1973, Rodriguez-Iturbe 2000, Reynolds et al. 2004). Availability of groundwater is key to riparian habitat, seeps, springs, lakes and river aquatic systems, and even features such as wet playas.

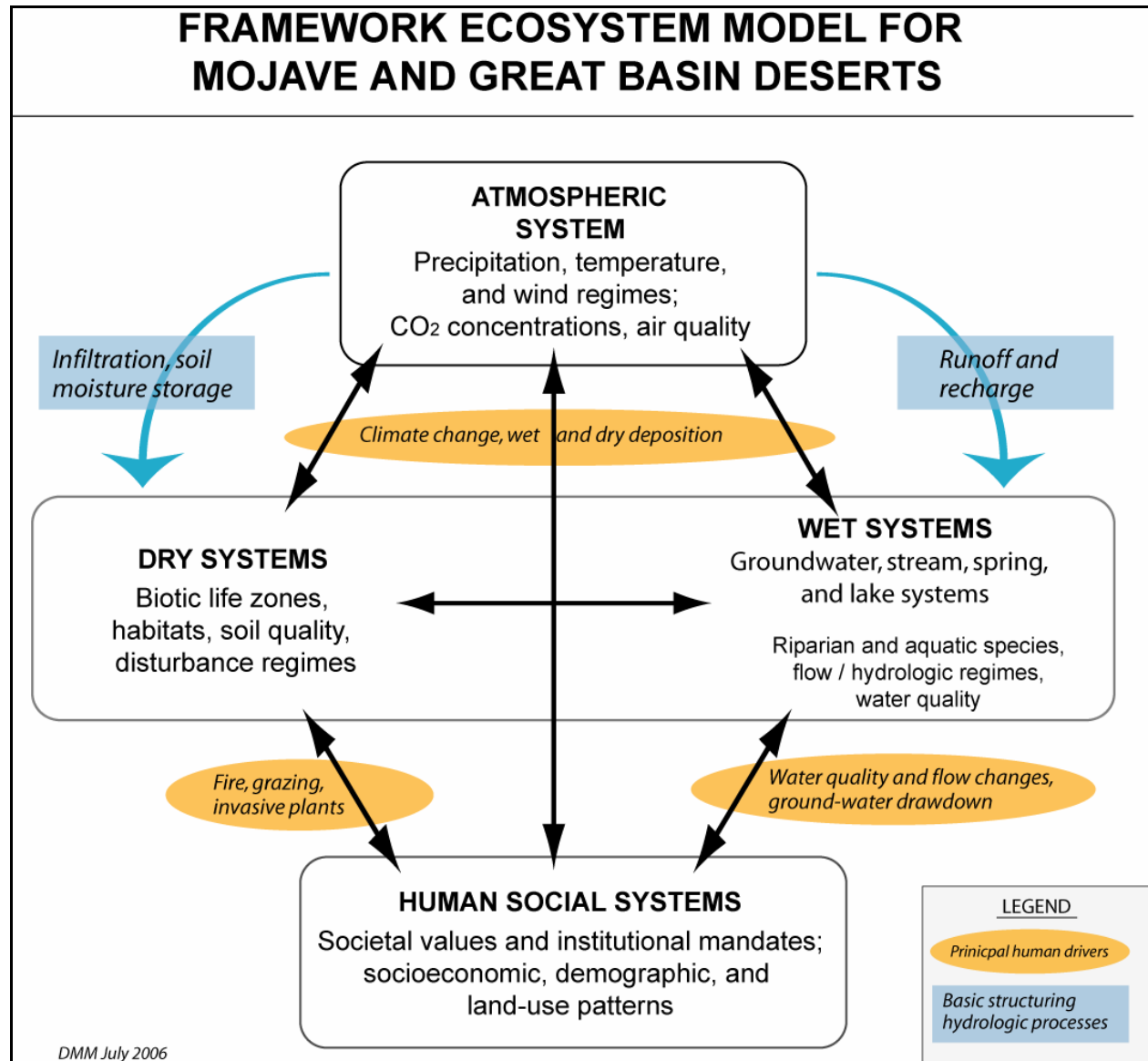


Figure 2-3. MOJN framework ecosystem model, showing the principal components and the processes that structure the landscape into fundamentally wet and dry systems. The model shows that human drivers from Atmospheric and Human systems act on the Dry and Wet Systems.

We combine components of the Jenny-Chapin model to arrive at a simplified structure for a MOJN framework conceptual model (Figure 2-3) that emphasizes the role of water. The model starts with the description of the principal climatic regimes in the MOJN (Chapter 1 and Appendix D), and illustrates how climatic inputs of precipitation are partitioned to dry and wet

1 systems. Precipitation inputs from the atmospheric system are partitioned into runoff, infiltrated
2 water stored in the near surface, and recharge, and thereby provide water for different biotic
3 systems. These same partitioning processes affect surface sediment fluxes, and thus surface
4 stability. Within the dry systems, soil characteristics and processes are linked to landscape
5 characteristics and processes, and all components together structure plant communities and
6 animal habitat. Within the wet systems, recharge to groundwater is key because groundwater
7 drives all springs, lakes, and streams in the network. Ecosystem dynamics in a reference state
8 devoid of human influence involve climate variability, hydrologic interactions with soils, and
9 adaptive strategies of biota to capitalize on spatially and temporally variable moisture and
10 nutrient dynamics, as well as interactions among biota such as interference and facilitation.
11 Natural large-magnitude events such as floods and fire also contribute to the structuring of the
12 ecosystem. These dynamics are altered by human drivers in a number of ways, some of which
13 are illustrated in Figure 2-3.

15 **2.4 System Models**

17 **2.4.1 Introduction**

18
19 The ecosystems of the MOJN are water limited, and can be described effectively at many scales
20 by the availability of water for biota. In a general sense, the divisions for water availability are
21 between saturated, “free” water (such as springs, streams, and lakes) and moisture held in soil
22 and fractured rock. Within each of these “wet” and “dry” categories the amount of water
23 available, its location, when it is available, and water quality define subdivisions that we develop
24 as system and control models. The models form a hierarchy from general to specific (Figure 2-
25 1), with the specific models designed to address high-priority vital signs of the MOJN (Table 2-
26 1). Table 2-1 describes how models in Appendix S connect to specific vital signs. We describe
27 below how the system models operate, and then present two detailed submodels to illustrate their
28 characteristics. Other submodels are presented in Appendix S, to which the reader is referred for
29 in-depth treatments for all models.

31 **2.4.2 Atmospheric System**

32
33 The atmospheric system drives weather, whose long-term behavior is described as climate, and it
34 is the system that conducts most mass and energy, including pollution, to and from the MOJN
35 (Figure 2-4). The atmosphere receives solar radiation, which is mediated by reflective aerosols
36 and absorbent trace gases before reaching Earth’s surface. It also receives water vapor from
37 evaporation at the Earth’s surface and transpiration from plants. In this zone near the Earth’s
38 surface, heat exchange mediates the vertical temperature gradient in the atmosphere (Bradley
39 1985, Monin and Shishkov 2000). Although the atmosphere has low heat capacity, it couples
40 with water bodies of much higher heat capacity with the result that energy in the atmosphere is
41 primarily driven by oceanic circulation patterns. Interactions between the atmosphere and land
42 include evaporation and transpiration, reflected radiation, precipitation, wind, and heat exchange.

Climate of the Great Basin and Mojave deserts varies due to latitudinal and elevation effects on temperature, the rain shadow of Sierra Nevada and Transverse Ranges which sharply reduce winter storm precipitation (see Chapter 1 for description of climate), and the influence of monsoonal systems from southern water bodies during summer. The result is a mosaic of temperature, precipitation, and seasonality of precipitation that drives plant community patterns (vegetation zones). Despite being remarkably adapted to the harsh and variable climate conditions of the deserts, biota are limited by extremes in climate such as temperature extremes and lengths of drought. Changes in climate created by anthropogenic increases in CO₂, particulates, aerosols, ozone, and other pollution have potential to drive many ecosystem processes outside the reference range of variability.

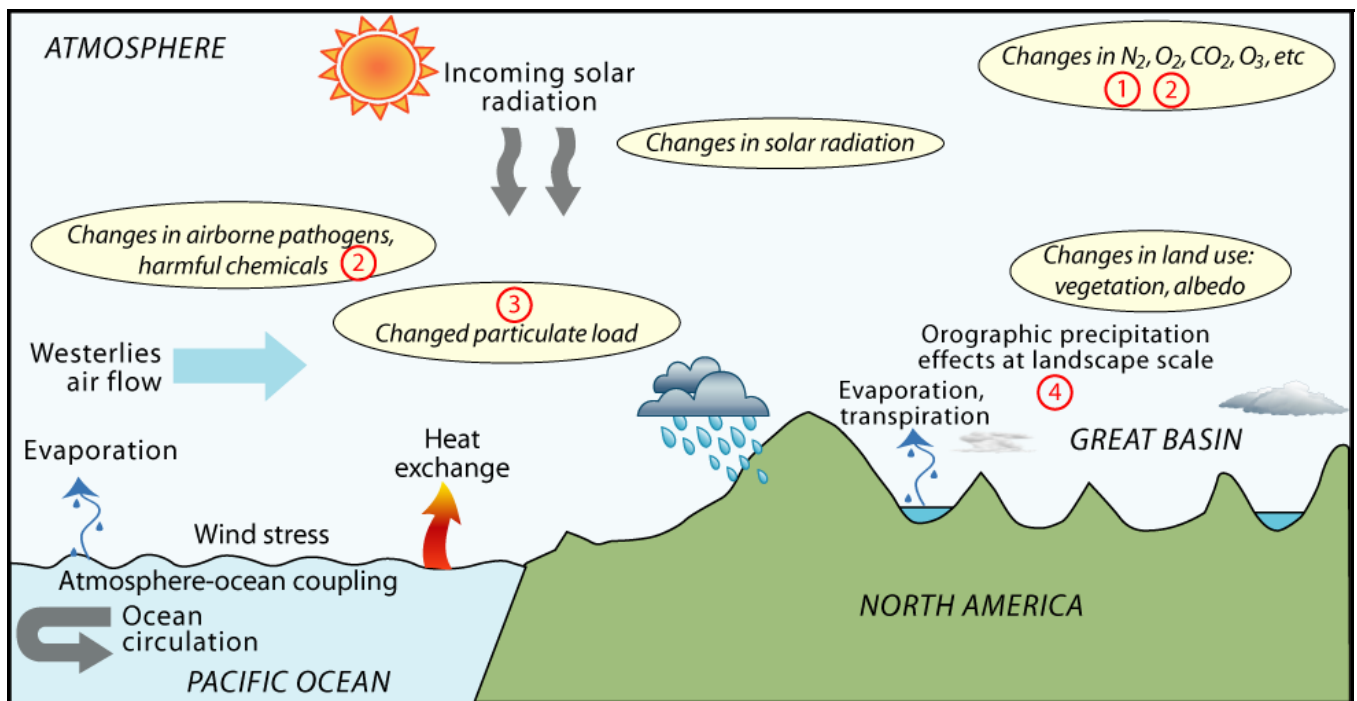


Figure 2-4. Model depicting principal components of the atmospheric system and some drivers (in ovals) associated with the atmosphere and climate. Circled numbers link to vital signs in Table 2-1.

2.4.3 Human Social Systems

Human social systems influence the parks of the MOJN at scales from global to site-specific, and many of these influences are not directly in the control of the National Park Service. Global climate change, regional air pollution patterns, and light in night skies are examples of large-scale human drivers of the ecosystems. Local and site-specific impacts range widely; examples are water use, road and trail use, campfires, and illegal dumping. Underlying all of these drivers is the magnitude of human population, position of local population centers, and the presence of disposable income in the local communities combined with technology for recreation. In

1 particular, local population centers require water extraction with accompanying impacts on
2 groundwater levels and subsequent impacts on riparian and aquatic habitat.

3
4 The history of human impacts is critical to evaluate for understanding current landscape
5 condition. Legislation for homesteading, mining, grazing, and water resource use enacted more
6 than a century ago has left a legacy in and near all of the parks in the Network. Community
7 infrastructure, roads, utility corridors, water diversion infrastructure, and all the uses associated
8 with public lands are the result of a complex interplay of values, social structure, and human
9 survival. For park lands now freed of former uses, a knowledge of that history of use is needed to
10 manage the land.

12 **2.4.4 Wet Systems**

13
14 The wet systems of the Great Basin and Mojave Deserts include springs, wetlands, streams, wet
15 playas, and lakes (Figure 2-5). These systems have in common the presence of "free" water on or
16 near the ground surface, associated typically with groundwater discharge, which distinguishes
17 them from the majority of the water-deficient desert. As a result these locations constitute
18 biological "hotspots" where biodiversity is concentrated into relatively small areas. Many vital
19 signs relate to the wet components of the deserts, indicating their importance to the Network.

20
21 Most springs and streams were treasured sites for early settlers and travelers, with desert routes
22 established along the highest density of springs and streams. As a result, these features are not
23 only of ecological significance, but have important historical significance. The most significant
24 surface water system is the Colorado River, which enters the Mojave Desert as it flows out of the
25 Grand Canyon into the Lake Mead reservoir behind Hoover Dam and then to Lake Mohave
26 reservoir. This major river is an ecosystem in itself, primarily not managed by the National Park
27 Service, and is not considered in the ecosystem conceptual models developed here. Nearly all
28 other aspects of the wet systems are intimately interconnected to the groundwater regime, and
29 the nature of the groundwater system controls the nature of the wet features including the
30 temporal and spatial availability of surface water, its chemistry, and related, often endemic,
31 biota. Thus we describe how groundwater systems behave (groundwater model, Appendix S) as
32 a basis for understanding the responses of aquatic and riparian habitat to hydrologic drivers and
33 stressors.

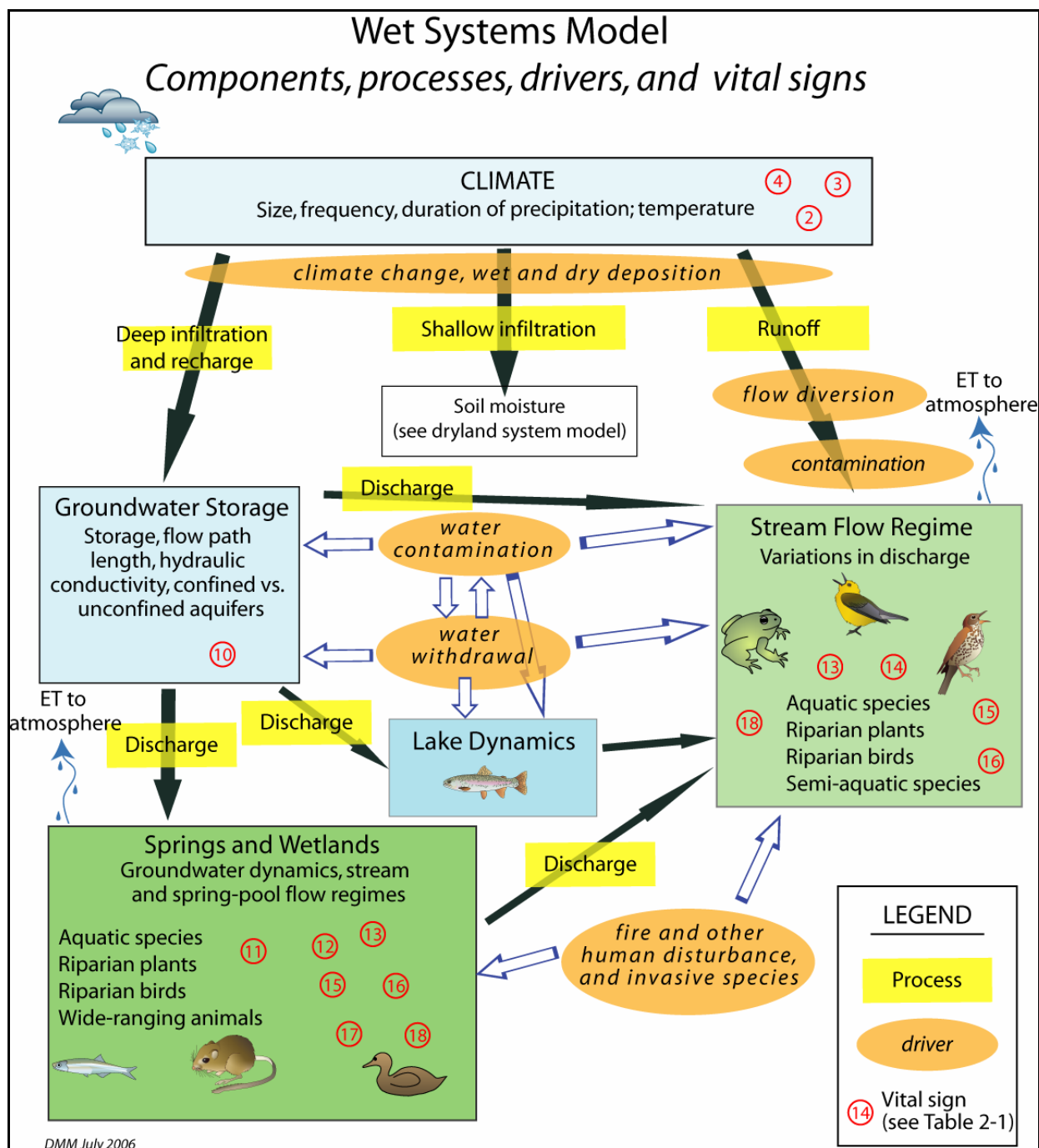


Figure 2-5. Conceptual model for wet systems, illustrating climate controls on groundwater and streams via recharge and runoff, as well as interactions among the main components (shown as large colored boxes). The model emphasizes groundwater as a foundation of all wet system components, from springs to streams to lakes. Drivers such as altered flow regime, groundwater withdrawal, and invasive species enter into the model in several places, demonstrating the potentially complex effects of a given disturbance.

1 Stream and stream-bank (riparian) ecosystems consist of common environment such as the
2 floodplain, channel bank, channel bed, and channel, and are used by many ecosystem
3 components such as plant communities, aquatic species, and wildlife. The function and
4 distribution of these habitats are driven by temporal and spatial variations in water flow (Ward
5 and Tockner 2001, Power and Dietrich 2002, Biggs et al. 2005, Caylor et al. 2005, Thorp et al.
6 2006), commonly summarized as flow regime. These variations occur on many scales, from
7 general longitudinal and lateral changes in discharge and streambed form, to temporal variations
8 in discharge (e.g. floods). Large streams and rivers are also complex networks in which the
9 organization of channels and their tributaries uniquely shape flow characteristics (Benda et al.
10 2004). The flow regime (i.e. discharge, velocity, channel form, floodplain configuration, etc)
11 shapes habitats through disturbances (e.g. bed friction and sediment transport), temperature and
12 light variations, and water chemistry (including nutrient concentrations) (Scott et al. 2004). The
13 flow regime strongly influences aquatic species from fish (including listed species such as the
14 Virgin River chub (*Gila seminude*) and the woundfin (*Plagopterus argentissimus*) to springsnails
15 and amphibians, as well as riparian vegetation such as cottonwoods, willows, seep willows,
16 arrowweed, ash, cattails, rushes, and sedges. Because streams and riparian zones are associated
17 with available water, they are utilized by wide-ranging wildlife such as deer, bighorn sheep, and
18 a wide variety of birds. They are also attractors to invasive species that alter the habitat and
19 stream function, such as tamarisk, and can act as corridors for invasive species.

20
21 Desert spring-fed wetlands can be broadly characterized as pools, streams, and muddy or boggy
22 areas. Extensive wetlands and multiple spring pools form where a regional carbonate aquifer
23 system discharges, such as at Ash Meadows. These pools are habitat for rare and endemic
24 species, such as species of springsnails, frogs, and fish. In JOTR, five fan palm oases are
25 important habitat and historical sites. The desert fan palm (*Washingtonia filifera*) is the only
26 palm native to the western United States. In one of these springs and at two other sites,
27 California treefrogs (*Hyla cadaverina*) occupy a small part of their historical habitat. Where
28 broad, sediment-filled valleys discharge, streams and riparian corridors form, such as at Darwin
29 Falls and Piute Spring. Much more common are the seeps and springs at the mouths of
30 mountainous canyons, which can be ephemeral on time scales that depend on precipitation and
31 the volume of groundwater stored in sediments. Higher precipitation and snowmelt feed streams
32 and groundwater that flow off Wheeler Peak in GRBA, forming at least one small lake, then
33 disappearing into fissures in carbonate rocks and valley fill sediments. Devils Hole in DEVA is a
34 unique window into a regional carbonate aquifer and is home to the endangered Devils Hole
35 pupfish. Since water is so scarce in the desert, people have undertaken substantial effort to
36 develop nearly every possible source. Places where groundwater exists near surface often
37 support dense vegetation. Humans have removed some of this vegetation, tunneled into the soil,
38 and piped groundwater to the surface, creating a source of water where otherwise only dense
39 vegetation would exist.



Figure 2-6. Saratoga Springs in southern Death Valley consists of several spring mouths that provide water to three open-water ponds that total 2.7 ha. They support surrounding salt grass, common reed, and bulrush as well as aquatic plants, fish, and invertebrates. The Saratoga pupfish (*Cyprinodon nevadensis nevadensis*) and five rare invertebrate species Amaragosa tyronia snail (*Tryonia variegata*), Amargosa spring snail (*Pyrgulopsis amargosae*), Saratoga Springs belostoma bug (*Belostoma saratogae*), Amargosa naucorid bug (*Pelocoris Shoshone*), and Death Valley June beetle (*Polyphylla erratica*) occur at Saratoga Springs. Two rare water-dependent plant communities exist here, the transmontane alkali marsh and alkali seep habitats. This is the third largest marsh habitat in the Park. Photograph D.M. Miller, 2002.

Spring-fed wetlands form a wide variety of important riparian and aquatic habitat (Stevens and Springer 2004). In general, biological importance is correlated with the size of the wet area – brook length for flowing streams and size of pools – which are in turn a function of spring discharge. Groundwater discharge at springs is thus a key indicator of riparian biologic health and integrity. The drivers of groundwater systems, which discharge to these springs, at landscape levels are primarily precipitation, recharge, and climate change. More locally, drivers include groundwater extraction, distribution of contaminants, and disturbance – especially paving and diversion – of recharge zones. Because streams in the desert are intimately connected to groundwater, flowing both above and below the ground surface, they are affected by the same drivers, but are also susceptible to surface diversions and contamination (Figure 2-5). Spring-fed wetlands and stream systems are affected by invasive plants (e.g., tamarisk) and animals (e.g. mosquitofish [*Gambusia affinis*] and Asian tape worm [*Bothriocephalus achelognathii*]), as well as by direct human disturbance and fire. Vital signs reflect many of these drivers as well as the importance of wet systems for endemic and at-risk populations of pupfish, Mojave tui chub (*Siphateles bicolor mojavensis*), amphibians, riparian bird communities, and aquatic macroinvertebrates.

2.4.5 Dry Systems Model

Soil, water, and air are the media from which primary producers acquire resources. As the abiotic matrix that supports the biota, they form the foundation of ecosystems. These media also are characterized by condition attributes (e.g. temperature, surface stability) that affect the physiological performance of organisms. The availability of water is limiting to many desert organisms and is largely controlled by soils, and therefore geology provides the first-order template with which biota build integrated ecological systems, particularly at broad regional to landscape scales (Table 2-2).

Table 2-2. Scales of ecosystem attributes that structure the biotic communities of drylands.

Spatial scale	Ecosystem attribute	Description	Ecosystem effect
Regional (25 to 250 km)	Climate	Latitudinal precipitation and temperature patterns	Cold desert – hot desert gradient
	Geology moderating climate	Elevation precipitation and temperature gradients	Vegetation zones
Coarse Landscape (1 to 25 km)	Surficial deposits	Soil moisture	Plant composition and pattern
	Elevation and aspect	Effective moisture	
Fine Landscape (50 m to 1000 m)	Surficial deposits	Soil moisture	Plant pattern
	Landform	Catena effect on effective moisture	
	Plant communities	Invasive plants	Disturbance regimes altered
Site/Local (<1 m to 50 m)	Plants and animals	Competition, facilitation, herbivory, seed caching, etc.	Plant and animal patch pattern
	Soils and microtopography	Soil moisture	

At the regional scale, desert ecosystems are structured by precipitation and temperature patterns, as well as the elevation gradients that create the life zones of desert mountains. Merriam (1898) established the life zone concept of regional climate-controlled biotic provinces. This concept was refined in the Great Basin by Billings (1951) and later by the closely related biome concept of Lowe and Brown (1994), which we adopt in this report. Biomes (biotic communities) are characterized by distinctive vegetation and are regional in scope due to responses to climate factors, principally temperature and precipitation (effective moisture). In the desert, precipitation is the major driver, except for the high mountain communities, and thus biomes mark availability of effective moisture. At the regional scale, the dryland system can be described by component biomes that we develop as separate models: alpine tundra, mixed conifer forest, pinyon-juniper woodland, and shrublands (Figure 2-1). These communities are described in Appendix D.

At the landscape scale, geomorphology and deposit characteristics have a large influence on plant communities (Figure 2-7). Mountains have relatively high near-surface moisture that is locally stored in small colluvial and alluvial sediment deposits within the complex topography underlain by eroded rock. The greater effective moisture supports diverse woodlands and forests, rare wet meadows, and open dry meadows. Piedmonts support highly variable plant communities, primarily in response to climate conditions that are correlated with elevation gradients, but also in response to landforms and characteristics of geologic deposits. Surficial geologic deposits vary in soil texture (grain size distribution and packing), bulk density,

1 chemistry, and other factors; horizontal variation is largely influenced by depositional processes
2 and vertical variations by soil development (pedogenesis). Soil texture is critical in the moisture
3 budget since, in general, coarse soils have higher infiltration rates and low retention capacity,
4 whereas finer grained soils have lower infiltration rates but higher retention capacities (Noy-Meir
5 1973). The resulting spatial patterns of amount of moisture stored, depth of storage, and time
6 period it is stored structure species composition and cover in shrubland ecosystems (McFadden
7 and Knuepfer 1990, McDonald 1994).

8
9 In the dry systems model (Figure 2-7), climate plays a driving role in shaping the soil moisture
10 regime and thereby soil biota. Soil moisture influences, and to a large extent structures, the plant
11 and biological soil crust communities. The geologic-climate system outlined in preceding
12 paragraphs is mediated by biotic influences, resulting in a complex landscape mosaic with
13 feedbacks plants influence animal communities, which likewise affect plants and the soil system.
14 Examples of the structuring effects of plants include facilitation, interference, transpiration, and
15 several factors related to microsites under plants (McAuliffe 1988).

16
17 The landscape mosaic creates the primary texture and physiognomy of the plant and animal
18 community at scales from tens of meters to kilometers. Patch structure at finer scales is created
19 by interference and facilitation among perennial plants, competition within annual plant
20 communities, nutrient cycling by decomposers, herbivory that coincides with environmental
21 pulses and plant responses to the extent that herbivory can cause disturbance areas, and the
22 dispersal of plant propagules by a variety of granivores (Vander Wall et al. *In Press*). At scales
23 of tens to hundreds of kilometers the landscape is shaped by plant invasions that alter disturbance
24 regimes, such as stream channel pattern (Birken and Cooper 2006), fire (Billings 1990, Brooks
25 1998), and albedo and evapotranspiration feedbacks to climate. Table 2-2 summarizes the
26 elements that structure desert communities at various scales.

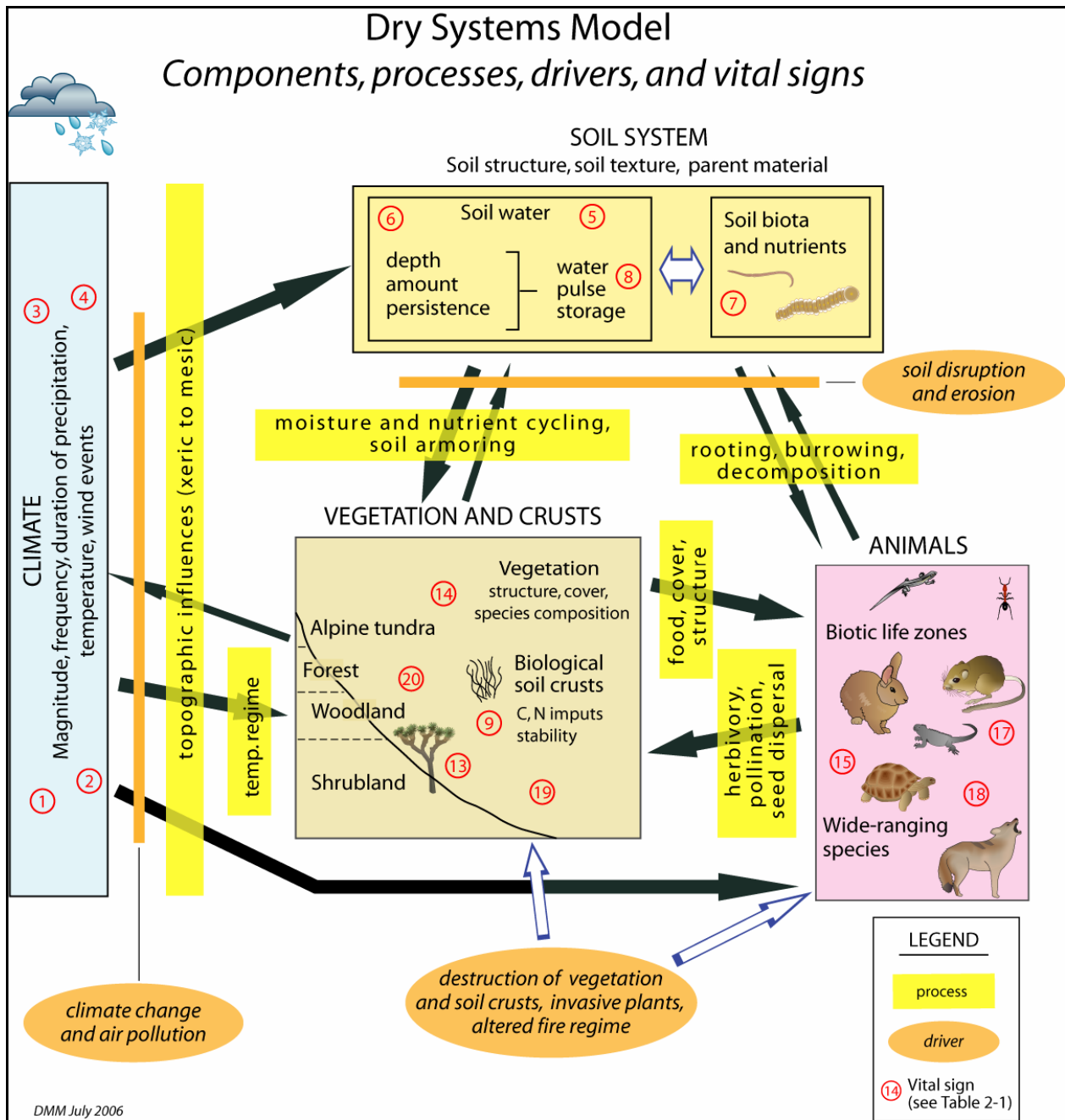


Figure 2-7. Conceptual model for dryland systems function, illustrating climate controls on soils, vegetation, and animals, as well as interactions among the components and some of the key processes by which they interact. The model emphasizes the shrubland system but forest system and alpine system have many analogous components and processes. Climate drivers, along with topographic influences, dictate the availability of soil moisture, which is further modulated by surficial deposits and pedogenesis as landscape-scale structure for vegetation and animal communities. Vegetation structure and function influence animal communities, which in turn modify soils and nutrients, and plant communities. The model incorporates categories of human drivers and illustrates some of most important parts affected by those drivers.

1 Soil erosion and deposition are mediated by soil stability conferred by chemical and biological
2 crusts and by vegetation; areas of dense crust or vegetation are relatively stable. Precipitation
3 dynamics govern the location and type of erosion, transportation, and deposition of sediment, as
4 does the landform. In general, streams in the Great Basin are perennial in proximal and medial
5 piedmont position, and sediment transport from mountains to distal piedmonts is ongoing, with
6 pulses driven by snowmelt and intense storms. By contrast, few streams in the Mojave Desert are
7 perennial beyond the canyons within mountains, and sediment pulses onto the piedmont are
8 highly stochastic with respect to time and location. Gullying and enhanced erosion is largely a
9 disturbance-caused phenomenon in areas with steep hillslopes or compacted soils.

10
11 Drylands wildlife responds to patterns of ecosystem structure at multiple scales. Habitat-use
12 patterns range from patch-level structure such as plant patterns to landscape-level attributes such
13 as the mosaic of patch types (Wiens et al. 2002).

14
15 Human drivers of the dryland components and processes are wide-ranging, but the principal
16 drivers, such as climate processes associated with global change, disruption of soils, and invasive
17 plants, are shown in Figure 2-7. Many of these drivers are closely linked to the high-priority vital
18 signs of the MOJN.

20 **2.5 Example Detailed Sub-models**

21
22 Several detailed models were developed to emphasize parts of the general system models briefly
23 described above. The detailed models more specifically describe systems of greater interest, with
24 goals ranging from generally describing how a specific system operates (e.g., shrubland model
25 below) to describing how drivers such as fire and invasive grasses affect shrublands (e.g. fire
26 model below). The following models are presented to illustrate approaches with detailed models;
27 the models themselves are fully described in Appendix S.

29 **2.5.1 Shrubland Model**

30
31 The desert shrublands system of the MOJN is characterized by a general lack of trees,
32 interspaces between shrubs that are only partly covered with grasses and forbs, and plants that
33 are adapted to long, hot, dry summers. The dominant species in shrublands range from big sage
34 and shadscale in much of the Great Basin cold desert, to widespread creosote bush (*Larrea*
35 *tridentata*)-white bursage (*Ambrosia dumosa*) scrub of the warm Mojave Desert, and includes
36 narrower regions of salt desert scrub and blackbrush (*Coleogyne ramosissima*) dominated
37 shrubland in the Mojave Desert. A particularly noteworthy community that we include in the
38 shrubland model is a higher elevation mixed shrub and Joshua tree community that has varying
39 shrub and grass species.

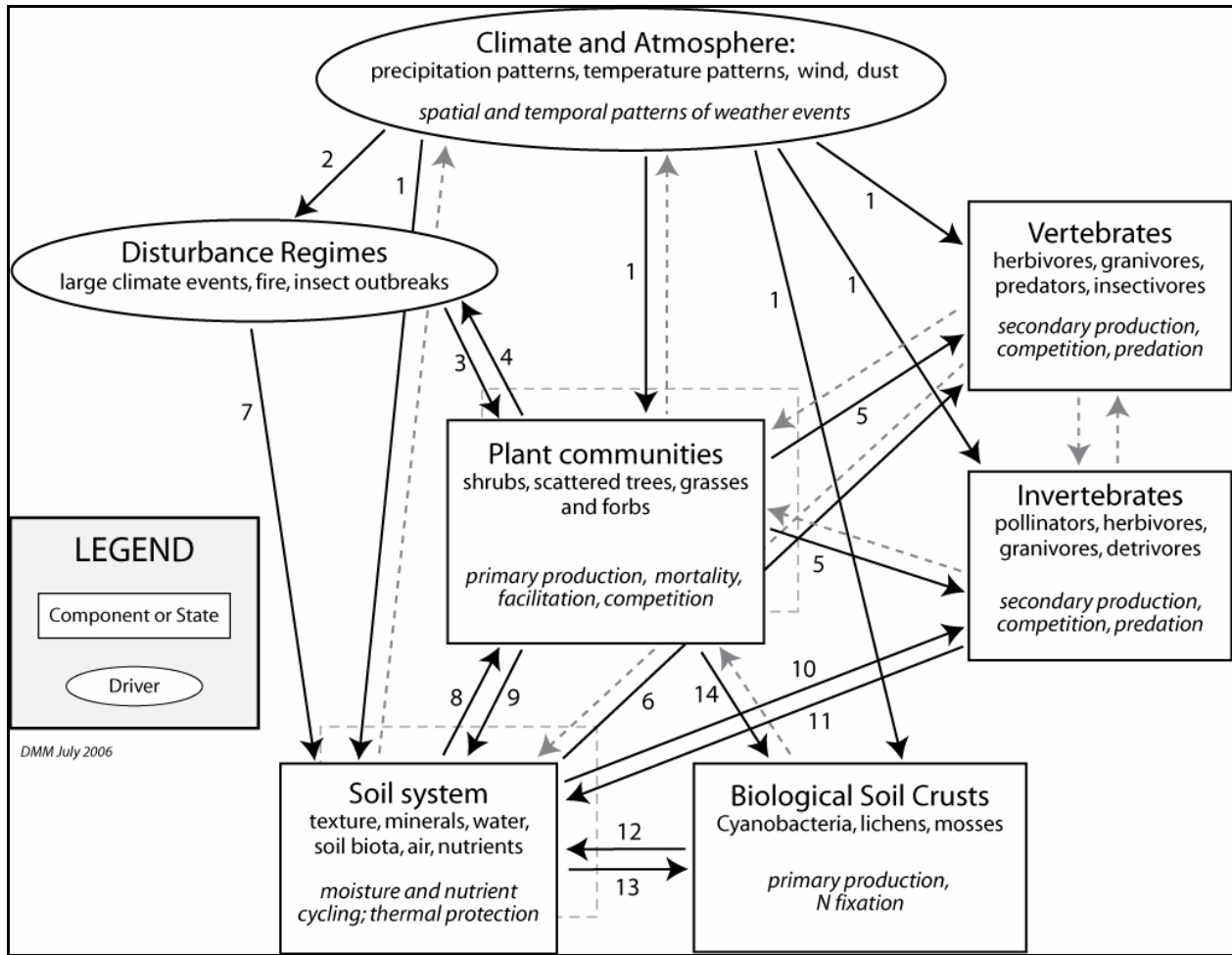


Figure 2-8. General conceptual model of shrublands, including Mojave Desert shrublands, Great Basin shrublands, Joshua tree “woodland”, and salt desert scrub. The model shows principal components with a brief description of each component, plus (in italics) principal functions of each component. Arrows indicate primary functional relations among components (solid lines) and secondary relations (dashed lines) and are described more fully in Appendix S. At the landscape scale of this model, most drivers that structure the plant and animal communities are abiotic, and climate-related. The model is constrained by the regional atmosphere conditions and geologic and topographic controls. Modified from Miller 2005.

1 The shrubland model is designed to examine functional relations among plant communities,
2 soils, and animal communities, in order to set a stage for examining anthropogenic drivers. The
3 model focuses on these components of the shrubland system, incorporating two major driver
4 systems (Figure 2-8), and illustrating functional relations with arrows among the components.
5 The model operates within the context of the higher-level dry systems model, incorporating the
6 boundary conditions of that model such as topographic influences, without graphically depicting
7 them.

9 **2.5.2 Fire Model**

11 The purpose of the fire model is to describe interrelations among vegetation, fire, and small
12 animals, as well as the invasive grasses that play a large role in the fire-fuel cycle. The processes,
13 mechanisms for change, and consequences of the interrelations in this system are depicted in
14 models that give several levels of detail, an example of which is the general state-and-transition
15 model in Figure 2-9. The models explore the effect of invasive flammable exotic grasses that
16 increase fuel continuity in shrub interspaces, the ability of blackbrush community to recover
17 from fire, and the role that small seed-caching rodents play in blackbrush recovery.

19 State-and-transition models present two or more alternate states of shrub community, along with
20 functional relations describing transitions among the states, as a tool for evaluating ecosystem
21 dynamics and land-use practices. The model in Figure 2-9 represents desert shrub communities
22 (based on models by Bestelmeyer et al. 2003 and Miller 2005) that undergo dramatic transitions
23 caused by fire. The model consists describes a transition that is modeled as a threshold, and to
24 return back across that threshold requires substantial energy and time. The model demonstrates
25 monitoring needs such as invasion of grasses, fire pattern and frequency, and climate parameters.

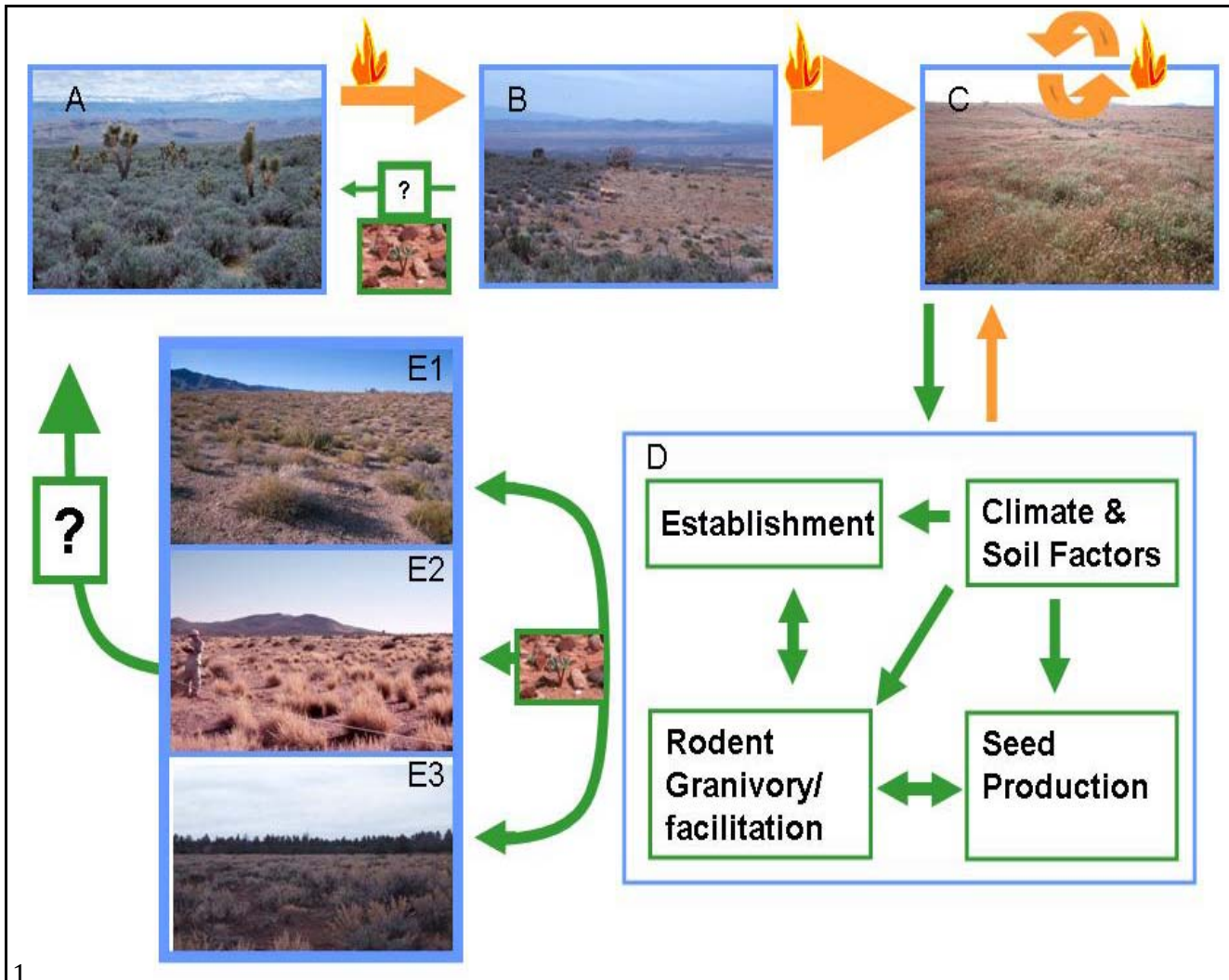


Figure 2-9. Shrub and fire model. An undisturbed blackbrush – Joshua tree stand (A) is burned and invaded by red brome (*Bromus madritensis rubens*) (B), which may increase fuel continuity. After repeated fires, brome grasslands (C) dominate the landscape. Recovery processes (D) may lead to reestablishment of shrub communities in the Mojave Desert (E1 and E2) and Great Basin Desert (E3). However, invasive grasses create conditions for which even a partial recovery (state E) is unlikely.

Chapter 3 Vital Signs

3.1 Introduction

Monitoring seeks to determine the status of and detect trends in ecological indicators of interest (Busch and Trexler 2003). An effective monitoring strategy directly addresses resource monitoring goals (Elzinga et al. 1998) that are applicable to land managers in determining appropriate actions and measuring success. These monitoring goals have traditionally been vague and reference maintaining or attaining some state of favorable “ecosystem health” or “ecosystem integrity” as their ultimate goal (Busch and Trexler 2003). As the traditional view of the balance of nature has been replaced by recognition that ecosystems are dynamic, variable systems, the use of ecosystem “health” and “integrity” has been criticized (Suter 1993). Further, these terms imply that science has some objective, precise, quantitative definition of a “healthy” ecosystem. Noon (2003) acknowledged the limitations of “ecological integrity,” but contended that, though vague, the term has merit for communicating monitoring goals to managers. We prefer the more value-neutral term “ecological condition,” (Busch and Trexler 2003) because:

A. Desired conditions are set by the managers and policy makers entrusted with the care of the land management unit. An overarching set of ideal conditions is not assumed. For the NPS, these desired future conditions are described in the mission of the park, environmental laws, and enabling legislation. Linking these generally vague mandates for resource management and protection to specific, measurable conditions is the shared task of scientists, managers, policy makers, and the public in whose name these lands are managed.

B. “Integrity” implies a binary assessment of ecological conditions; either the ecosystem has integrity (is functioning) or does not (is not functioning). While thresholds and trigger points play important roles in ecosystem dynamics and monitoring, “ecological condition” better reflects the non-equilibrium character of ecosystems, in which natural disturbances such as fire, flood, and climatic extremes play important roles.

Because the field of potential indicators to assess “ecological condition” is large, monitoring programs must select the best subset of those indicators for ecosystem study, working under such additional constraints as management relevance, budgetary and staffing limitations, and feasibility of implementation. The term “vital signs” was coined by NPS to represent these ecosystem indicators, reflecting their similarity to critical measures of human health such as pulse and respiration. Vital signs may occur at any level of organization (e.g. landscape, population, community) and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Given this complexity, selecting the best vital signs for monitoring requires a logical, step-wise approach. An 8-step approach was taken by the network to identify, prioritize, and select vital signs (Figure 3-1). This process was designed to allow selection of vital signs at both the park and network level.

<u>Steps in Identification, Prioritization, and Selection of Vital Signs for the Mojave Network</u>	2
	4
	6
	8
1. Identify ecosystem drivers, stressors, and important processes through development of an initial conceptual ecological model for the network (NPS 2003).	10
	12
	14
	16
2. Conduct a series of small, park-based workshops to identify important resources (abiotic, biotic, processes), resource threats, management concerns, monitoring questions and vital signs for each network park.	18
	20
	22
	24
3. Identify similarities and differences across parks and summarize vital signs, threats, management concerns, and monitoring questions at the network-level.	26
	28
	30
4. Park staff review network-level information.	32
	34
5. Prioritize vital signs for each park based on management significance and legal mandate.	36
	38
	40
6. Conduct a network-level vital signs scoping workshop to complete scientific review of network-level vital signs and associated information; complete prioritization of vital signs based on ecological significance; provide additional information helpful to monitoring for high priority vital signs (e.g. partnership opportunities, monitoring objectives).	42
	44
	46
	48
	50
	52
7. Conduct a small workshop(s) for network and park staff to initially select a “short list” of high priority vital signs for the Mojave Network of parks.	54
	56
	58
8. Conduct a small workshop for network and park staff to select vital signs that the network will focus their efforts on in the next 5 years.	60
	62
	64
	66

Figure 3-1. Steps in Identification, Prioritization, and Selection of Vital Signs for the MOJN.

3.2 Overview of Vital Signs Selection Process

The complex task of developing a network monitoring program requires a front-end investment in planning and design to ensure that monitoring will meet the most critical information needs of each park and produce scientifically credible data that are accessible to managers and researchers in a timely manner. The investment in planning and design also ensures that monitoring will build upon existing information on park ecosystems and make maximize partnerships with other agencies and academia. Collectively, the information used to build the monitoring program also

functions as ideal criteria by which ecological indicators can be compared and selected for inclusion in the network's vital signs monitoring program. An overview of the progression is provided in Table 3-1.

Table 3-1. Completion dates for different steps of the MOJN vital signs selection process (based on Figure 3-1).

Vital Sign Step	Event	Dates	Objective	Resulting Number of Vital Signs
Steps 1-5	Lake Mead candidate vital signs vital signs scoping workshop	Spring 1999	Develop a list of candidate vital signs for Lake Mead	(N=88)
Steps 1-5	Geologic resource evaluation workshops held at GRBA, JOTR, MANZ, MOJA, and PARA	May to September 2003	Evaluate the geologic resources at MOJN parks.	
Steps 1-5	Park-Level Vital Signs Scoping Workshops at DEVA, GRBA, JOTR, LAME, and MOJA	November to December 2003	Develop a list of candidate vital signs for MOJN parks.	(N=113)
Step 6	Network-Level Vital Signs Scoping Workshop	May 2004	Various - see section 3.2.4	(N=69)
Step 7	Technical Committee Meeting	July 2004	Selection of "short list" of vital signs	(N=26)
Step 8	Technical Committee Meeting	November 2005	Select vital signs to be part of long term monitoring program	(N=20)

3.2.1 1999 Lake Mead National Recreation Area Vital Signs Scoping Workshop

Results of the Lake Mead National Recreation Area Vital Signs Scoping Workshop (NPS 1999e) were used in the development of candidate vital signs for the MOJN. The objectives of the LAME Vital Signs Workshop were to: (1) Provide a peer review of the park's current resource management program, including comments on the overall program framework and ecosystem model, current management and monitoring activities; (2) Ensure that functions or processes necessary to maintain ecosystem integrity have not been overlooked in program planning; and (3) Provide direction for a monitoring program that assesses the health of the park's ecosystem including its condition and trend. The majority of workshop participants were scientists (academia) involved in research in the Mojave Desert or a similar ecosystem, representatives of federal or state agencies that had management or research activities occurring within the boundaries of the recreation area, and NPS staff. Workshop products included a list of reviewed ecosystem/park stressors and associated monitoring questions, and candidate vital signs. Candidate vital signs identified at the LAME workshop were adapted, as appropriate, to each individual network park and served as a baseline for subsequent park-level vital sign scoping workshops. The LAME Vital Signs Workshop Summary is available on-line at <http://hrcweb.lv->

hrc.nevada.edu/mojn/data/lamewksp_report.htm. A listing of vital signs identified at the workshop is provided in Appendix T.

3.2.2 2003 Geologic Resource Evaluation Workshops

Geologic Scoping Meetings were held for GRBA, JOTR, MOJA, MANZ, and PARA between May and September 2003. MANZ was discussed only briefly at the MOJA workshop. Workshop participants included park and network staff, NPS-GRD staff, and other non-NPS participants (e.g. USGS, university staff, etc.). Workshop objectives were: (1) to identify the status of geologic mapping efforts in each park, identify data gaps, and develop a strategy for acquiring information to complete baseline geologic maps; (2) introduce participants to the vital signs monitoring program and geologic indicators; (3) identify important geologic resources and related management issues and concerns; (4) identify resource threats; and (5) identify management/monitoring and research questions related to park geologic resources. Candidate vital signs were discussed and identified within the context of the geosindicator checklist initially developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning and revised by NPS-GRD staff. The primary workshop product was a final report including a basic description of park physiography and geology, important geologic features and processes, identification of threats and management concerns related to geologic resources, and identification of monitoring and research questions. The results of geologic resource evaluation workshops were used by the MOJN in conjunction with the results of other workshops to develop materials and populate databases used at subsequent park-level vital signs scoping workshops. Final geo-scoping workshop reports are available from the MOJN upon request (NPS 2003b, NPS 2003c, NPS 2003d, NPS 2003e, NPS 2004c, NPS 2004d, NPS 2004e).

3.2.3 2003 Park-Level Vital Signs Scoping Workshops

Between November and December 2003, the Network conducted park-level vital signs scoping workshops at DEVA, GRBA, JOTR, LAME, and MOJA. Participation in park workshops ranged from 13-18 individuals representing park and network staff, park cooperators/scientists and park volunteers. Park staff represented various branches/divisions including administration, interpretation, cultural resource management, natural resource management and protection. Workshop objectives were to: (1) identify important park resources; (2) identify important management issues; (3) identify and prioritize park stressors; (4) identify park monitoring and research questions; and (6) identify candidate vital signs. At LAME, the purpose of this workshop was slightly different in light of the park workshop held in 1999 (see above). The purpose of the LAME park-level workshop in 2003 was to review the vital signs, monitoring questions, etc. previously identified and to update appropriate information. Information and candidate vital signs for MANZ were cooperatively developed by the MOJN Network Coordinator and the MANZ Superintendent.

Candidate vital signs at the park-level were identified within 5 broad categories: Air/Climate, Geology/Soils, Hydrology, Animals, and Plants. Issues related to human use were identified

1 within each of the broader resource categories. For each resource category, participants were
2 asked to identify ‘specific resources’ important to their park and responses ranged from small-
3 scale, discrete resources (e.g. Devils Hole pupfish) to broad-scale ecosystem processes (e.g.
4 geomorphic processes), and resources of value for societal reasons (e.g. charismatic species).
5 This exercise was designed to be a brain-storming session for park staff to provide critical input
6 on those ‘resources’ and resource issues important to individual park units. For each ‘specific
7 resource’, park staff also identified associated ecosystem stressors, specific threats, management
8 concerns, and monitoring questions. All information provided by participants was captured in an
9 MS Access database table that was projected for viewing during the workshops. Fields under
10 Geology/Soils were populated by network staff with information from park geo-scoping
11 workshops, and this information was reviewed and revised during vital signs scoping workshops
12 at parks. Park-level databases were merged into a single, network-level database (discussed in
13 section 3.2.4) and used to develop a vital signs framework for the network that addressed both
14 vital signs common across parks as well as vital signs for individual parks. A total of 113
15 candidate vital signs were initially identified for the MOJN.

17 Prior to park-level workshops network staff used several sources of information to summarize
18 priority resources, stressors, and resource concerns for the network. Park planning documents
19 were reviewed and summarized, and key resources identified through this process were reviewed
20 and revised through park-level vital signs scoping workshops. Reviewed documents included
21 General Management Plans, Resource Management Plans, and Strategic Plans. Ecosystem
22 stressors identified in an early general conceptual model for the MOJN and reviewed through
23 park-level scoping workshops also were prioritized for each park and the network. At each
24 workshop participants broke into small groups and assigned scores (1=low, 2=medium, 3=high)
25 to each park stressor based on significance to management and potential impacts on resources.
26 For each park, scores were summed across all groups to provide an overall park ranking. Scores
27 were summed across parks to identify stressors of most concern at the network-level. Stressors
28 that were prioritized ‘high’ across the network, meaning they pose a significant threat to natural
29 resources within network parks, were invasive species (#1), water quantity alteration (#2), land
30 use change/development (#3), and air quality degradation (#4). Of note is that 3 parks identified
31 certain park resource management decisions as threats to park resources, particularly at DEVA.
32

33 **3.2.4 2004 Network-Level Vital Signs Scoping Workshop**

34
35 The MOJN Vital Signs Scoping Workshop was held on May 25-27, 2004 in Las Vegas, NV.
36 Over 60 individuals participated in the workshop and represented 15 organizations including
37 federal and state agencies, academic and research institutions, and non-profit organizations. The
38 workshop objectives were to: (1) review identified management and scientific issues, resource
39 threats, and monitoring questions; (2) review, revise, and coarsely prioritize candidate vital signs
40 that would serve as the focus of long-term ecological monitoring at the network and park levels;
41 (3) for the top 20% of vital signs, review their justification statement, develop initial monitoring
42 objectives, identify existing protocols and methodologies, identify potential partnerships and cost
43 sharing opportunities, and identify appropriate ecological and operational scales for
44 measurement; and (4) develop a network of stakeholders with the common goal of preserving the

1 most important resources within MOJN. An MS Access database was used to capture comments
2 and provide information during the workshop.

3
4 Participants were organized into work groups (approximately 10 individuals per group) based on
5 5 broad categories: (1) Air, Geology and Soils; (2) Hydrology; (3) Animals; (4) Plants; and (5)
6 Human Use and Ecosystem. Participants in the Human Use and Ecosystems group had expertise
7 in the other 4 categories. Each work group was assigned a specific set of candidate vital signs
8 and each group was provided with a facilitator, recorder, and at least one park staff member with
9 appropriate expertise to facilitate work flow and capture workshop results. Work groups were
10 combined for specific exercises (e.g. overall prioritization) and information sharing (e.g.
11 workshop introduction, group summary presentations). Criteria for vital signs prioritization were
12 based on management significance, ecological significance, and legal mandate. Weightings for
13 these ranking criteria were 40%, 40%, and 20%, respectively.

14
15 Workshop products were: (1) a reviewed and revised list of management concerns and resource
16 threats for level 2 vital signs; (2) a reviewed and revised list of vital signs for the network (N=69
17 vital signs) and individual parks (Appendix Q, Table 1; (3) a prioritized list of candidate vital
18 signs for the network (Appendix Q, Table 3) and individual parks; and (4) supporting
19 information to minimally include the top 20% of network level vital signs (e.g. justification
20 statement, monitoring questions, identification of existing protocols and collaborative
21 opportunities). The 2004 MOJN Vital Signs Scoping Workshop Report is provided in Appendix
22 Q. Report appendixes including database output is available on-line at:
23 <http://hrcweb.lv-hrc.nevada.edu/mojn/workshop.htm>.

25 **3.2.5 Selection of High Priority Vital Signs**

26
27 The MOJN Technical Committee reviewed prioritized lists of vital signs for the network and
28 individual parks to initially select a “short list” of high priority vital signs for the network. High
29 priority vital signs on park lists that were not a high priority at the network level were reviewed
30 and discussed based on management and ecological significance (relevance and management
31 information need), potential partnership and cost-sharing opportunities, availability of existing
32 baseline data, and socio-political considerations. See Table 1 in Appendix U for the resulting
33 “short list” of MOJN vital signs and the justification for their selection (based on review of
34 prioritized network and park vital signs). Ecological justification and monitoring questions for
35 each high priority vital sign is presented in Appendix U, Table 2.

37 **3.2.6 Selecting Final Network Vital Signs**

38
39 The MOJN convened a final workshop on November 29-30, 2005 at LAME in Boulder City,
40 Nevada to select “final vital signs” that will be monitored. This workshop was attended by a
41 quorum of members of the MOJN Technical Committee, resource specialists, and USGS
42 professionals. The goal of this workshop was to choose and prioritize a list of final vital signs
43 from among the 26 vital signs that the Technical Committee had selected at previous workshops
44 (Table 3-2). The result of the workshop was a list of final vital signs that the Technical

Committee was committed to funding for the next five years. The ensuing discussion assumed that the network would not be able to fund all 26 vital signs because of programmatic and fiscal restraints. The workshop held a facilitated and directed discussion toward the merits of each of the 26 vital signs.

As a basis to the decision making step of the process, the 26 vital signs were ranked according to their priority as assigned in the previous vital signs workshop. After the discussion of the 26 vital signs it was agreed that the workshop attendees should indicate which of the vital signs each individual believed to merit the final vital sign status. Each workshop participant was given seven “votes” of which they could indicate which vital signs they believed should be selected. The voting members of the technical committee agreed to use the vote not as binding vote- but as a recommendation, and that the final decision of the selection of vital signs was ultimately that of the technical committee. After the initial vote and second round of discussion, the technical committee agreed to a list of 20 final vital signs (Table 3-3). The MOJN network vital signs framework is presented in Table 3-4.

Table 3-2. Criteria by which the MOJN technical committee selected the final vital signs.

Vital Sign	Applicable to ALL Parks	In top 20% for Network	Management Significance	Ecological Significance	Partnership Opportunities
Ozone	Yes	Yes	High	High	High
Wet and Dry Deposition	Yes	Yes	Moderate	Moderate	High
Visibility and Particulate Matter	Yes	Yes	High	High	High
Basic Meteorology	Yes	Yes	High	High	High
Cave/Karst Features and Processes	No	No	Low	Low	Moderate
Soil Quality - Erosion and Deposition	Yes	Yes	High	High	High
Soil Quality - Soil Disturbance	Yes	No	High	High	High
Soil Quality - Soil Chemistry and Nutrient Cycling	Yes	Yes	High	High	Moderate
Soil Quality - Hydrologic Function	Yes	Yes	High	High	High
Soil Quality - Biological Soil Crust Dynamics	No	No	Moderate	Moderate	Moderate
Groundwater Dynamics and Chemistry	Yes	Yes	High	High	Moderate
Surface Water Dynamics	Yes	Yes	High	High	Moderate
Surface Water Chemistry	Yes	Yes	Low	Moderate	High
Invasive/Exotic Plants	Yes	Yes	High	High	High
Vegetation Change	Yes	Yes	High	High	High
Riparian Communities	Yes	Yes	High	High	High
Reptile Communities	Yes	No	Moderate	Moderate	Moderate
Small Mammal Communities	Yes	No	Moderate	Low	Low
Riparian Bird Communities	Yes	Yes	High	Moderate	High
Bighorn Sheep	No	No	Moderate	Moderate	Moderate
At-Risk Populations	No	No	Moderate	Low	Moderate
Federal T&E Species	No	No	Moderate	Low	High
Visitor Use and Recreation	Yes	Yes	High	High	High
Cultural Landscape Condition	Yes	No	Low	Low	Low
Fire and Fuel Dynamics	No	No	Moderate	Moderate	High
Landscape Dynamics	Yes	No	Moderate	High	High

- 1 Table 3-3. Final list of Mojave Network vital signs, ranked in order of priority, and their
- 2 associated conceptual model.
- 3

Funded Vital Signs	Link to General System Model
Basic Meteorology	Atmospheric Systems
Vegetation change	All
Invasive/Exotic Plants	All
Surface water dynamics	Wet Systems
Groundwater dynamics and chemistry	Wet Systems
Visibility and particulates	Atmospheric Systems
Ozone	Atmospheric Systems
Wet and dry deposition	Atmospheric Systems
Soil Quality – chemistry and nutrient cycling	Dry Systems
Soil Quality- hydrologic function	Dry Systems
Soil Quality – erosion and deposition	Dry Systems
Soil Quality – disturbance	Dry Systems
Soil Quality – biological soil crust dynamics	Dry Systems
Surface water chemistry	Wet Systems
Fire and fuel dynamics	Dry Systems
Landscape Dynamics	All
At-risk populations	All
Riparian birds	Wet Systems
Reptile communities	Dry and Wet Systems
Small mammal communities	Dry and Wet Systems

Table 3-4. Vital Signs framework for the MOJN.

Level 1	Level 2	Level 3	MOJN Vital Signs	Specifics	DEVA	GRBA	JOTR	LAME	MANZ	MOJA
Air and Climate	Air Quality	Ozone	Ozone		X	X	X	X	X	X
		Wet and Dry Deposition	Wet and Dry Deposition		X	X	X	X	X	X
		Visibility and Particulate Matter	Visibility and Particulate Matter		X	X	X	X	X	X
	Weather/Climate	Weather and Climate	Basic meteorology		X	X	X	X	X	X
Geology and Soils	Soil Quality	Soil function and dynamics	Soil erosion and deposition		X	X	X	X	X	X
			Disturbance - soil surface		X	X	X	X	X	X
			Soil chemistry and nutrient cycling		X	X	X	X	X	X
			Soil hydrologic function		X	X	X	X	X	X
			Presence and dynamics of Biological Soil Crusts		X	X	X	X		X
Water	Hydrology	Groundwater dynamics	Groundwater dynamics and chemistry		X	X	X	X	X	X
		Surface water dynamics	Surface water dynamics		X	X	X	X	X	X
	Water Quality	Water Chemistry	Surface water chemistry		X	X	X	X	X	X
Biological Integrity	Invasive Species	Invasive/Exotic plants	Invasive/Exotic plants	invasive grasses and other annuals	X	X	X	X	X	X
				alpine/subalpine	X	X				
	Focal Species or Communities	Desert communities	Vegetation Change	fan palm oases			X			
				pinyon-juniper woodland	X	X	X	X		X

Level 1	Level 2	Level 3	MOJN Vital Signs	Specifics	DEVA	GRBA	JOTR	LAME	MANZ	MOJA
				sagebrush-grass/scrub	X	X	X	X	X	X
				calcicolous scrub	X	X	X	X	X	
				relictual communities	X					
				mesquite communities	X			X		X
				dune communities	X		X	X		X
				blackbrush communities	X		X	X	X	X
				cactus communities	X	X	X	X		X
				joshua tree woodland	X		X	X		X
				ponderosa pine	X	X		X		X
				ancient bristlecone pine	X	X				
				smoke tree	X		X	X		X
				cliff communities	X	X	X	X		X
		Amphibians and Reptiles	Reptile communities		X	X	X	X	X	X
		Birds	Riparian bird communities		X	X	X	X	X	X
		Mammals	Small mammal communities		X	X	X	X	X	X
	At-risk Biota	T&E species and communities	At-risk Populations	rare plants	X	X	X	X		X
				rare animals	X	X	X	X		X
Landscapes (Ecosystem Pattern and Processes)	Fire and Fuel Dynamics	Fire and fuel dynamics	Fire and fuel dynamics		X	X	X	X	X	X
	Landscape Dynamics	Land cover and land use	Land use, land cover and landscape pattern		X	X	X	X	X	X

3.3 Justification for Vital Signs

3.3.1 Basic Meteorology

Climate is a primary factor controlling the structure and function of ecosystems in the MOJN. Key to understanding ecosystem dynamics is an understanding of the roles of climate variability, hydrologic interactions with soils, and adaptive strategies of biota to capitalize on spatially and temporally variable moisture dynamics (Noy-Meir 1973, Rodriguez-Iturbe 2000, Reynolds et al. 2004). This information provides significant power to the interpretation of other vital signs and provides a basis for understanding the response of desert ecosystems to future climate variation (Hereford et al. 2004). Measurements of temperature, precipitation, wind, humidity, soil moisture and soil temperature can indicate changing climatic conditions and weather patterns. Four parks (DEVA, GRBA, JOTR, and LAME) currently monitor basic meteorological parameters such as precipitation and temperature. Weather stations in the vicinity of MOJA have been identified, mapped, and data (historical and current) are being collected and summarized by the USGS. Additionally, DEVA and GRBA are accepted sites for the Climate Reference Network.

3.3.2 Focal Species and Communities - Vegetation Change

This vital sign combines the specific justifications for the individual vegetation communities that have been separated out as vital signs, as well as communities that are present but have not been considered of enough significance to have their own vital sign. Specific plant communities and species of interest are provided in Table 3-4.

3.3.3 Invasive Species – Invasive/Exotic Plants

Non-native, invasive plant species are invading new areas and establishing at unprecedented rates because global trade and transportation have allowed these species to cross biogeographical barriers. This breakdown of biogeographical barriers is having profound consequences on ecosystems worldwide and is second only to habitat destruction as a threat to wildland biodiversity. Potential ecological damage from exotic invasive species includes impacts to native flora and fauna, natural disturbance regimes, and ecosystem function. Specific concerns include threatened and endangered species sustainability, alteration of density, biomass, and diversity of native plant communities, species extirpation/extinction due to changes in fire regime, and alteration of basic soil processes. At least 66 non-native plant species have been identified in two or more park units within the Mojave Network. Invasive annual grasses are the most widespread and the greatest concern to park managers. Research suggests that early detection monitoring of annual plants should focus on regions of high rainfall and nitrogen deposition and on washes and beneath-canopy microhabitats (Brooks 1999a).

3.3.4 Surface Water Dynamics

Water is the lifeblood of the desert. Infrequent precipitation and long periods of drought are defining characteristics of the Mojave and Sonoran Deserts, and water availability is the primary factor limiting plant productivity (Whitford 2002). Ninety percent of Southern Nevada's water supply comes from Lake Mead. Due primarily to recent drought conditions, the lake level dropped 20 m between 2000 and 2003. Water management officials predict further drops if weather and water use predictions are correct (Allen 2003). Surface waters are fed by groundwater and surface run-off (e.g. snow melt, rain events). Change in groundwater flow systems, climate change, and climate variability may have significant impacts on the availability of surface water. Pressures on groundwater resources in California and Nevada are expected to increase into the future, posing significant future threats to surface water availability in network parks. Hydrologic changes are of concern in relation to stream/spring high and low flows, impacts to special status species (67% of Federally endangered species in the network are desert fishes), impacts to recreational users (e.g. hikers, boaters), and impacts to drinking water resources for Las Vegas and surrounding areas.

3.3.5 Groundwater Dynamics and Chemistry

Understanding groundwater dynamics has been identified as a top management priority for network parks. Increasing groundwater withdrawal is considered a significant ecosystem stressor within the MOJN. An understanding of water table levels, ground water flow paths, and the connection between groundwater and surface water resources is required for predicting the effects of natural and human-induced hydrological changes (e.g. municipal groundwater withdrawal) and the fate of contaminants (e.g. landfill leach). Precipitation events slowly recharge desert basin aquifers, and this recharge feeds scattered springs and wetland habitats. Removing only a small fraction of groundwater from these basins can lower the water table and potentially dry up critical surface water resources. Water-level declines of more than 25 m that occurred between the 1950's and 1990's have been linked with subsidence of portions of the Mojave Desert by as much as four inches (between 1992 and 1999). In places around Las Vegas, groundwater levels have declined 75 m since the first flowing artesian well was drilled in 1907 (Bawden et al. 2003). Land subsidence can disrupt surface drainage, reduce aquifer storage, cause earth fissures, and damage wells and other infrastructure (Bawden et al. 2003).

The chemical constituents of groundwater relate to groundwater source, age, and movement. Groundwater chemistry can provide information on changes in groundwater flow paths because the chemical signature of groundwater changes as it flows through different types of rock. At Pipe Springs National Monument, changes in the chemical signature may have indicated that a change in flow occurred, possibly due to seismic events (M. Truini, *personal communication*). The isotopic signature of groundwater (oxygen-18, deuterium) provides information about recharge. Change in the isotopic signature of groundwater can indicate environmental changes such as a shift in type of precipitation from rain to snow, an event that may be associated with climatic changes.

3.3.6 Air Quality – Visibility and Particulate Matter

Particulate matter is a park concern because of its negative effects on human health and visitor enjoyment of parks. Particulate matter has been linked to respiratory ailments in humans, including eye irritation, bronchitis, wheezing, asthma, heart disease, and premature mortality. Portions of JOTR and MOJA are within or adjacent to San Bernadino County, the county reported in 2004 to have the unhealthiest air in the nation (ozone and particulates) (American Lung Association 2004). Particulates such as sulfates and carbon particles are efficient at scattering light and reducing visibility, particularly when humidity is high. Particulate matter also can combine with tropospheric ozone to produce photochemical smog, which may be of concern in areas subject to thermal inversions, such as southern Nevada and California. Particulate matter and smog degrade visitor experience by obscuring scenic vistas and night skies. In contrast, the best visibility in the contiguous United States occurs in an area centered around GRBA. Trend analysis indicates that visibility is improving slightly on the 20 percent clearest days and worsening on the 20 percent haziest days. Visibility is specifically mentioned as an important resource in the General Management Plan for DEVA, GRBA, JOTR, and MOJA. Visibility also is considered a critical element of the cultural landscape at MANZ. Visibility is currently monitored at DEVA, GRBA, and JOTR (IMPROVE) (NPS 2004b).

3.3.7 Ozone

Ozone damages human health, vegetation, and many common materials. It is also a key component of urban smog. JOTR is the only park in a Class I Airshed. Nonetheless, JOTR exceeded the national 1- hour ozone standard on 46 days between 1992 and 1999. Most other parks exceed this standard only occasionally. JOTR also was one of nine park units that failed to meet the EPA 8-hour ozone standard based on data from 1997-1999. Most network units are in/near recently designated 8-hr ozone non-attainment areas. As mentioned above in 3.3.6, portions of both JOTR and MOJA are within or adjacent to San Bernadino County, the county with the highest levels of ozone and particulates in 2004. DEVA, GRBA, JOTR, and LAME are part of the NPS Ozone Monitoring Network. In 2004, NPS-Air Resources Division completed a risk assessment of foliar injury to vegetation from ozone in network parks. This assessment concluded that JOTR, MANZ, and MOJA are at high risk for foliar injury to plants from elevated ozone levels. The report also identified ozone sensitive and bioindicator plant species at DEVA, GRBA, JOTR, LAME, and MOJA (NPS 2004a).

3.3.8 Wet and Dry Deposition

Sulfur and nitrogen are the principal constituents of acidic deposition, which can impact aquatic and terrestrial ecosystems as well as cultural resources. Alpine lakes and soils are particularly vulnerable to acidification due to their low buffering ability. Mojave network ecosystems may also experience significant impacts from atmospheric nitrogen deposition because they are generally adapted to low nitrogen conditions (NPS 1992a). Impacts may include an increase in density and biomass of invasive plant species (particularly invasive annual grasses), decrease in density, biomass, and species richness of native plant communities, and change in fire frequency.

DEVA, GRBA, and JOTR are part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for wet deposition and the Clean Air Status and Trends Network (CASTNet) for dry deposition. Data from these sites indicates that deposition of both nitrogen and sulfur are elevated above natural levels of deposition (NPS 2004b)

3.3.9 Soil Quality – Soil Chemistry and Nutrient Cycling

Soil chemical properties provide the foundation for plant growth in conjunction with soil moisture. Nutrient cycles are essential ecosystem processes and the linkages to decomposition are complex and important. Ecosystems on stable trajectories have biological interactions that tend to conserve key nutrients. Significant loss or gain of elements, such as acidification or nitrification, are good indicators of change (Whitford 2002). Increased levels of soil nitrogen caused by atmospheric nitrogen deposition may increase the dominance (density and biomass) of invasive plant species, particularly invasive grasses, and decrease the density, biomass, and species richness of native plant communities (Brooks 1999a). Decreased soil buffering and pH affects availability of N, P, and K and thus invasive grass distribution. Soil salinity also is one of the primary factors affecting growth and distribution of plant communities in the MOJN. Extremes in soil chemistry have also resulted in unique landscape/plant assemblages and management problems (salinity/toxicity) in network parks.

3.3.10 Soil Quality – Hydrologic Function

In deserts, geology and soils provide the template upon which biota build integrated ecological systems. The availability of water is crucial, and small variations in available water can drastically alter plant and animal communities. Both physical and chemical geologic attributes commonly control important variation in water availability. Surficial geologic deposits vary in soil texture (grain size distribution and packing), bulk density, and other factors. Horizontal variations are largely influenced by depositional processes, and vertical variations are influenced by soil development (pedogenesis). Soil texture is critical in the moisture budget because coarse soils generally have higher infiltration rates whereas fine grained soils have lower infiltration rates (but higher retention capacities) (Blair and McPherson 1994). Soil type in conjunction with plant communities and their dynamics, topography, and climate regimes are primarily responsible for broad scale differences in soil moisture across the landscape. Plant-available soil moisture is a key to understanding ecosystem maintenance in desert ecosystems. This indicator integrates soil water features with climate fluctuations.

3.3.11 Soil Quality – Soil Erosion and Deposition

Loss of topsoil changes the capacity of soil to function and restricts its ability to sustain future uses. Erosion removes or redistributes topsoil, the layer of soil with the greatest amount of organic matter, biological activity and nutrients (Belnap 2003a). Erosion breaks down soil structure exposing organic matter within aggregates to accelerated decomposition and loss. Degraded soil structure reduces the rate of water infiltration and increases runoff which can lead

1 to further erosion. Erosion of nutrient rich topsoil can cause a shift to less desirable plants
2 including invasive plant species. The ability of a plant community to recover after topsoil is lost
3 is restricted. The materials deposited by erosion can bury plants, cover roads and trails,
4 accumulate in streams, rivers and reservoirs, degrade water and air quality, and damage or
5 degrade cultural landscapes.
6

7 **3.3.12 Soil Quality – Soil Disturbance**

8
9 Disturbance of the soil surface is a natural process (e.g. animal burrowing, flooding, etc.) that
10 can be exacerbated by anthropogenic activities such as grazing, off-highway vehicle use, and
11 mining. Disturbance of the soil surface results in increased invasive plant species cover, dust
12 generation, surface runoff, erosion, increased bare ground, and decreased soil organic matter, all
13 of which may negatively affect burrowing mammal habitat. Post-settlement changes in plant
14 communities have changed the extent of bare ground and accelerated soil loss. Research in the
15 eastern Mojave Desert indicates that disturbed soils may produce up to 36 times more sediment
16 when compared to undisturbed sites (Belnap 2003a). Hydrophobic soils, or soils that repel water,
17 are of great concern at GRBA due to high intensity fire events. Hydrophobic soils retard
18 vegetation recovery and may result in increased runoff and significant erosion, subsequently
19 affecting other park resources (e.g. water quality, spawning habitat for Bonneville Cutthroat trout
20 [*Oncorhynchus clarki utah*]). Within a given climate regime, severity of disturbance and soil
21 texture may be the best determinants of recovery rate, and soil texture the may be best predictor
22 of resistance to disturbance (Belnap 2001).
23

24 **3.3.13 Soil Quality – Biological Soil Crust Dynamics**

25
26 Crusts generally cover most soil spaces not occupied by green plants and are concentrated in the
27 top 1/8 inch of the soil. The main components of soil crusts are cyanobacteria, bryophytes, and
28 lichens. In many areas, they comprise over 70% of the living ground cover and are key in
29 reducing erosion, increasing water retention, and increasing soil fertility (Belnap 2001). Because
30 plant cover is sparse, crusts are an important source of organic matter for desert soils. The
31 biomass and species richness of biological soil crusts increases as the amount of precipitation
32 increases and the temperature at which it falls decreases. The lichen and moss components of the
33 crusts are most prevalent at locations dominated by winter precipitation, whereas warm season
34 precipitation seems to be a limiting factor for the distribution of these organisms (J. Belnap,
35 *personal communication*). In the Mojave Desert, biological soil crusts appear to exhibit a marked
36 preference for younger piedmont deposits with weaker pedogenic soils, and they are relatively
37 rare on active and very old deposits. In addition, biological soil crust cover tends to be denser on
38 substrates rich in granitic or limestone detritus and sparse on those with >85% eolian sand.
39 Therefore, potential biological soil crust cover is predictable and these relations can be used to
40 manage lands that have reduced crust cover. Large scale disturbance of biological soils crusts
41 poses a significant threat to ecosystem integrity by increasing soil loss (erosion/dust), increasing
42 the rate of water loss, and reducing soil fertility all of which may alter plant and animal
43 communities. Initial studies in the Mojave Desert indicate that crusts require more than a century
44 for recovery if significant shearing occurs. Recovery rates are most dependent on climatic

1 history, in particular precipitation. Within a given climate regime, severity of disturbance and
2 soil texture may be the best determinants of recovery rate, and soil texture may be the best
3 predictor of resistance to disturbance.
4

5 **3.3.14 Water Chemistry – Surface Water Chemistry**

6

7 Under Section 305(b) of the Clean Water Act, each state is required to conduct water quality
8 surveys to determine the overall health of the waters of the state, including whether or not
9 designated uses are being met. States report to the EPA every two years. When impaired water
10 bodies are identified through 305(b) assessments, they are included in 303(d) lists for ranking of
11 priority sites and Total Maximum Daily Load (TMDL) development in order to limit discharges
12 of specific pollutants to that water body (Ledder 2003). LAME is the only network park that
13 contains waters designated as 303(d) or “impaired”. The Las Vegas Wash carries approximately
14 160 million gallons of treated sewage effluent and contaminated groundwater into Lake Mead
15 each day. Between 1990-1994 the Las Vegas Wash received the 2nd highest amount of toxic
16 water pollution in the state of NV. Effluent may also contain high levels of ammonia, nitrates,
17 nitrites, and other nutrients. The addition of nutrients alters the productivity of aquatic plants and
18 is a primary contributor to lake eutrophication. Significant levels of contaminants accumulated in
19 organisms can lead to stress, illness, neurologic disorders, and/or death of aquatic biota (67% of
20 Federally endangered species in the network are desert fishes). Additionally, the Clean Water
21 Act includes a provision for the identification of Outstanding National Resource Waters
22 (ONRW) to provide protection to the Nation’s most treasured water bodies and signifies that no
23 lowering of water quality is allowed for that specific high quality water body and provides the
24 maximum amount of protection under the Clean Water Act. Several ONRW are present within
25 GRBA.
26

27 **3.3.15 Fire and Fuel Dynamics – Fire and Fuel Dynamics**

28

29 The annual area burned in wildfires has generally increased in the Western United States, an
30 increase attributable partly to build-up of woody fuels, partly to drought, and partly to the
31 invasion of non-native plant species such as *Bromus* spp. An understanding of fire and fuel
32 dynamics is critical to science-based management of shrubland, woodland, and forested
33 ecosystems. Change in fire regime (size, frequency, intensity) is a significant threat to parks in
34 the MOJN. Fire is considered a critical element in maintenance of natural ecosystems,
35 particularly patch mosaic dynamics, at GRBA. In recent years, GRBA has experienced a greater
36 number of large, high intensity, stand-replacing fires that have threatened significant park
37 resources such as ancient bristlecone pine stands. Change in fire regime at GRBA is primarily
38 attributed to fire suppression activities and grazing over the last century. In 1990, a fire history
39 was reconstructed for pinyon-juniper woodlands at GRBA. The fire history until 1860 was
40 complex and variable, whereas only 3% of the recorded fires occurred after 1900. Initial fire
41 history in mixed-conifer stands at GRBA reveal a mean fire interval of 5.6 years prior to Euro-
42 American settlement (1859) and no record of fire from 1881 to 2001 (Eddleman and Jaindle
43 1994). A fuel characteristic class map is currently being developed for GRBA.
44

Fire in the Mojave Desert is considered historically infrequent, and desert shrublands were once considered 'fire-proof'. The invasion of alien annual grasses such as red brome (*Bromus madritensis rubens*) and cheatgrass (*Bromus tectorum*) (Mack 1986, Salo 2004) has increased fire frequencies and intensities, and fire has become a resource management problem throughout low elevations in the Sonoran, Mojave, and Great Basin deserts (Brooks and Pyke 2001). In the Mojave Desert, recurrent fire may have devastating impacts on native plants that are poorly adapted to fire, leading to loss of native species, transitional shifts in communities, and potentially permanent replacement of native plant communities by alien annual grasslands (Brooks et al. 2003). Fuels modeling can provide information useful in predicting fire behavior, monitoring fuel condition changes, providing a means for fuel assessments, and developing fuels management plans.

3.3.16 Landscape Dynamics – Land Use, Land Cover, and Landscape Pattern

Land Use: Over three quarters of the Mojave Desert is in federal jurisdiction (77%). The three main federal land administrators are the BLM (34%), National Park Service (28%), and Department of Defense (14%). The U.S. Forest Service and BLM also administer significant lands adjacent to GRBA. Private lands, comprising 21% of the Mojave, are held primarily by ranchers, farmers, utility companies, mining interests, and urban development. Private and state lands occur in a checkerboard pattern embedded in a matrix of federal properties (Davis et al. 1998). Human population in the Great Basin-Mojave Desert region is predicted to experience continued growth into the future with the highest probability of future development on private undeveloped lands near existing development. These areas are often located near military bases in the Mojave Desert. Changes in land use are expected to be most significant in and around 29 Palms, CA (JOTR), Barstow, CA (MOJA), and Las Vegas, NV (LAME). Land-use practices at the local and regional scale can dramatically affect soil quality, water quality and quantity, air pollution, level of habitat fragmentation, habitat loss, and contribute to the spread and introduction of invasive species. Understanding changes in land use lends interpretive power to other vital signs and may contribute to early detection and prediction of future resource issues.

Land Cover: Three vegetation types contribute to 75% of the land cover in the Mojave region, Creosote Bush Scrub (57%), Mojave Mixed Woody Scrub (13%), and Desert Saltbush Scrub (5%)(Davis et al. 1998). Land cover at GRBA and in portions of LAME (e.g. PARA) are dominated by woodland and forest cover. Land cover is affected by natural events, including climate variation, flooding, vegetation succession, and fire, all of which can be changed in character or magnitude by human activities. Today, land cover is altered primarily by direct human use. Human-induced change in land cover is a primary factor in habitat loss, the most significant contributor in the listing of plant and animal species. A sustainable ecosystem maintains characteristic processes (geomorphic, hydrologic, soil, biological and atmospheric), allowing the system to deliver ecosystem services (Christensen et al. 1996). Understanding of change in land cover provides critical insights into current or future changes in ecosystem services (habitat, recreation, stabilizing soils, etc.).

Landscape Pattern: Spatial heterogeneity in desert ecosystems has significant effects on basic ecological processes. Landscape mosaics are created by repeating units of several patch types across the landscape. Landscape-level processes such as habitat patch mosaic structure may

strongly influence local populations. The character of a landscape's pattern (patch size and structure, distribution, shape, dispersion, connection, etc.) directly influences the distribution, abundance, and movement of animals, and distribution, abundance, germination, and dispersal of plants. In deserts, where many of the organisms are living at or near the threshold for surviving the climatic extremes, the availability of resources in patches is a critical variable (Whitford 2002). In the Great Basin, fire can be an important element in maintaining patch mosaic dynamics. Patch mosaic dynamics is of special interest in GRBA related to the management of habitat, including patch size, composition, and structure for bighorn sheep. Changes in climate, fragmentation, change in fire regime, and grazing have had the greatest past and current impacts on landscape pattern in the Great Basin-Mojave Desert region.

3.3.17 At-Risk Biota - At-Risk Populations

At-risk populations include species designated as rare, endemic, and NPS sensitive (e.g. Bonneville Cutthroat trout). All network parks except MANZ have "at-risk" species that are important components of the park's biodiversity and that are the focus of park managers. Nearly 1,000 native plant species have been identified at DEVA, and approximately 12% of these native plants are considered special status species, including two federally listed plant species and 12 endemic plant species. The DEVA General Management Plan lists the "perpetuation of rare and endangered plants and animals and those endemic to [the park]" as a park management goal.

3.3.18 Focal Species and Communities - Riparian Bird Communities

Obligate riparian bird species may be particularly good indicators of change in riparian communities. Obligate riparian bird species are those that place >90% of their nests in riparian vegetation or those for which >90% of their abundance occurs in riparian vegetation during the breeding season (e.g. least Bell's vireo). Almost all birds in the MOJN depend on wetland and riparian habitats during at least some phase of their annual cycle. More than half of the breeding birds in the Great Basin are associated primarily with riparian habitat. Riparian bird communities are also significant in terms of maintaining bird species of special concern, including the federally endangered Southwest willow flycatcher. Degradation and destruction of riparian areas are widely viewed as the most important causes of the decline of land bird populations in the MOJN (Brussard et al. 1998). Nearly all springs sites and riparian areas across the network have been altered by human use throughout history.

3.3.19 Focal Species and Communities - Reptile Communities

Reptiles tend to be long-lived and abundant in arid ecosystems and may potentially serve as a good indicator of environmental change, particularly lizards. Research suggests that snake species richness may be a good indicator of edge effects. Reptiles also represent a vertebrate taxa with a significant number of species of special concern. For example, desert tortoise and gila monster (*Heloderma suspectum*) are species that network parks already spend a significant amount of time and money monitoring. In 1993, 19 commercial pet collectors reported a harvest of 21,794 reptiles in Nevada. Arizona has recently made the decision to allow reptile collection under a state hunting permit (with associated bag limits). Because hunting is permitted in LAME

1 with an Arizona hunting license the potential for a significant collecting to occur within the park
2 exists
3 (K. Turner, *personal communication*). Commercially popular species include chuckwalla
4 (*Sauromalus obesus*) and gila monsters (both species of concern), as well as more common
5 reptiles such as the California king snake (*Lampropeltis getulus californiae*), long-nosed leopard
6 lizard (*Gambelia wislizenii*), and Panamint rattlesnake (*Crotalus mitchelli stephensi*) (Brussard et
7 al. 1998).
8

9 **3.3.20 Focal Species and Communities - Small Mammal Communities**

10 Contemporary populations of 16 montane mammal species across the Great Basin-Mojave
11 Desert region are presently isolated on mountains and probably have been since the Pleistocene
12 Epoch (Brussard et al. 1998). Research in National Park units on the Colorado Plateau, Sierra-
13 Cascades, and Rocky Mountains indicate that the number of mammal population extinctions has
14 exceeded the number of colonizations since park establishment and that the rate of extinction is
15 inversely related to park area (Newmark 1995). If extirpated, relict mammal populations
16 inhabiting isolated montane islands probably could not recolonize under current climatic
17 conditions. Research suggests that five environmental variables (including seasonal extremes in
18 temperature, annual energy and moisture, and elevation) may predict up to 88% of the variation
19 in mammalian species density for the whole continent (Badgley and Fox 2000). Mammalian
20 populations and communities may be good indicators of environmental change because
21 environmental variables largely influence species composition and density. Small mammals are
22 of particular interest due to their potentially significant role in soil processes, seed distribution
23 and germination, their relative abundance, and the fact that they are relatively cheap and easy to
24 monitor.
25

Chapter 4 Sampling Design

Chapter 5 Sampling Protocols

Chapter 6 Data Management and Archiving

Chapter 7 Data Analysis and Report Writing

Chapter 8 Administration/Implementation of the Monitoring Program

Chapter 9 Schedule

Chapter 10 Budget

Chapter 11 Literature Cited

- Allen, J. 2003. Drought lowers Lake Mead. NASA Earth Observatory Feature, November 13, 2003. On-line. (<http://earthobservatory.nasa.gov/Study/LakeMead/>). Accessed 30 August 2005.
- Ambrose, J. P. and S. P. Bratton. 1990. Trends in landscape heterogeneity along the borders of Great Smoky Mountains National Park. *Conservation Biology* **4**:135-143.
- American Lung Association. 2004. State of the air: 2004. American Lung Association, New York, New York. On-line. (<http://lungaction.org/reports/stateoftheair2004.html>). Accessed 30 August 2005.
- Atlas, R. M. and R. Bartha. 1998. Microbial ecology: fundamentals and applications. Benjamin/Cummings Science Publishing, Menlo Park, CA.
- Avery, H. W. 1998. Nutritional ecology of the desert tortoise (*Gopherus agassizii*) in relation to cattle grazing in the Mojave Desert. Ph.D. dissertation, University of California, Los Angeles.
- Badgley, C. and D. L. Fox. 2000. Ecological biogeography of North American mammals: species density and ecological structure in relation to environmental gradients. *Journal of Biogeography* **27**:1437-1467.
- Bahre, C. J. 1991. A legacy of change: historic human impact on vegetation of the Arizona borderlands. University of Arizona Press, Tuscon, AZ.
- Bailey, R. G. 1995. Description of the ecoregions of the United States, 2nd edition. USDA Forest Service, Washington, D.C. Miscellaneous Publication 1391.
- Bailey, R. G. 1998. Ecoregions: The ecosystem geography of the oceans and continents. Springer-Verlag, New York, New York.
- Bailey, D. A., P. Mazurak, and J. R. Rosowski. 1973. Aggregation of soil particles by algae. *Journal of Phycology* **9**:99-101.
- Bawden, G. W., M. Sneed, S. V. Stork, and D. L. Galloway. 2003. Measuring human-induced land subsidence from space. U. S. Department of Interior, U. S. Geological Survey, Denver. USGS Fact Sheet 069-03.
- Belnap, J. 2001. Biological soil crusts: webs of life in the desert. U. S. Department of Interior, U. S. Geological Survey, Denver. USGS Fact Sheet FS-065-01.

- Belnap, J. 2003a. Biological soil crusts and wind erosion. Pages 339-347 in J. Belnap and O. L. Lange eds. Ecological Studies Series 150, Biological soil crusts: structure, function, and management. Springer-Verlag, Berlin.
- Belnap, J. 2003b. Factors influencing nitrogen fixation and nitrogen release in biological soil crusts. Pages 241-261 in J. Belnap and O. L. Lange eds. Ecological Studies Series 150, Biological soil crusts: structure, function, and management. Springer-Verlag, Berlin.
- Belnap, J., and D.A. Gillette. 1998. Vulnerability of desert biological soil crusts to wind erosion: The influences of crust development, soil texture, and disturbance. *Journal of Arid Environments* **39**:133-142.
- Benda, L., N. L. Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004. The network dynamics hypothesis: How channel networks structure riverine habitats. *Bioscience* **54**:413-427.
- Bestelmeyer, B. T., J. R. Brown, K. M. Havstad, R. Alexander, G. Chavez, and J. E. Herrick. 2003. Development and use of state-and-transition models for rangelands. *Journal of Range Management*. **56**:114-126.
- Biggs, B. J. F., V. I. Nikora, and T. H. Snelder. 2005. Linking scales of flow variability to lotic ecosystem structure and function. *River Research and Applications* **21**:283-298.
- Billings, W. D. 1951. Vegetational zonation in the Great Basin of western North America. Les bases écologiques de la régénération de la végétation des zones arides. p. 101-122 in International Union of Biological Sciences, Series B, No. 9.
- Billings, W. D. 1990. *Bromus tectorum*, a biotic cause of ecosystem impoverishment in the Great Basin. Pages 301-322 in G. M. Woodwell, ed. The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Cambridge University Press, New York.
- Birken, A. S., and D. J. Cooper. 2006. Processes of *Tamarix* invasion and floodplain development along the lower Green River, Utah. *Ecological Applications* **16**:1103-1120.
- Blair, T. C., and J. G. McPherson. 1994. Alluvial fan processes and forms. Pages 354-402 in A. D. Abrahams and A. J. Parsons, eds. Geomorphology of Desert Environments. Chapman and Hall, London, UK.
- Boarman, W. I. 2002. Threats to desert tortoise populations: a critical review of the literature. U. S. Department of Interior, U. S. Geological Survey, Western Ecological Research Center, Las Vegas, NV.
- Bradley, R.S. 1985. Quaternary Paleoclimatology. Allen and Unwin, Boston. 472 p.
- Brotherson, J. D., and S. R. Rushforth. 1983. Influence of cryptogamic crusts on moisture relationships of soils in Navajo National Monument. *Great Basin Naturalist* **43**:73-78.

- Brooks, M. L. 1998. Ecology of a biological invasion: alien annual plants in the Mojave Desert. Ph.D. Dissertation. University of California - Riverside, Riverside, CA.
- Brooks, M. L. 1999a. Habitat invasibility and dominance by alien annual plants in the western Mojave Desert. *Biol. Invasions* **1**:325-337.
- Brooks, M. L. 1999b. Alien annual grasses and fire in the Mojave Desert. *Madrono* **46**:13-19.
- Brooks, M. L. 2000. Competition between alien annual grasses and native annual plants in the Mojave Desert. *American Midland Naturalist* **144**:92-108.
- Brooks, M. L. and D. Pyke. 2001. Invasive plants and fire in the deserts of North America. Proceedings of the Invasive Plant Workshop: The role of fire in the control and spread of invasive species. Tallahassee, FL: Tall Timbers Research Station. K. E. M. Galley and T. P. Wilson, eds. Pages 1-14.
- Brooks, M. L. and T. C. Esque. 2003. Alien plants and fire in desert tortoise (*Gopherus agassizii*) habitat of the Mojave and Colorado Deserts. *Chelonian Conservation Biology* **4**: 330-340.
- Brooks, M. L., T. C. Esque, and T. A. Duck. 2003. Fuels and fire regimes in creosotebush, blackbrush, and interior chaparral shrublands. Technical Report for the Southern Utah Demonstration Fuels Project. USDA, Forest Service, Rocky Mountain Research Station, Fire Science Lab, Missoula, Montana.
- Brussard, P. F., D. A. Charlet, and D. S. Dobkin. 1998. The Great Basin-Mojave Desert Region. In M. J. Mac, P. A. Opler, C. E. Puckett-Haecker, and P. D. Doran eds. The status and trends of the nation's biological resources. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.
- Busch, D. E. and J. C. Trexler. 2003. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, D.C.
- Carothers, S. W., R. R. Johnson, and S. W. Aitchison. 1974. Population structure and social organization of Southwestern riparian birds. *American Zoologist* **14**:97-108.
- Caylor, K. K., S. Manfreda, and I. Rodriguez-Iturbe. 2005. On the coupled geomorphological and ecohydrological organization of river basins. *Advances in Water Resources* **28**:69-86.
- Chaney, E., W. Elmore, and W. S. Platts. 1990. Livestock grazing on western riparian areas. U.S. Environmental Protection Agency, Region 8, Denver, Colorado.
- Chapin III, F.S., M. S. Torn, M. and Tateno. 1996. Principles of ecosystem sustainability. *The American Naturalist* **148**:1016-1037.

- Chesson, P., R. L. E. Gebauer, S. Schwinning, N. Huntly, K. Wiegand, M.S.K. Ernest, A. Sher, A. Ovoplansky, and J.F. Weltzin. 2004. Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia* **141**:236-253.
- Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M.G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* **6**:665-691.
- Cleland, D. T., P. E. Avers, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, and W. E. Russell. 1997. National hierarchical framework of ecological units. Pages 181-200 in M. S. Boyce and A. Haney, eds. *Ecosystem management: applications for sustainable forest and wildlife resources*. Yale University Press, New Haven, Connecticut.
- Cole, D. N., and N. G. Bayfield. 1993. Recreational trampling of vegetation: standard experimental procedures. *Biological Conservation* **63**:209-215
- Davis, F. W., D. M. Stoms, A. D. Hollander, K. A. Thomas, P. A. Stine, D. Odion, M. I. Borchert, J. H. Thorne, M. V. Gray, R. E. Walker, and others. 1998. The California Gap Analysis Project – Final Report. University of California, Santa Barbara. On-line. (http://www.biogeog.ucsb.edu/projects/gap/gap_rep.html) Accessed 30 August 2005.
- DeAngelis, Donald L., L. J. Gross, E. J. Comiskey, W. M. Mooij, M. P. Nott and S. Bellmund. 2003. The use of models for a multi-scaled ecological monitoring system. Pages 167-188 in D. E. Busch and J. C. Trexler eds. *Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.
- Desert Research Institute. 2005. Precious jewels of the desert. Research notes from southern Nevada. Vol. 1, Issue 1.
- Birnbaum, C. A. 2005. Protecting Cultural Landscapes. On-line. (www.cr.nps.gov/hps/tps/briefs/brief36.htm) Accessed 30 August 2005.
- DuBois, D. and M. Green. 2005. Evaluation of existing and future air quality monitoring at Great Basin National Park. U. S. Department of Interior, National Park Service, Great Basin National Park, NV. Great Basin Cooperative Ecosystem Studies Unit Task Agreement Number J8R07020007.
- Eastman, K. 2002. The risk of tamarisk. Parkway Current. Winter 2002. On-line. (<http://www.riverparkway.org/html/newstam.html>). Accessed 30 August 2005.
- ECOMAP. 1993. National hierarchical framework for ecological units. USDA Forest Service. Washington, D.C.

- Eddleman, L. E. and R. Jaindle. 1994. Range analysis for Great Basin National Park. U. S. Department of Interior, National Park Service, Great Basin National Park, NV. Oregon State University Cooperative Park Studies Unit, Cooperative Agreement 9000-8-0006, Subagreement 14, NPS/PNROSU/NRTR-94/02.
- Elzinga, C. L., D. W. Salzer, and J. W. Willoughby. 1998. Measuring and monitoring plant populations. Bureau of Land Management Tech. Reference 1730-1. BLM/RS/ST-98/005+1730.
- Esque, T. C. 1994. Diet and diet selection of the desert tortoise (*Gopherus agassizii*) in the northeast Mojave Desert. Thesis. Colorado State University, Fort Collins, CO.
- Fenneman, N. M. and D. W. Johnson. 1946. Physical divisions of the United States. Special USGS Map. U. S. Department of Interior, U. S. Geological Survey, Washington, D. C. Metadata available on-line. (<http://aa179.cr.usgs.gov/metadata/wrdmeta/physio.htm#section7>). Accessed 30 August 2005.
- Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* **8**:629-644.
- Garratt, K. 1984. The relationship between adjacent lands and protected areas: issues of concern for the protected area manager. Pages 65-71 in McNeely, J. A., and K. R. Miller, eds. *Proceedings of the World Congress on National Parks*, Bali, Indonesia, October 11-22, 1982. Smithsonian Institution Press, Washington, D. C.
- Glinski, R. L. 1977. Regeneration and distribution of sycamores and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona. Pages 166-174 in R. R. Johnson and D. A. Jones, technical coordinators. *Importance, preservation, and management of riparian habitat: a symposium*. General Technical Report RM-43. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.
- Grayson, D. K. 1993. *The Desert's Past: A Natural Prehistory of the Great Basin*. Smithsonian Institution Press, Washington, D. C.
- Gross, John E. 2003. Developing Conceptual Models for Monitoring Programs. Department of Interior, National Park Service, Inventory and Monitoring Program, Fort Collins, CO. On-line. (http://science.nature.nps.gov/im/monitor/docs/Conceptual_Modelling.pdf). Accessed 30 August 2005.
- Hansen, A. J. and J. J. Rotella. 2002. Biophysical factors, land use, and species viability in and around nature reserves. *Conservation Biology* **16**:1112-1122.

- Hansen A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. J. Bartlein. 2001. Global change in forests: Responses of species, communities, and biomes. *BioScience* **51**:765-779.
- Harper, K. T., and J. R. Marble. 1988. A role for nonvascular plants in management of arid and semiarid rangelands. Pages 135-169 *in* T. Tueller, editor. Application of plant science to rangeland management and inventory. Martinus Mijhoff/W Junk, Amsterdam, Netherlands.
- Harper, K. T., and R. L. Pendleton. 1993. Cyanobacteria and cyanolichens: can they enhance availability of essential mineral for higher plant? *Great Basin Naturalist* **53**:59-72.
- Hazard, L. C., D. R. Shemanski and K. A. Nagy. 2001. Calcium and phosphorus availability in native and exotic food plants: abstract. Desert Tortoise Council Symposium. Las Vegas, March 2001.
- Hereford, R., R. H. Webb, and C. I. Longpre. 2004. Precipitation history of the Mojave Desert region, 1893-2001. U. S. Department of Interior, U. S. Geological Survey, Denver. USGS Fact Sheet 117-03. On-line. (<http://pubs.usgs.gov/fs/fs117-03/>). Accessed 30 August 2005.
- Jeffries, D. L., and J. M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. *Journal of Range Management* **40**:390-392.
- Jenkins, K., A. Woodward and E. Schreiner. 2002. A framework for long-term ecological monitoring in Olympic National Park: prototype for the coniferous forest biome. USGS Forest and Rangeland Ecosystem Science Center, Olympic Field Station, Port Angeles, WA.
- Johnson, H. B. 1976. Vegetation and plant communities of southern California deserts: a functional view. Pages 125-164 *In* J. Latting, ed. Plant communities of southern California. California Native Plant Society Special Publication No. 2.
- Knopf, F. L., and R. W. Cannon. 1982. Structural resilience of a willow riparian community to changes in grazing practices. Pages 198-207 *in* L. Nelson, J. M. Peek, and P. D. Dalke, editors. Proceedings of the wildlife-livestock relationships symposium. Forest, Wildlife, and Range Experiment Station, University of Idaho, Moscow, Idaho.
- Lange, O. L., J. Belnap, and H. Reichenberger. 1998. Photosynthesis of the cyanobacterial soil-crust lichen *Collema tenax* from arid lands in southern Utah, USA: role of water content on light temperature responses of CO₂ exchange. *Functional Ecology* **12**:195-2002.
- Ledder, T. 2003. Water resource information and assessment for the Great Lakes Inventory and Monitoring Network. U. S. Department of Interior, National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, WI. Great Lakes Technical Report: GLKN/2003/05.

- Leopold, A. 1924. Grass, brush, timber and fire in southern Arizona. *Journal of Forestry* **22**:1-10.
- Loope, W. L., and G. F. Gifford. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. *Journal of Soil Water Conservation* **27**:164-167.
- Lowe, C.H., and D. E. Brown. 1994. Introduction, p. 8-16 in D.E. Brown, ed., *Biotic communities: southwestern United States and northwestern Mexico*.
- Machlis, G. E. and D. L. Tichnell. 1985. The state of the world's parks: an international assessment for resource management, policy, and research. Westview Press, Boulder, Colorado.
- Mack, R. N. 1986. Invasion of *Bromus tectorum* into western North America: an ecological chronicle. *Agroecosystems* **7**:145-165.
- MacMahon, J. A. 1979. North American deserts: their floral and faunal components. p. 21-82 in D. W. Goodall and R. A. Perry, eds. *Arid-land ecosystems*, Vol 1. International Biological Programme 16. Cambridge University Press, Cambridge, UK.
- Marion, J. L., and L. C. Merriam. 1985. Predictability of recreational impact on soils. *Soil Science Society of America Journal* **49**:751-753.
- Margoluis, R. and N. Salafsky. 1998. Measures of success : designing, managing, and monitoring conservation and development projects. Island Press, Washington, D.C.
- Mason, W. T. 1995. Invertebrates. Pages 159-160 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, eds. *Our living resources: a report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems*. U. S. Department of the Interior, National Biological Service, Washington, D.C.
- McDonald, E.V. 1994. The relative influences of climatic change, desert dust, and lithologic control on soil-geomorphic processes and soil hydrology of calcic soils formed on Quaternary alluvial-fan deposits in the Mojave Desert, California. Dissertation. University of New Mexico, Albuquerque.
- McFadden, L. D. and P. L. K. Knuepfer. 1990. Soil geomorphology: The linkage of pedology and surficial processes. *Geomorphology* **3**:197-206.
- McGill, B.J., B.J. Enquist, E. Weiher, and M. Westoby. 2006. Rebuilding community ecology from functional traits. *TREE* **21**:178-185.
- McLaughlin, S.P. 1989. Natural Floristic Area of the Western United States. *Journal of Biogeography* **16**:239-248.

- McNab, W. H. and P. E. Avers, compilers. 1994. Ecological subregions of the United States: section descriptions. U. S. Department of Agriculture, U. S. Forest Service, Washington, D.C. Technical Report(?) WO-WSA-5.
- Meffe, G. K. and C. R. Carroll. 1997. Conservation reserves in heterogeneous landscapes. Pages 305-346 *in* Meffe, G. K. and C. R. Carroll, eds. Principles of conservation biology, 2nd Edition. Sinauer Associates, Sunderland, Massachusetts.
- Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountain region and desert of the Little Colorado, Arizona. U.S. Department of Agriculture, Division of Ornithology and Mammalogy, North American Fauna Series No. 3, Government Printing Office, Washington, D.C
- Merriam, C. H. 1898. Life-zones and crop-zones of the United States. U.S. Department of Agriculture, Division of Biological Survey, Bull. 10. 79 pp.
- Miller, M. E. 2005. The structure and functioning of dryland ecosystems--conceptual models to inform long-term ecological monitoring. U.S. Geological Survey Scientific Investigations Report 2005-5197, 74 p.
- Miller, M. E. and L. P. Thomas. 2004. The structure and functioning of dryland ecosystems – conceptual models to inform the vital-sign selection process. U. S. Department of Interior, National Park Service, Southern Colorado Plateau Network, Flagstaff, AZ. Draft. 4 February 2004.
- Monin, A. S. and Y. A. Shishkov. 2000. Climate as a problem of physics. Physics—Uspekhi **43**:381-406.
- Mosconi, S. L., and R. L. Hutto. 1982. The effect of grazing on the land birds of a western Montana riparian habitat. Pages 221-233 *in* L. Nelson, J. M. Peek, and P. D. Dalke, editors. Proceedings of the wildlife-livestock relationships symposium. Forest, Wildlife, and Range Experiment Station, University of Idaho, Moscow, Idaho.
- Nagy, K. A., B. T. Henen and D. B. Vyas. 1998. Nutritional quality of native and introduced food plants of wild desert tortoises. *Journal of Herpetology* **32**:260-267.
- Newmark, W. D., D. N. Manyanza, D. M. Gamassa and H. I. Sariko. 1994. The conflict between wildlife and local people living adjacent to protected areas in Tanzania: human density as a predictor. *Conservation Biology* **8**:249-255.
- National Park Service. 1916. National Park Service Organic Act of 1916. PL Chapter 408, 39 Sta. 535 et seq. 16 USC 1.
- National Park Service. 1980. State of the Parks-1980: A report to the congress. U. S. Department of Interior, National Park Service, Washington, D.C.

- National Park Service. 1992a. General management plan for Great Basin National Park. U. S. Department of Interior, National Park Service, Great Basin National Park, NV.
- National Park Service. 1992b. NPS-75: Natural resources inventory and monitoring guidelines. U. S. Department of Interior, National Park Service, Washington, D.C.
- National Park Service. 1995. General management plan for Joshua Tree National Park. U. S. Department of Interior, National Park Service, Joshua Tree National Park, CA.
- National Park Service. 1996. General management plan and environmental impact statement for Manzanar National Historic Site. U. S. Department of Interior, National Park Service, Manzanar National Historic Site, CA.
- National Park Service. 1998. National Parks Omnibus Management Act of 1998. 16 USC 5901-6011; PL 105-391.
- National Park Service. 1999a. Natural resource challenge: the National Park Service's action plan for preserving natural resources. U. S. Department of the Interior, National Park Service, Washington D.C.
- National Park Service. 1999b. Resource management plan for Great Basin National Park. U. S. Department of Interior, National Park Service, Great Basin National Park, NV.
- National Park Service. 1999c. Resource management plan for Death Valley National Park. U. S. Department of Interior, National Park Service, Death Valley National Park, CA.
- National Park Service. 1999d. Lake Mead National Recreation Area business plan executive summary. U. S. Department of Interior, National Park Service, Lake Mead National Recreation Area, NV.
- National Park Service. 1999e. Lake Mead National Recreation Area vital signs workshop summary. U. S. Department of Interior, National Park Service, Lake Mead National Recreation Area, NV.
- National Park Service. 2000. Mojave National Preserve general management plan. U. S. Department of Interior, National Park Service, Mojave National Preserve, CA.
- National Park Service. 2001a. 2001 National Park Service management policies. U. S. Department of Interior, National Park Service, Washington, D.C.
- National Park Service. 2001b. General management plan Death Valley National Park. U. S. Department of Interior, National Park Service, Death Valley National Park, CA.
- National Park Service. 2003a. Outline for vital signs monitoring plans. U. S. Department of Interior, National Park Service, Inventory and Monitoring Program, Ft. Collins, Colorado. Internal guidance document.

- National Park Service. 2003b. Grand Canyon-Parashant National Monument geologic resources evaluation scoping meeting summary. U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2003c. Great Basin National Park geologic resources evaluation scoping meeting summary. U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2003d. Joshua Tree National Park geologic resources management issues scoping summary. U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2003e. Mojave National Preserve geologic resources management issues scoping summary. U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2004a. Assessing the risk of foliar injury from ozone on vegetation in parks in the Mojave Desert Network, October 2004. U. S. Department of Interior, National Park Service, Air Resources Division, Fort Collins, CO.
- National Park Service. 2004b. Air quality and air quality related values monitoring considerations for the Mojave Desert Network, May 2004. U. S. Department of Interior, National Park Service, Air Resources Division, Fort Collins, CO.
- National Park Service. 2004c. Death Valley National Park geologic resources management issues scoping summary (Revised). U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2004d. Lake Mead National Recreation Area geologic resources management issues scoping summary (Revised). U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2004e. Manzanar National Historic Site geologic resources management issues scoping summary. U. S. Department of Interior, National Park Service, Geologic Resources Division, Fort Collins, CO.
- National Park Service. 2005a. National Park Service I&M Vital Sign Framework. On-line. (<http://science.nature.nps.gov/im/monitor/vsmAdmin.htm#Framework>). Accessed 30 August 2005.
- National Park Service. 2005b. National Park Service strategic plan–fiscal Year 2005 to 2008. U. S. Department of Interior, National Park Service, Washington, D. C. National Parks and Conservation Association. 1979. NPCA adjacent lands survey: no park is an island. National Parks and Conservation Magazine 53:4-9.

- National Park Service. 2005. National Park Service Public Use Statistics Office. On-line, (<http://www2.nature.nps.gov/stats/>). Accessed 30 August 2005.
- National Research Council. 1995. Review of EPA's environmental monitoring and assessment program: Overall evaluation. National Academy Press, Washington, D.C.
- Nevada Division of Environmental Protection. 2005. NAC 445A.124. On-line. (<http://www.ndep.nv.gov/>). Accessed 30 August 2005.
- Newmark, W. L. 1995. Extinction of Mammal Populations in Western North American National Parks. *Conservation Biology* **9**:512-526.
- Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 in D. E. Busch and J. C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.
- Noon, B. R., T. A. Spies and M. G. Raphael. 1999. Conceptual basis for designing an effectiveness monitoring program. P. 21-48 in B. S. Mulder, B. R. Noon, T. A. Spies, M. G. Raphael, J. Craig, A. R. Olsen, G. H. Reeves, and H. H. Welsh, eds. *The strategy and design of the effectiveness monitoring program for the Northwest Forest Plan*. U. S. Department of Agriculture, U. S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-437.
- Noss, R. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* **4**:355-364.
- Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics* **4**:25-51.
- Olsen, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, and others. 2001. *Terrestrial Ecoregions of the World: A New Map of Life on Earth*. *Bioscience* **51**: 933-938.
- Osenberg, C. W., R. J. Schmitt, S. J. Holbrook, K. E. Abu-Saba, and A. R. Flegal. 1994. Detection of environmental impacts: natural variability, effect size, and power analysis. *Ecological Applications* **4**:16-30.
- Pickett, S. T. A., V. T. Parker, and P. L. Fiedler. 1992. The new paradigm in ecology: Implications for conservation above the species level. Pages 65-88 in P. L. Fiedler and S. K. Jain, eds. *Conservation biology: The theory and practice of nature conservation, preservation, and management*. Chapman and Hall, New York.
- Power, M. E., and W. E. Dietrich. 2002. Food webs in river networks. *Ecological Research* **17**:451-471.

- Pulliam, H. R. and M. R. Brand. 1975. The production and utilization of seeds in plains grassland of southeastern Arizona. *Ecology* **56**:1158-1156.
- Reichman, O.J. 1977. Optimization of diets through food preferences by heteromyid rodents. *Ecology* **58**:454-457.
- Reynolds, J. F., P. R. Kemp, K. Ogle, and R. J. Fernandez. 2004. Modifying the 'pulse-reserve' paradigm for deserts of North America: precipitation pulses, soil water, and plant responses. *Oecologia* **141**:194-210.
- Ricklefs, R.E. 1990. *Ecology*. 3rd Edition. W.H. Freeman and Company. New York, NY.
- Roath, L. R., and W. C. Krueger. 1982. Cattle grazing influence on a mountain riparian zone. *Journal of Range Management* **35**:100-103.
- Rodriguez-Iturbe, I. 2000. Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamics. *Water Resources Research* **36**:3-9.
- Roman, C. T., and N. E. Barrett. 1999. Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore. U. S. Department of Interior, U. S. Geological Survey, Patuxent Wildlife Research Center, University of Rhode Island, Providence, Rhode Island.
- Rowe, J. S. 1992. The ecosystem approach to forest management. *Forest Chronicle* **68**:222-224.
- Rychert, R. C. and J. Skujine. 1974. Nitrogen fixation by blue-green algae-lichen crusts in the Great Basin Desert. *Soil Science Society of America Proceedings* **38**:768-771.
- Salo, L. F. 2004. Population dynamics of red brome (*Bromus madritensis rubens*): times for concern, opportunities for management. *Journal of Arid Environments* **57**:291-296.
- Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: A review. *Conservation Biology* **5**:18-32.
- Schonewald-Cox, C. M. 1988. Boundaries in the protection of nature reserves: Translating multidisciplinary knowledge into practical conservation. *BioScience* **38**:480-486.
- Scott, M. L., M. E. Miller, and J. C. Schmidt. 2004. The structure and functioning of riparian ecosystems of the Colorado Plateau– Conceptual models to inform the vital-sign selection process: Southern Colorado Plateau Network Phase Two Supplement (Draft)
- Sinclair, A. R. E. 1998. Natural regulation of ecosystems in protected areas as ecological baselines. *Wildlife Society Bulletin* **26**:399-409.

- Snyder, W. D., and G. C. Miller. 1992. Changes in riparian vegetation along the Colorado River and Rio Grande, Colorado. *Great Basin Naturalist* **52**:357-363.
- Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecological Applications* **9**:1189-1206.
- Stevens, L.E., and A. E. Springer. 2004. A conceptual model of springs ecosystem ecology: Task 1B Final Report: Southern Colorado Plateau Network Phase Two Supplement.
- Suter, G. W. 1993. *Ecological risk assessment*. Lewis Publishers, Chelsea, MI.
- Szaro, R. C. 1989. Riparian forest and scrubland community types of Arizona and New Mexico. *Desert Plants* **9**:69-138.
- Szaro, R. C., and C. P. Pase. 1983. Short-term changes in a cottonwood-ash-willow association on a grazed and an ungrazed portion of Little Ash Creek in Central Arizona. *Journal of Range Management* **36**:382-384.
- Takhtajan, A. L. 1986. *Floristic regions of the world*. University of California Press, Berkeley, CA.
- Thompson, R.S. and K.H. Anderson. 2000. Biomes of Western North America at 18,000, 6,000 and 0 ¹⁴C yr BP reconstructed from pollen and packrat midden data. *Journal of Biogeography* **27**:555-584.
- Thorp, J. H., M. C. Thoms, and M. D. Delong. 2006. The riverine ecosystem synthesis: iocomplexity in river networks across space and time. *River Research and Applications* **22**:123-147.
- Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2001. *Landscape ecology in theory and practice*. Springer-Verlag, New York.
- U.S. Census Bureau. 2005. Data Access Tools. On-line. <http://www.census.gov/main/www/access.html>). Accessed 30 August 2005.
- Vander Wall, S.B., T.C. Esque, D.F. Haines, B.A. Waitman, and M. Garnett. *In Press*. Are Joshua Tree (*Yucca brevifolia*) seeds dispersed by seed-caching rodents?
- Van Vuren, D. 1982. Comparative ecology of bison and cattle in the Henry Mountains, Utah. Pages 449-457 in L. Nelson, J. M. Peek, and P. D. Dalke, editors. *Proceedings of the wildlife-livestock relationships symposium*. Forest, Wildlife, and Range Experiment Station, University of Idaho, Moscow, Idaho.
- Ward, J. V., and K. Tockner. 2001. Biodiversity: towards a unifying theme for river ecology. *Freshwater Biology* **46**:807-820.

- Warren, S. D. 2003. Synopsis: Influence of biological soil crusts on arid land hydrology and soil stability. Pages 349-362 in J. Belnap and O. L. Lange eds. Ecological Studies Series 150, Biological soil crusts: structure, function, and management. Springer-Verlag, Berlin.
- Webb, R. H., H. G. Wilshire, and M. A. Henry. 1983. Natural recovery of soils and vegetation following human disturbance. Pages 279-305 in R. H. Webb and H. G. Wilshire eds. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.
- Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego. 343 p.
- Wiens, J. A., B. Van Horne, and B. R. Noon. 2002. Integrating landscape structure and scale into natural resource management. p. 23-67 in J. Liu and W. W. Taylor, eds. Integrating landscape ecology into natural resource management. Cambridge University Press, Cambridge.
- Wiggs, G. F. S., D. S. G. Thomas, J. E. Bullard, and I. Livingstone. 1995. Dune mobility and vegetation cover in the southwest Kalahari Desert. *Earth Surface Processes and Landforms* **20**:515-529.
- Wilkerson, C. 2004. The Mojave Desert: Land of Power and Passions, Land of Vulnerability. Presentation at the Mojave Desert Science Symposium, University of Redlands, California, November 16-18, 2004.
- Windell, J. T., B. E. Willard, D. J. Cooper, S. Q. Foster, C. Knud-Hansen, L. P. Rink, and G. N. Kiladis. 1986. An ecological characterization of Rocky Mountain montane and subalpine wetlands. Fish and Wildlife Service, U. S. Department of the Interior, Biological Report 86 (11). U. S. Department of the Interior, Washington, D.C.
- Woodruff, W. P. and D. V. Armbrust. 1968. A monthly climatic factor for the wind erosion equation: *Journal of Soil Water Conservation* **23**:103-104.

Reference A. Scientific and common names for species listed in Mojave Network Phase I Report.

Scientific Name	Common Name
<i>Plants</i>	
<i>Abies concolor</i>	White fir
<i>Abies lasiocarpa</i>	Subalpine fir
<i>Acacia greggii</i>	Catclaw
<i>Acer glabrum</i>	Rocky Mountain Maple
<i>Achnatherum</i> spp.	Needlegrass
<i>Achnatherum hymenoides</i>	Indian ricegrass
<i>Allenrolfea occidentalis</i>	Pickle weed
<i>Ambrosia dumosa</i>	White bursage
<i>Artemisia</i> spp.	Sagebrush
<i>Artemisia tridentata</i>	Big sagebrush
<i>Atriplex</i> spp.	Saltbush
<i>Baccharis sarathroides</i>	Desert broom (eastern Mojave)
<i>Brassica tournefortii</i>	Sahara mustard
<i>Bromus madritensis rubens</i>	Red brome
<i>Bromus tectorum</i>	Cheatgrass
<i>Calochortus kennedyi</i>	Desert Mariposa lily
<i>Carex</i> spp.	Sedges
<i>Centaurea</i> spp.	Knapweeds and star thistles
<i>Cercocarpus</i> spp.	Mountain mahogany
<i>Chilopsis linearis</i>	Desert willow
<i>Coleogyne ramosissima</i>	Blackbrush
<i>Cucurbita palmate</i>	Palmate-leaved gourd
<i>Distichlis</i> spp.	Saltgrass
<i>Echinocactus polycephalus</i>	Cottontop cactus
<i>Erodium cicutarium</i>	Redstem filaree
<i>Fouquieria splendens</i>	Ocotillo
<i>Juncus</i> spp.	Rushes
<i>Juniperus osteosperma</i>	Utah juniper
<i>Juniperus scopularum</i>	Rocky Mountain juniper
<i>Larrea tridentata</i>	Creosote bush
<i>Lepidium latifolium</i>	Tall white top
<i>Lepidospartum squamatum</i>	Desert broom (western Mojave)
<i>Lycium andersonii</i>	Wolfberry
<i>Oenothera</i> spp.	Evening primrose
<i>Opuntia basilaris</i>	Beavertail cactus
<i>Picea engelmannii</i>	Engelmann spruce
<i>Pennisetum setaceum</i>	Fountain grass
<i>Phoradendron</i> spp.	Mistletoe
<i>Pinus contorta</i>	Lodgepole pine
<i>Pinus edulis</i>	Two-needle pinyon pine
<i>Pinus flexilis</i>	Limber pine
<i>Pinus longaeva</i>	Bristlecone pine
<i>Pinus monophylla</i>	Single-needle pinyon pine
<i>Pinus ponderosa</i>	Ponderosa pine
<i>Pleuraphis jamesii</i>	Evergreen plantain
<i>Pleuraphis rigida</i>	Big galleta

Scientific Name	Common Name
<i>Populus angustifolia</i>	Narrowleaf cottonwood
<i>Populus fremontii</i>	Fremont cottonwood
<i>Populus tremuloides</i>	Quaking aspen
<i>Prosopis velutina</i>	Velvet mesquite
<i>Pseudotsuga menziesii</i>	Douglas fir
<i>Psoralea argophylla</i>	Smoke tree
<i>Purshia glandulosa</i>	Bitterbrush
<i>Rosa woodsii</i>	Mountain rose
<i>Salix</i> spp.	Willow
<i>Sarcobatus vermiculatus</i>	Greasewood
<i>Schismus</i> spp.	Mediterranean grass
<i>Schismus arabicus</i>	Mediterranean grass
<i>Schismus barbatus</i>	Mediterranean grass
<i>Stanleya elata</i>	Panamint prince's plume
<i>Tamarix</i> spp.	Tamarisk
<i>Tamarix athel</i>	Athel tree
<i>Tamarix ramosissima</i>	Salt cedar
<i>Tessaria sericea</i>	Arrowweed
<i>Washingtonia filifera</i>	Desert fan palm
<i>Yucca brevifolia</i>	Joshua tree
<i>Yucca schidigera</i>	Mojave yucca
<i>Animals</i>	
<i>Acrididae</i> (Family)	Grasshoppers
<i>Ammospermophilus</i> spp.	Ground squirrel
<i>Anabrus simplex</i>	Mormon cricket
<i>Antilocarpa</i>	Pronghorn
<i>Aphonopelma chalcodes</i>	Tarantula
<i>Auriparus flaviceps</i>	Verdin
<i>Belostoma saratogae</i>	Saratoga Springs belostoma bug
<i>Bothriocephalus achelognathii</i>	Asian tape worm
<i>Brachylagus idahoensis</i>	Pygmy rabbit
<i>Canis latrans</i>	Coyotes
<i>Castor Canadensis</i>	Beaver
<i>Centruroids exilicauda</i>	Scorpion
<i>Cervus elaphus</i>	Elk
<i>Charadrius vociferous</i>	Killdeer
<i>Clethrionomys gapperi</i>	Red-backed vole
<i>Cottus bairdi</i>	Mottled sculpin
<i>Crotalus mitchelli stephensi</i>	Panamint Rattlesnake
<i>Cyprinodon diabolis</i>	Devils Hole pupfish
<i>Cyprinodon nevadensis nevadensis</i>	Saratoga pupfish
<i>Dendroica petechia</i>	Yellow warbler
<i>Dipodomys microps</i>	Kangaroo rat
<i>Dipsosaurus dorsalis</i>	Desert iguana
<i>Empidonax trailii</i>	Southwester willow flycatcher
<i>Equus asinus</i>	Feral burro
<i>Equus caballus</i>	Feral horse
<i>Erethizon dorsatum</i>	Porcupine
<i>Euphagus cyanocephalus</i>	Brewers blackbird
<i>Falco peregrinus</i>	Peregrine falcon
<i>Felis concolor</i>	Mountain lion
<i>Gambusia affinis</i>	Mosquitofish

Scientific Name	Common Name
<i>Siphateles bicolor mojavenis</i>	Mohave tui chub
<i>Gambelia wislizenii</i>	Long-nosed leopard lizard
<i>Gila elegans</i>	Bonytail chub
<i>Gila seminude</i>	Virgin River chub
<i>Glaucomys sabrinus</i>	Northern flying squirrel
<i>Gopherus agassizii</i>	Desert tortoise
<i>Hadrurus arizonensis</i>	Scorpion
<i>Haliaeetus leucocephalus</i>	Bald eagle
<i>Heloderma suspectum</i>	Gila Monster
<i>Hyla cadaverina</i>	California treefrog
<i>Hyles lineate</i>	White-lined sphinx caterpillar
<i>Hymenoptera</i> (Order)	Ants
<i>Isoptera</i> (Order)	Termites
<i>Lampropeltis getulus californiae</i>	California king snake
<i>Latrodectus hesperus</i>	Black widow spider
<i>Lepus californicus</i>	Black-tailed hares
<i>Lynx rufus</i>	Bobcat
<i>Melospiza melodia</i>	Song sparrow
<i>Molothrus ater</i>	Brown-headed cowbird
<i>Microtus</i> spp.	Voles
<i>Microtus richardsoni</i>	Water vole
<i>Neotoma</i> spp.	Woodrats
<i>Odocoileus hemionus</i>	Mule deer
<i>Oncorhynchus clarki utah</i>	Bonneville cutthroat trout
<i>Oncorhynchus mykiss</i>	Rainbow trout
<i>Ovis canadensis</i>	Desert bighorn sheep
<i>Ovis canadensis canadensis</i>	Rocky mountain bighorn sheep
<i>Passerculus sandwichensis</i>	Savannah sparrow
<i>Passer domesticus</i>	House sparrow
<i>Passerina amoena</i>	Lazuli bunting
<i>Pelocoris Shoshone</i>	Amargosa naucorid bug
<i>Phainopepla</i> spp.	Silky flycatcher
<i>Phrynosoma desertii</i>	Horned lizard
<i>Plagopterus argentissimus</i>	woundfin
<i>Polyphylla erratica</i>	Death Valley June beetle
<i>Pyrgulopsis amargosae</i>	Amargosa spring snail
<i>Rana catsbeiana</i>	American bullfrog
<i>Richardsonius balteatus</i>	Red-sided shiner
<i>Rhinichthys osculus</i>	Speckled dace
<i>Sauromalus obesus</i>	Chuckwalla
<i>Sorex vagrans</i>	Vagrant shrew
<i>Spermophilus variegates</i>	Rock squirrel
<i>Sturnus vulgaris</i>	European starling
<i>Sylvaagus</i> spp.	Cottontail rabbit
<i>Tachycineta thalassina</i>	Violet-green swallow
<i>Tamiasciurus hudsonicus</i>	Red squirrel
<i>Tegeticula</i> spp.	Yucca moths
<i>Thomomys talpoides</i>	Pocket gopher
<i>Tryonia variegata</i>	Amaragosa tyronia snail
<i>Uma</i> spp.	Fringe toed lizard
<i>Vireo bellii pusillus</i>	least Bell's vireo
<i>Vireo gilvus</i>	Warbling vireo

Scientific Name	Common Name
<i>Vulpes</i> spp.	Fox
<i>Zapus princeps</i>	Woodland jumping mouse

Reference B. Glossary of Key Terms and Concepts

Alluvium – a general term for detrital deposits made by streams on riverbeds, flood plains, and alluvial fans.

Alluvial fan – an outspread, gently sloping mass of alluvium deposited by a stream, especially in an arid region where a stream issues from a narrow canyon onto a plain or valley floor.

Anthropogenic effects – are caused by or attributed to humans. As used here, they are human influenced factors that cause stress in natural systems.

Attributes – any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term indicator is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon, 2003; <http://science.nature.nps.gov/im/monitor/Glossary.htm>).

Bajada – a broad, gently inclined, detrital surface extending from the base of mountain ranges into an in-land basin.

Biological integrity – the ability to maintain and support a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region.

Biome – a climax community that characterizes a particular natural region.

Biota – the animal and plant life of a region.

C₄ – a set of photosynthetic reactions through which carbon dioxide is fixed to yield a 4 carbon intermediate (a reaction often associated with desert grasses, adaptation to save water)

CAM – a variant of the C₄ pathway in which carbon dioxide is fixed at night (often associated with succulents such as cactus, processes done at night to avoid extreme heat during that day, an adaptation to curtail water loss).

Carbonate rock – rock formed from the carbonates of calcium, magnesium, and/ or iron (e.g. limestone or dolomite).

Caudex – a thickened underground base of stem from which new leaves may arise.

Colluvium – a general term applied to loose deposits, usually at the foot of a cliff, and brought there by gravity.

Community – is a group of populations of different species occupying a given place at a given time that are viewed as interdependent, an aggregation of interacting species.

Corm – a thickened underground stem in which plant storage products are accumulated.

Composition – defined as the identity and variety of elements within an ecosystem, including species present and their population structure, abundance, and genetic diversity (Noss 1990).

Degradation – an anthropogenic reduction in the capacity of a particular ecosystem or ecosystem component to perform desired ecosystem functions (e.g., degraded capacity for conserving soil and water resources). Human actions may degrade desired ecosystem functions directly, or they may do so indirectly by damaging the capacity of ecosystem functions to resist or recover from natural disturbances and/or anthropogenic stressors (derived from concepts of Whisenant 1999, Archer and Stokes 2000, and Whitford 2002).

Disturbance – “...any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment” (White and Pickett 1985:7). In relation to monitoring, disturbances are considered to be ecological factors that are within the evolutionary history of the ecosystem (e.g., drought). These are differentiated from anthropogenic factors that are outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

Driver – The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>)

Ecological integrity – a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes (<http://science.nature.nps.gov/im/monitor/Glossary.htm>).

Ecoregion – an area over which the climate is sufficiently uniform to permit development of similar ecosystems on sites having similar properties. Ecoregions contain many landscapes with different spatial patterns of ecosystems.

Ecosystem – a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries (Likens 1992, cited by Christensen et al.1996:670).

Ecosystem functioning – the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. Includes many ecosystem processes such as primary production, trophic transfer from plants to animals, nutrient cycling, water dynamics and heat transfer. In a broad sense, ecosystem functioning includes two components: ecosystem resource dynamics and ecosystem stability (Díaz and Cabido 2001).

Ecosystem health – a metaphor pertaining to the assessment and monitoring of ecosystem structure, function, and resilience in relation to the notion of ecosystem “sustainability” (following Rapport 1998 and Costanza et al. 1998). A healthy ecosystem is sustainable (see *Sustainable ecosystem*, below).

Ecosystem integrity – see *ecological integrity*.

Ecosystem management – the process of land-use decision making and land-management practice that takes into account the full suite of organisms and processes that characterize and comprise the ecosystem. It is based on the best understanding currently available as to how the ecosystem works. Ecosystem management includes a primary goal to sustain ecosystem structure and function, a recognition that ecosystems are spatially and temporally dynamic, and acceptance of the dictum that ecosystem function depends on ecosystem structure and diversity. The whole-system focus of ecosystem management implies coordinated land-use decisions (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Edaphic – related to or caused by particular soil conditions, as of texture or drainage, rather than by physiographic or climate factors.

Endemic species – any species naturally confined to a particular area or region.

Endolithic – within the soil or rock layer.

Eolian – pertaining to the wind, esp. said of such deposits as loess and dune sand.

Equilibrium – a condition of balance between two opposing forces.

Evapotranspiration – the portion of precipitation returned to the area through evaporation and transpiration.

Focal resources – park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they would be monitored as an indication of ecosystem integrity. Focal resources might include ecological processes, such as deposition rates of nitrates and sulfates in certain parks; or they may be a species that is harvested, endemic, alien, or has protected status.

Focal species / organisms – species and/or organisms that play significant functional roles in ecological systems by their disproportionate contribution to the transfer of matter and energy, by structuring the environment and creating opportunities for additional species and/or organisms, or by exercising control over competitive dominants and thereby promoting increased biological diversity (derived from Noon 2003:37). [Encompasses concepts of keystone species, umbrella species, and ecosystem engineers.]

Forcing functions – a natural agent external to the processes being modeled responsible for causing temporal changes or variability in quantitative measures of structural and functional

attributes of ecosystems. Examples include solar radiation, N and P loading, turbidity, and temperature (Culver 1999).

Functional groups – groups of species that have similar effects on ecosystem processes (Chapin et al. 1996) – frequently applied interchangeably with *functional types*.

Functional types – sets of organisms sharing similar responses to environmental factors such as temperature, resource availability, and disturbance (= functional *response types*) and/or similar effects on ecosystem functions such as productivity, nutrient cycling, flammability, and resistance / resilience (= functional *effect types*) (Díaz and Cabido 2001).

Genotype – the genetic constitution, latent or expressed, of an organism, the sum total of all genes present in an organism.

Geomorphic – pertaining to the shape of the earth or its surface features.

Geophyte – plants that expend major part of their growth in the soil.

Hydrologic function (lotic and lentic systems) – capacity of an area to: dissipate energies associated with (1) high stream flow (lotic); or (2) wind action, wave action, and overland flow (lentic); thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and groundwater recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; support greater biodiversity (from Prichard et al. 1998, 1999).

Hydrologic function (upland systems/soils) – capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).

Iteroparous – producing offspring at more than one time during a lifetime.

Indicators – a subset of monitoring attributes that are particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2003). Indicators are a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the system (Noon 2003; <http://science.nature.nps.gov/im/monitor/Glossary.htm>).

Indicators of ecosystem health – measurable attributes of the environment (biotic or a biotic) that provides insights regarding (1) the functioning status of one or more key ecosystem processes, (2) the status of ecosystem properties that are clearly related to these ecosystem processes, and/or (3) the capacity of ecosystem processes or properties to resist or recover from natural disturbances and/or anthropogenic stressors (modified from Whitford 1998). In the context of ecosystem health, key ecosystem processes and properties are those that are closely

associated with the capacity of the ecosystem to maintain its characteristic structural and functional attributes over time (including natural variability).

Inherent soil properties – soil properties that are relatively unaffected by management activities, climatic fluctuations, and natural disturbances (e.g., texture, color, depth, mineralogy, horizonation).

Inventory – an extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Karst – an area of limestone formations characterized by sinks, ravines, and underground streams.

Landscape – a spatially structured mosaic of different types of ecosystems interconnected by flows of materials (e.g., water, sediments), energy, and organisms.

Lentic – referring to standing freshwater habitats, such as ponds and lakes.

Lotic – referring to running freshwater habitats.

Measures – specific feature(s) used to quantify an indicator, as specified in a sampling protocol. For example, pH, temperature, dissolved oxygen, and specific conductivity are all measures of water chemistry (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Mesic – of or pertaining to a relatively moist and benign environment.

Microclimate – variations of climate within a given area.

Monitoring – collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective (Elzinga et al. 1998). Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Natural variability – the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal (Landres et al. 1999).

Orographic – of or pertaining to mountains or mountain ranges.

Paleobotany – the study of fossil plants.

Pediment – a broad gently sloping erosion surface or plain of relief, typically developed by running water, in an arid region at the base of an abrupt and receding mountain front.

Pedogenesis – the process of soil formation.

Phenology – term referring to the timing of an organisms lifecycle (ex: producing flowers only with certain periods of light).

Phreatophytes – a plant species which extends its roots into the saturated zone of the water table.

Piedmont – lying or formed at the base of a mountain or mountain range.

Playa – a term used in the Southwestern US for a dry, barren area in the lowest part of an undrained desert basin, underlain by clay, silt, or sand and commonly by soluble salts. It may be marked by an ephemeral lake.

Reference conditions – the range of historic (or natural) variability in ecological structures and processes, reflecting recent evolutionary history and the dynamic interplay of biotic and abiotic conditions and disturbance patterns (Morgan et al 1994; Swanson et al. 1994).

Research – the objective of understanding ecological processes and, in some cases, determining the cause of changes observed by monitoring.

Resilience – the capacity of a particular ecological attribute or process to recover to its former reference state or dynamic after exposure to a temporary disturbance and/or stressor (adapted from Grimm and Wissel 1997). The ability of a natural ecosystem to restore its structure following acute or chronic disturbance (Westman 1978). Resilience is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Resistance – the capacity of a particular ecological attribute or process to remain essentially unchanged from its reference state or dynamic despite exposure to a disturbance and/or stressor (adapted from Grimm and Wissel 1997). Resistance is a dynamic property that varies in relation to environmental conditions (Scheffer et al. 2001).

Rhizome – a more or less horizontal underground stem.

Riparian – pertaining to or situated on the banks of a body of water, esp. a river.

Saturated zone – a sub-surface zone in which all the soil interstices are filled with water, under pressure greater than that of the atmosphere.

Semelparous – species which reproduce only once during their lifetime.

Soil / site stability – the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).

Soil quality – the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and

air quality, and support human health and habitation (Karlen et al. 1997:6). From an NPS perspective, soil quality is defined by a soil's capacity to perform the following ecological functions: (a) regulate hydrologic processes; (b) capture, retain, and cycle mineral nutrients; (c) support characteristic native communities of plants and animals. Soil quality can be regarded as having (1) an inherent component defined by the soil's inherent soil properties as determined by the five factors of soil formation, and (2) a dynamic component defined by the change in soil function that is influenced by human use and management of the soil (Seybold et al. 1999).

Speleothem – a mineral deposit formed in a cave by the action of water.

State – as applied to state-and-transition models, a *state* is defined as “a recognizable, resistant and resilient complex of two components, the soil [or geomorphic] base and the vegetation structure” (Stringham et al. 2003:109). These two ecosystem components interactively determine the functional status of the primary ecosystem processes of energy flow, nutrient cycling, and hydrology. States are dynamic and “... are distinguished from other states by relatively large differences in plant functional groups and ecosystem processes [including disturbance and hydrologic regimes] and, consequently, in vegetation structure, biodiversity, and management requirements” (Bestelmeyer et al. 2003:116). (Also see *threshold* and *transition*.)

Stressor – physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976:192). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, land-use change, and air pollution (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Structure – the spatial organization of the constituent parts of the ecosystem, including large-scale patterns.

Succulent – a plant with fleshy, water storing, stems and leaves.

Threshold – as applied to state-and-transition models, a *threshold* is a point “...in space and time at which one or more of the primary ecological processes responsible for maintaining the sustained [dynamic] equilibrium of the state degrades beyond the point of self-repair. These processes must be actively restored before the return to the previous state is possible. In the absence of active restoration, a new state is formed” (Stringham et al. 2003:109). Thresholds are defined in terms of the functional status of key ecosystem processes and are crossed when capacities for resistance and resilience are exceeded. (Also see *state* and *transition*.)

Transition – as applied to state-and-transition models, a *transition* is a trajectory of change that is precipitated by natural events and/or management actions which degrade the integrity of one or more of the primary ecological processes responsible for maintaining the dynamic equilibrium of the state. Transitions are vectors of system change that will lead to a new state without abatement of the stressor(s) and/or disturbance(s) prior to exceeding the system's capacities for resistance and resilience (adapted from Stringham et al. 2003). (Also see *state* and *threshold*.)

Trend – as used by this program, refers to directional change measured in resources by monitoring their condition over time. Trends can be measured by examining individual change (change experienced by individual sample units) or by examining net change (change in mean response of all sample units) (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Unsaturated zones – a sub-surface zone in which soil interstices are not filled with water.

Variable – any quantitative aspect of an object of concern.

Vital signs – 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. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes) (<http://science.nature.nps.gov/im/monitor/Glossary.cfm>).

Watershed – a drainage basin, usually described as into a river or lake.

Xeric – of or pertaining to a relatively dry, often stressful environment.

Xerophytic – used to describe plants with very low water requirements.

Literature Cited for Glossary

- Archer, S. and C. J. Stokes. 2000. Stress, disturbance and change in rangeland ecosystems. Pages 17-38 in O. Arnalds and S. Archer eds. *Rangeland Desertification, Vegetation Science* Vol. 19. Kluwer Publishing Company.
- Chapin III, F. S., E. O. Sala, C. I. Burke, J. P. Grime, D. U. Hooper, W. K. Lauernroth, A. Lombard, H. A. Mooney, A. R. Mosier, S. Naeem, S. W. Pacala, J. Roy, W. L. Steffen, and D. Tilaman. 1998. Ecosystem consequences of changing biodiversity. *Bioscience* **48**:45-52.
- Chapin III, F. S., M. S. Torn, and M. Tatenno. 1996. Principles of ecosystem sustainability. *The American Naturalist* **148**:1016-1037.
- Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. M. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* **6**:665-691.
- Costanza, R., R. Arge, R. de-Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. Oneil, J. Paruelo, R. Raskin, P. Sutton, and J. van denBelt. 1998. The value of ecosystem services; putting the issues in perspective. *Ecological Economics* **25**: 67-72.
- Culver, D. A. 1999. *Ecological Modeling of Lake Erie Trophic Dynamics*. Department of Evolution, Ecology, and Organismal Biology, The Ohio State University. On-line. (<http://www.ijc.org/php/publications/html/modsum/culver.html>). Accessed 30 August 2005.
- Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* **10**:639-670.
- Díaz, S. and M. Cabido. 2001. Vive la différence: Plant functional diversity matters to ecosystem processes. *Trends in Ecology and Evolution* **16**:646–655.
- Frid, A. and L. M. Dill. 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* **6**(1):11.
- Grimm, V. and C. Wissel. 1997. Babel or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. *Oecologia* **109**:323-334.
- Harwell, M. A., V. Myers, T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P.

- Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. *BioScience* **49**:543-556.
- Herrick, J. E. and M. M. Wander. 1998. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition, and soil biological activity. Pages 405-425 *in* R. Lal, J. M. Kimble, R. F. Follett, and B. A. Steward eds. *Soil Processes and the carbon cycle*. CRC-Lewis, Boca Raton, FL.
- Jones C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. *Oikos* **69**: 373-386.
- Karlen, D. L., M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. *Soil Science Society of America Journal* **61**:4-10.
- Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems.
- Likens, G. 1992. *An ecosystem approach: its use and abuse*. Excellence in ecology, book 3. Ecology Institute, Oldendorf/Luhe, Germany.
- Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, and W. D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecological change. *Journal of Sustainable Forestry* **2**:87-111.
- Noon, B. R. 2003. Conceptual issues in monitoring ecological systems. Pages 27-71 *in* D. E. Busch and J.C. Trexler, eds. *Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives*. Island Press, Washington, D.C.
- Noss, R. 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. *Conservation Biology* **4**:355-364.
- Pellant M., P. Shaver, D.A. Pyke, and J. E. Herrick. 2000. Interpreting indicators of rangeland health, version 3. Technical Reference 1734-6, USDI, BLM, National Science and Technology Center, Denver, CO U.S.A.
- Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, and J. Staats. 1998. *Riparian Area Management: A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lotic Areas*, Technical Reference 1737-15, BLM/RS/ST-98/001+1737, Bureau of Land Management, Denver, CO. 136 pp.
- Rapport D. J. 1998. Defining ecosystem health. Pages 18-33 *in* D. J. Rapport, R. Costanza, P. R. Epstein, C. L. Gaudet, and R. Levins, eds. *Ecosystem Health*. Blackwell Science, Malden, MA.

- Ringold, P. L., B. Mulder, J. Alegria, R. L. Czaplewski, T. Tolle, and K. Burnett. 1999. Establishing a regional monitoring strategy: the Pacific Northwest Forest Plan. U. S. Environmental Protection Agency, Corvallis, OR. *Environmental Management* **23**:179–192.
- Scheffer, M., S. Carpenter, J. Foley, C. Folke, and B. Walker, 2001. Catastrophic regime shifts in ecosystems. *Nature* **413**:591-596.
- Seybold, C. A., J. E. Herrick, and J. J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. *Soil Science* **164**:224-234.
- Stringham, T. K., W. C. Krueger, and P. L. Shaver. 2003. State and transition modeling: An ecological process approach. *Journal of Range Management* **56**:106-113.
- Swanson, F. J., J. A. Jones, D. A. Wallin, and J. H. Cissel. 1994. Natural variability implications for ecosystem management. Pages 85–99 *in* M. E. Jensen and P. S. Bourgeron eds. Eastside forest ecosystem health assessment, Volume II. Ecosystem management: principles and applications. U. S. Department of Agriculture Forest Service, Northern Region, Missoula, MT.
- Westman, W. E. 1978. Measuring the inertia and resilience of ecosystems. *Bioscience* **28**:705-710.
- Whisenant, S.G. 1999. Repairing damaged wildlands: A process-oriented landscape scale approach. Cambridge University Press. Cambridge, UK.
- White, P. S. and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. Pages 3-13 *in* S. T. A. Pickett and P. S. White, eds. The ecology of natural disturbance and patch dynamics. Academic Press, San Diego, CA.
- Whitford, W. G. 1998. Validation of indicators. Pages 205-209 *in* D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. Ecosystem health. Blackwell Science, Malden, MA.
- Whitford, W. G. 2002. Ecology of desert systems. Academic Press, San Diego, CA.