Sonoran Desert

Rapid Ecoregional Assessment Report

U.S. Department of Interior
Bureau of Land Management

May 2012

BLM MISSION STATEMENT

It is the mission of the Bureau of Land Management to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations.

Suggested Citation: Strittholt, J.R., S.A. Bryce, B.C. Ward, and D.M. Bachelet. 2012. Sonoran Desert Rapid Ecoregional Assessment Report. Prepared for the U.S. Department of the Interior, Bureau of Land Management, Denver, Colorado.

To find this report online and to access data portal go to:
http://www.blm.gov/wo/st/en/prog/more/climatechange.html

Cover Photo: Colorado River near Moab, Utah BLM
Title Page Photo: Palm oasis near Palm Springs, Gary Burzell

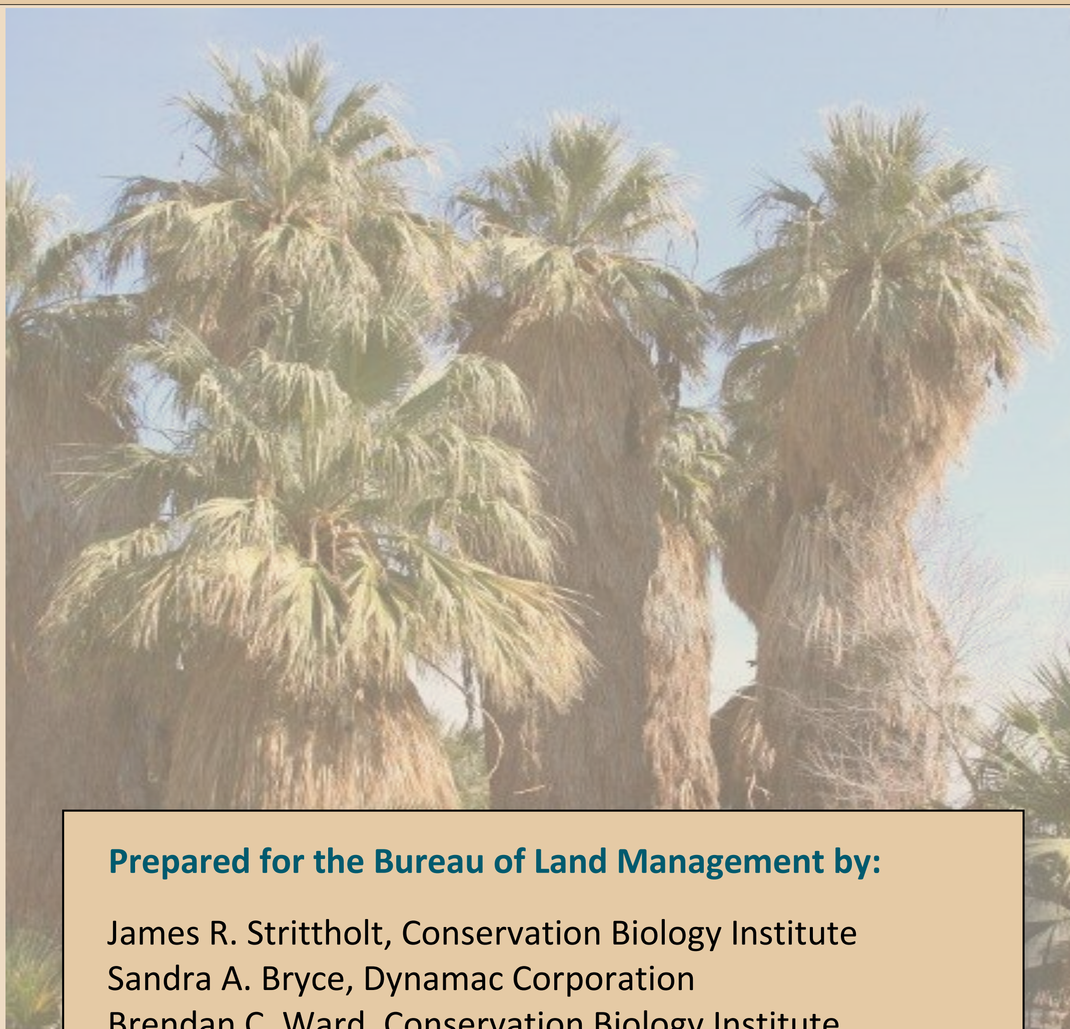
U.S. Bureau of Land Management
BLM National Operations Center
Building 50, Denver Federal Center
Denver, CO 80225

Dynamac Corporation
10301 Democracy Lane
Suite 300
Fairfax, Virginia 22030

Conservation Biology Institute
136 SW Washington Ave
Suite 202
Corvallis, OR 97333

Sonoran Desert

Rapid Ecoregional Assessment Report



Prepared for the Bureau of Land Management by:

James R. Strittholt, Conservation Biology Institute
Sandra A. Bryce, Dynamac Corporation
Brendan C. Ward, Conservation Biology Institute
Dominique M. Bachelet, Conservation Biology Institute

BLM Project Manager: Karl Ford,
National Operations Center, Denver, Colorado

Sonoran Desert REA Contributors:

Matt Bobo	BLM National Operations Center
James Callegary	USGS Tucson
Lane Cowger	BLM Arizona State Office
Ashley Conrad-Saydah	BLM California State Office
Julie Decker	BLM Arizona State Office
Charles Drost	USGS Flagstaff
Todd Esque	USGS Boulder City
Adrian Farmer	Wild Ecological Consultants
Karl Ford	BLM National Operations Center
Gerry Horak	Dynamac, Inc.
Steve Hostetler	USGS Corvallis
Carly Jerla	BOR Boulder
Bill Lamb	Quadstate
Peter Lattin	Dynamac, Inc. (to 2/11)
Jeffrey Lovich	USGS Flagstaff
Elroy Masters	BLM Arizona State Office
David Mattson	USGS Flagstaff
Ken Nussear	USGS Boulder City
Anna Oldak	MDA Information Systems, Inc.
Sabra Schwartz	Arizona Game and Fish Department
Russell Scofield	Desert Managers Group
June Shoemaker	BLM Arizona State Office
Charles Van Riper	USGS Tucson
Christina Vojta	FWS Flagstaff
James Weigand	BLM California State Office

Consultation and analytical work provided by Conservation Biology Institute staff:

Katie Brown	Patricia Gordon-Reedy	Heather Rustigan-Romsos
Pamela Frost	Kai Henefin	Henri Sanville
Dennis Grossman	Jeremiah Osborne-Gowey	Tim Sheehan
Ken Ferschweiler	Wendy Peterman	Alexandra Syphard

Table of Contents

FIGURES

TABLES

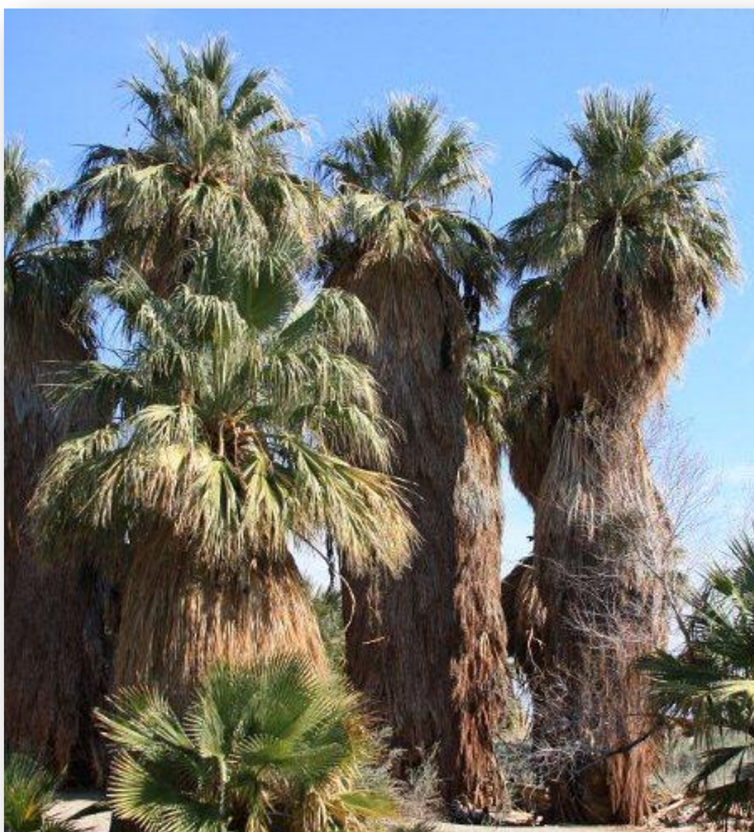


Photo: Palm oasis near Palm Springs, Gary Burzell

Executive Summary

Rapid Ecoregional Assessments: Purpose and Scope

Rapid Ecoregional Assessments (REAs) are a product of the evolution of the Bureau of Land Management (BLM) toward a landscape approach to land and resource management. Using the landscape approach, the BLM hopes to integrate available scientific data from BLM field offices, other federal and state agencies, and public stakeholders to develop collaborative management efforts across administrative boundaries. Regional-scale information and assessment analyses on current and future condition will be used by the BLM and its partners to assist with land use planning, developing best-management practices, authorizing uses, and establishing conservation and restoration priorities. REAs are informational tools, not decision documents.

The regional scope of the Sonoran Desert REA and the assessment of its numerous conservation elements and their interactions with change agents produced a massive volume of results that can only be summarized within the constraints of a report of reasonable length. Major highlights of the results appear in the body of the report and appendices provide more detailed information on methods and models. Several key aspects of the REAs highlight their utility to the BLM:

Management Questions: Management questions are the foundation and catalyst for the REAs because they determine the scope of data requirements and analyses. BLM land managers and partners provided a broad range of management questions to the REA to frame regional issues and data needs (full list in Section 2.4.1). The regionally-significant management questions developed for each REA match the scale of the assessment. The 32 management questions prepared for the Sonoran Desert REA refer to native and invasive flora and fauna, disturbance factors or change agents that affect present and future resource status, and significant (designated) sites and ecological functions and services.

Ecoregional Scale: Region-wide analyses explaining the association of native species, aquatic and terrestrial resources, and environmental change agents provide the BLM with another scale of consideration beyond the field office level. REAs thus inform future management planning across multiple spatial scales and jurisdictional boundaries to prioritize resource uses. They also provide a management mechanism for ensuring species' access to seasonal habitats and migration corridors by maintaining connectivity among populations. At the same time, while REAs are scaled at the ecoregional level, they also provide conceptual and geoprocessing models that can be reworked at the state or field office levels using more refined data.

Data Compilation: One of the more important components of the REA process is data compilation in topical areas that are regionally significant. REAs do not involve original research, but they use existing data, modeling, and geographic information system (GIS) analyses to answer a broad range of management questions. The REA effort provides a baseline of information and results built on spatial data that was publicly available during the 2010–2012 time frame. In all, 169 data layers were used to create hundreds of final derived results and maps. The intensive collection and organization of spatial data in itself is of value to the BLM as a library or atlas of spatial data for use in future agency investigations.

Assessing Current Condition: The evaluation of the current status of regionally-significant biotic elements (wildlife and plant species) and abiotic factors (e.g., soils, water resources) was a key aspect of the REA. Two characteristic vegetation communities of the Sonoran Desert represented the coarse-filter component (Table 2-2, Section 2.4.2). Fine filter elements were represented by 11 wildlife species conservation elements as well as a list of designated sites and essential ecosystem functions and services (e.g., aquatic systems, riparian areas, and soil stability).

Because of the spatial nature of the REAs, describing *status* for various conservation elements and resource values requires the ability to identify and map specific characteristics of that resource. As a result, REA results and the regional assessments, while valuable, must always be considered incomplete: some important elements will be absent because their effects were not visible or because data to represent them were not available.

Status is the current condition of various conservation elements resulting from all stressors and changes imposed on a prior historical condition or benchmark reference condition.

Projecting Future Condition: REAs also evaluate the potential of change agents—including wildland fire, invasive species, development, and climate change—to affect ecoregion condition. Assessment output products documenting potential-for-change demonstrate how current evidence of cumulative impacts may be projected into the future to identify potential trade-offs, alternatives, and mitigation strategies for BLM planning purposes. A development-related REA product of interest to the BLM is the location of areas with high potential for traditional or renewable energy development. REA results contain current and potential development data layers that were merged with mapped distributions for the various conservation elements to identify how and where the elements may be affected by various planned and potential energy development areas.

Application to Adaptive Management: REAs are timely in supporting planning, management, and mitigation strategies for impacts anticipated from rapidly-developing issues related to traditional and renewable energy development, the spread of invasive species, changing fire regimes, and climate change. REAs provide a foundation for an adaptive management approach that will allow implementation strategies to be adjusted for new information and changing conditions. REAs represent a baseline condition from which to evaluate the results of adaptive management and to characterize potential trends in resource condition both in the near-term (2025)—as a consequence of development activities—and in the long-term (2060) as a result of climate change. Chapters 5 and 6 provide examples showing how the data and results may be arranged and manipulated using mapped and tabular results, for all land ownerships and BLM-lands only, for areas of intact habitats, resource value hotspots, and opportunities for connectivity with existing designated protected lands.

REA Products and Results

Landscape Intactness

The BLM and other participants in the Sonoran Desert REA agreed to emphasize the concept of *intactness* for the mapping of ecological condition. As defined and used here, intactness is a measure of naturalness as well as an attribute that can be defensibly supported by existing geospatial datasets, mapped, and reasonably tracked through time. Because vegetative cover represents wildlife habitat, it serves as a surrogate to estimate the status of species that depend on that habitat, particularly since spatial data for the pre-disturbance distribution or abundances of various wildlife species are typically not available. For example, representative landscapes may be placed along a gradient of intactness (or conversely, along a gradient of disturbance) with sites that are experiencing increasing levels of disturbance considered to have lower intactness. The lowest intactness levels occur in areas completely converted from their original character. Terrestrial (Figure 1) and aquatic intactness models were created for the entire ecoregion. Intactness models are a critical element for assessing the status of conservation elements for current as well as near-term future (2025) condition.

Intactness is a quantifiable estimate of naturalness measured on a gradient of anthropogenic influence and based on available spatial data.

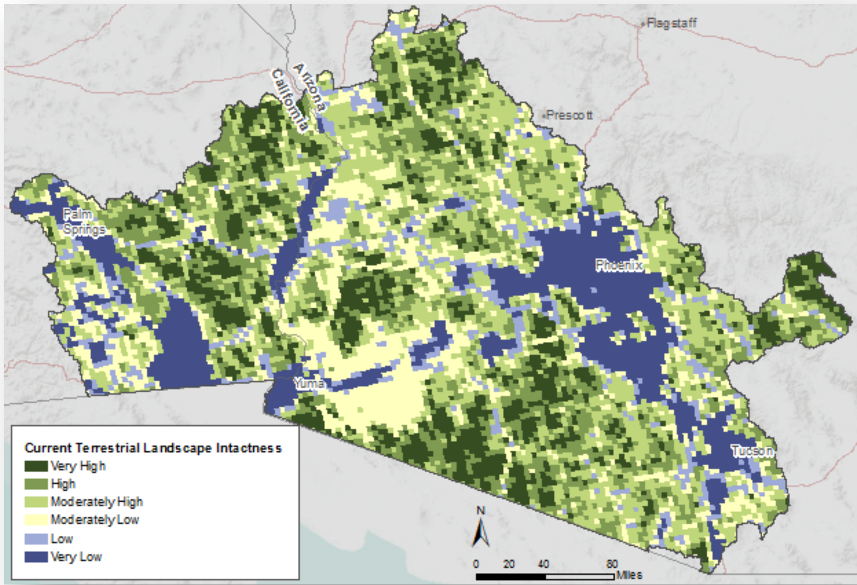


Figure 1. Sonoran Desert terrestrial landscape intactness in six classes from High (relatively undisturbed in dark green) to Very Low (highly disturbed from agriculture, resource development, or urbanization in dark blue) depicted with a 4 km X 4 km grid cell.

Change Agents Current and Future

The status or condition of various conservation elements cannot be discussed without first examining the risks that these elements experience from a collection of regional disturbances or change agents. Natural and anthropogenic disturbance factors are represented in the REA by four change agents: land and resource use (development), climate change, invasive species, and wildland fire. The major change agents and their effects on conservation elements are considered in the current time frame and projected over the near-term future (2025) for development and the longer term future (2060) for climate change. Land and resource use is the largest change agent class, encompassing urbanization and road density, oil, gas, and mining, renewable energy development, agriculture, grazing, ground and surface water extraction, and recreation.

REA results include mapped and tabular products describing historical and recent (within the last 20 years) change to major vegetation communities from disturbances such as urbanization and roads development, agriculture, invasive species, fire, and mechanical treatments. The greatest amount of total area changed based on modeled historical reference condition (LANDFIRE BpS data) was in palo verde-mixed cacti desert scrub (over 4.7 million acres or 30% of ecoregion area), with maximum acres altered for invasive species (about 2.3 million acres), urbanization and road development (over 1.2 million acres), and agriculture (about 670,000 acres). The highest percent change region-wide was observed in creosotebush-white bursage desert scrub with 51% (>4 million acres) of its distribution converted by invasives (nearly 3 million acres), urbanization and roads, and agriculture (about 400,000 acres each). Renewable energy development has the potential to be the most pressing change agent affecting the vegetation communities of the Sonoran Desert ecoregion, particularly in the creosotebush-white bursage-covered basins in the western part of the ecoregion. Renewable energy development also affects wildlife species that require unbroken expanses of desert habitat such as the desert tortoise.

The Mojave desert tortoise's distribution in the basins of the eastern Sonoran Desert puts them in direct conflict with some wind power development as well as prime locations for large (thousands of acres) solar arrays planned for the near future. Projected *mid-term* energy development (Figure 2) is represented by proposed wind and solar energy areas still subject to planning and approval over the next several decades. Data for the mid-term energy projection included features from BLM priority projects, California renewable energy rights-of-way, modified solar energy zones (SEZs), and Arizona restoration design energy project data.

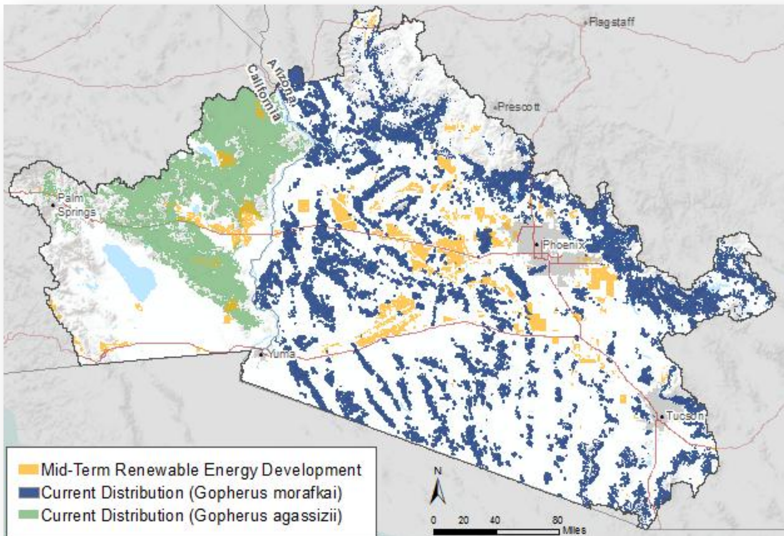


Figure 2. Map shows distribution of two desert tortoise species, the Mojave desert tortoise (in green) and the Sonoran desert tortoise (in blue) relative to mid-term (next several decades) renewable energy development (yellow) in the Sonoran Desert ecoregion.

Four invasive plant species of concern, riparian tamarisk and upland red brome, buffelgrass, and Sahara mustard were selected for the Sonoran Desert REA because they are considered significant change agents in the region. These species have the potential to expand their distributions in spite of human and natural disturbances and to adapt and shift their ranges in response to climate change. The models produced for current and near-term future distribution of invasive species for the REA used multiple models and mapped sources, but the results likely underestimate the total distribution of invasive vegetation in the ecoregion (Figure 2, Sections 4.3.1 and 5.3). Invasive species, such as red brome, increase fire frequency by increasing fine fuel loads and continuity, thus allowing fires to spread into areas that were once fuel-limited. The degree to which fire may become an ecologically significant change agent relates to the extent to which the fire regime is altered compared with reference conditions. Three fire-related management questions were addressed in the REA related to fire occurrence within the past decade, fire-adapted communities, and areas with potential to change from wildfire (Section 4.3.2).

A major portion of the report dedicated to future conditions in the Sonoran Desert covers projections of climate change for mid-century (circa 2060, Section 5.4). Three different future climate projections were investigated for the REA; but the ECHAM5-driven RegCM3 climate projections were selected for the body of the report to evaluate potential impact on the various conservation elements. ECHAM5 has been identified as one of the better models to represent natural climate variability, and the regional RegCM3 model represents the North American Monsoon (summer rainfall pattern) which is important to Sonoran Desert vegetation dynamics (see Climate Change Scenario below).

Conservation Element Status

Overlaying conservation element distribution with the overall intactness model (Figure 1) produced current status for each species and conservation element. The intactness model provides a regional perspective of vegetation condition, habitat quality, development, and natural habitat fragmentation patterns. Not all

species demonstrate the same level of tolerance to the various model inputs, but the overall intactness model provides a standard baseline from which to explore specific species' requirements or areas where tolerances to various components may vary. The regional intactness model may be rerun with new or higher resolution data to test specific thresholds for individual species.

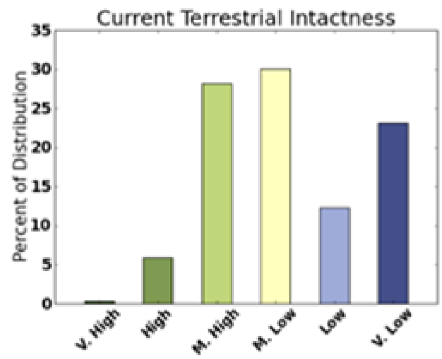


Figure 3. Histogram represents status for southwestern willow flycatcher in 6 intactness classes with about 35% of its distribution in the Low and Very Low intactness classes.

Of the wildlife species, southwestern willow flycatcher had the lowest overall status with 35–40% of its distribution in the Low and Very Low intactness category and about 66% of its entire distribution in the three lowest categories (Figure 3). Other species with low status signatures were Bell's vireo and lowland leopard frog, both riparian/wetland species. The two desert tortoise species showed similar status profiles with most of the distributions for both species within the three higher intactness classes. Such high results do not necessarily mean these two species are currently secure (for more details on both desert tortoise species, see Desert Tortoise Case Study Insert located after Section 4.2.1). As additional data becomes available specific to tortoise disturbance thresholds, the models can be further refined.

Climate Change Scenario

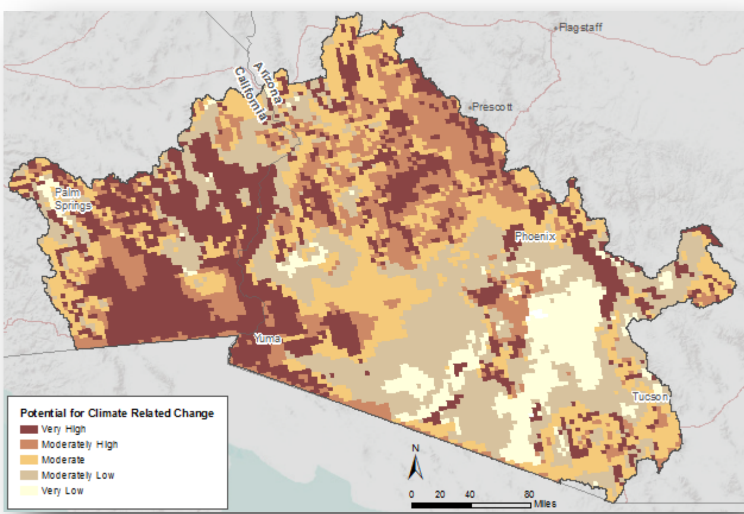


Figure 4. Map shows overall potential for climate change expressed in five classes from Very High (dark red-brown color) to Very Low (off-white). The southwest, west-central, and northeastern portions of the ecoregion have the highest potential for climate change.

To simplify the complex and numerous future climate projections, a number of the key findings were selected from the analyses and assembled into an overall relative climate change map (Figure 4). The model inputs included potential for summer temperature change and potential for winter temperature change averaged into a single factor, plus the potential for runoff change, potential for precipitation change, and potential for vegetation change. The exposure of species, habitats, and sites to predicted climate change is represented by overlaying the climate model with the distribution of each conservation element to identify the areas potentially affected by climate change. The three mammal species, mountain lion, mule deer, and desert bighorn sheep, showed roughly 40% of their existing distributions under Very High or Moderately High exposure to climate change by 2045–2060. Of the two tortoise species, Sonoran desert tortoise had 30% and Mojave desert tortoise had almost 50% of its distribution in the Very High and Moderately High climate change exposure categories. Unlike the mammals that are more mobile, the tortoise species are more likely to have physiological impacts and dispersal limitations. Of the vegetation communities, the one showing the most area under Very High climate change

potential was Sonoran-Mojave creosotebush-white bursage desert scrub found in the lower elevation basins of the western Sonoran Desert, followed by riparian vegetation and Sonoran palo verde-mixed cacti desert scrub. Climate change challenges the standard management practice of setting aside threatened species activity areas or critical habitats relative to areas deemed developable, when vegetation community, ecosystem, and even ecoregion boundaries will be in constant flux under climate change.

Application of Results

The vast amount of information produced by this REA can and must be examined in multiple ways and at multiple scales. Chapters 5 and 6 apply the results by manipulating maps and data tables in various planning scenarios using distributions and concentrations of conservation elements (or hotspots) for energy planning, and protected area or connectivity planning. The examples given in Chapter 6 are for hotspots over all lands, all lands minus developed and designated lands, and BLM-only lands. In the example below (Figure 5), one can see where high concentrations of conservation elements and areas of high intactness exist in BLM lands shaded in dark pink. A map of this kind highlights areas of potential conservation, restoration, or mitigation.

The application examples show the utility of examining the data in detail and becoming familiar with the strengths and weaknesses of the models and the underlying data sources. The models will acquire ecological meaning as they are calibrated with finer scale data and groundtruthing. It is highly likely that higher resolution data and analyses may modify REA results locally, but they will remain valid at the regional scale at which they were produced.

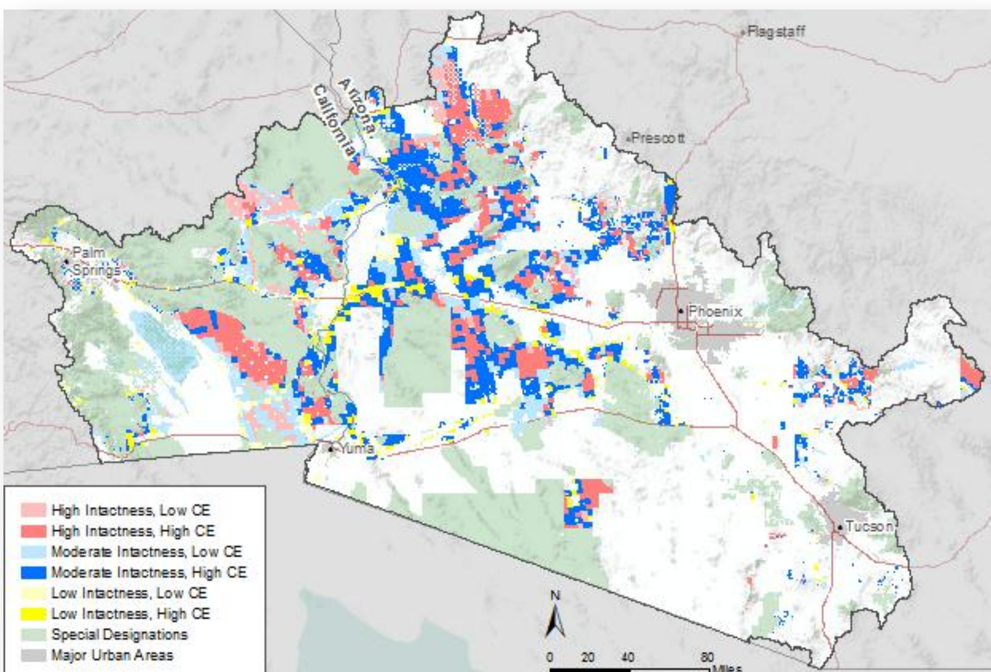


Figure 5. Map shows BLM-managed land areas of various intactness classes in the Sonoran Desert intersected with low and high concentrations of conservation elements (CEs). Designated protected areas are shown in green; white areas are non-BLM lands. Darker pink areas represent the intersection of high concentrations of conservation elements and areas of high intactness.

I. BLM's Approach to Ecoregional Direction and Adaptive Management

Assessments help managers address problems by providing information that can be integrated into future management action. The success of this Rapid Ecoregional Assessment (REA) ultimately depends on how well it helps inform management decisions (Johnson and Herring 1999): 1. Was it contextual? Did it significantly improve understanding about the conditions of the resources being studied within the ecoregion and the consequences of particular actions? 2. Was it integrated? Was that understanding integrated into managers' thinking to guide future action? 3. Was it pragmatic? Did the assessment lead to potential solutions for the management questions?

The contract for this assessment clearly requests information designed to be integrated into specific management approaches. However, the contract stops short of actually integrating the findings into management actions. REAs are informational tools, not decision documents. The BLM chose to retain responsibility for all aspects of integrating the assessment into management actions and decisions. The process presented here is conceptual; no process has yet been established as a commitment or accepted as a responsibility by the BLM.

This proposed process helps address the environmental changes the West is experiencing. To be effective in addressing these regional challenges, the process must address them at multiple scales and across multiple jurisdictions. All BLM programs can contribute to this effort. The BLM is exploring innovative approaches to a process in landscape direction across programs and geographic scales. The following paragraphs briefly describe a systematic approach to these ecoregional challenges:

Managing resources at multiple scales: Traditionally, the BLM has undertaken resource management project by project, permit by permit, and land use plan by land use plan, without systematically assessing landscape scale effects. To effectively address the projected environmental changes in the West, resource managers will have to develop the capacity to evaluate effects at multiple geographic scales.

Managing resources across ownerships and jurisdictions: Traditionally, resource managers have focused on activities within their own administrative units. To effectively address the environmental changes the West is experiencing, resource managers will have to develop the institutional and technical capacity to work across ownerships and jurisdictions.

Managing resources across programs: Traditionally, resource management has been defined by programs (e.g. wildlife, range, minerals). To address the environmental changes the West is experiencing, resource managers will have to more effectively integrate activities across programs by inter-disciplinary management.

Standardizing and integrating data: The ability to collect, synthesize and share geospatial information about resource conditions, change agents such as wildland fire, and on-the ground management activities is a critical part of this effort. Without the ability to compile and correlate such information within and outside of BLM, it is extremely difficult to achieve conservation, restoration, and adaptation strategies and to evaluate the effectiveness of such strategies once implemented.

Systematic integration requires some fundamental shifts in the BLM's traditional management practices. Although project-focused work and traditional practices will still be part of BLM's management strategy, the REAs will help the BLM to identify what processes are appropriate for the broader scale landscape approach (Table 1).

Table 1-1. Comparison of differences between aspects of BLM's traditional management practices and the landscape approach represented in the Rapid Ecoregional Assessments.

Traditional Practice	Landscape Approach
Project Focus	Landscape Focus
Program/Functional Direction	Integrated Direction Across Programs
Unit Decision Making	Cross Jurisdictional Decision Making
Unit Priorities	Collaborative and Partnership Priorities
Program Accomplishments	Integrated Accomplishments Across Programs
Authorize Uses and Mitigate Ecological Values	Ecological values and Use Authorizations Considered Equally
Ecological Component (Individual Species)	Ecological Function and Service
Agency Funding	Partnership Leveraged Funding

Many of the landscape approach activities listed in the table above have been part of BLM's approach at the land use planning scale. BLM is undertaking the following activities at the regional scale to deal with environmental changes:

Rapid Ecoregional Assessments

Working with agency partners, BLM is conducting rapid ecological assessments like this one, covering approximately 450 million acres of public and non-public lands in ten ecoregions in the American West to identify potential priority areas for conservation and development. Over time, the BLM anticipates collaboration with the Landscape Conservation Cooperatives (LCCs, public-private partnerships for adaptive management grounded in science) to periodically update ecoregional assessments and identify science needs.

Ecoregional Direction

BLM is developing a standard ecoregion-scale process for conserving or developing priority areas and for incorporating REA results into land use planning, environmental impact assessments, use authorizations, conservation and restoration project planning, and acquisition of conservation easements.

> Ecoregional direction uses the information from the REAs and stakeholders to develop a broad scale management strategy for an ecoregion's BLM-managed lands.

Ecoregional direction uses the information from the REAs, along with input from partner agencies, stakeholders, and Tribal agencies to develop a broad scale management strategy for an ecoregion's BLM-managed lands. This broad scale management strategy will identify focal areas on BLM-managed lands for conservation and development, including areas for conserving wildlife habitats and migration corridors and for potential energy development and urban growth. Ecoregional direction will also provide a blueprint for coordinating and implementing these priorities at the BLM's state and field-office levels. Ecoregional direction links REAs and the BLM's Resource Management Planning and other on-the-ground decision making processes. It also helps integrate existing initiatives and facilitates coordination across programs, offices, and partnerships. Ecoregional direction establishes a regional roadmap for reviewing and updating Resource Management Plans, developing multi-year projects for identified priority conservation and development areas, establishing Best Management Practices for authorized use, designing regional adaptation and mitigation strategies, and developing conservation land acquisitions.

Ecoregional direction development begins with conversations among regional partners about stepping the REAs down into management. Partners that guide the step-down process will likely include BLM State

Directors (or their representatives) and equivalent peers from other federal, state, and Tribal agencies and entities.
The partners will review the completed REA and other assessments to evaluate proposed findings and recommendations and:

- Delineate a schedule, process and expected products;
- Identify proposed and ongoing activities within the REA region. Such activities may include proposed or on-going assessments, planning efforts, National Environmental Policy Act (NEPA) analyses, or special area evaluations;
- Communicate with organizations knowledgeable about the REA or potentially affected by it; and
- Conduct partnership and stakeholder outreach.

Individual partners will develop their own respective direction to implement the agreements. In the case of the BLM, this will be in the form of ecoregional direction. In developing ecoregional direction, the proposed findings and recommendations will be discussed with:

- The affected BLM's State Management Teams;
- The leadership of local, state, federal and Tribal partners; and
- The Washington Office if there are potential national policy and coordination issues.

After reviewing the proposed findings and recommendations and discussing them with the leadership of potentially affected partners, the BLM State Director(s) may issue ecoregional direction outlining what the BLM will do over the next 3–5 years to incorporate the Rapid Ecoregional Assessments into management activities. If desired, the partners may coordinate the implementation of ecoregional direction among the participating entities.

Monitoring and Adaptive Management

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices. Ecoregional assessments help to move adaptive management from a concept to an applied approach; if rapid ecoregional assessments reoccur every 5 to 10 years as planned, they will serve as a monitoring and evaluation process for the effectiveness of adaptive management. Working with partners, BLM employs a national Assessment, Inventory and Monitoring (AIM) strategy that identifies core indicators of terrestrial and aquatic condition, performance indicators for fish and wildlife action plans, and scalable sampling designs to help integrate and focus BLM's monitoring activities and facilitate adaptive management.

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices.

1.1 References Cited

Johnson, K. N., and M. Herring. 1999. Understanding bioregional assessments. Pages 341–376 *in* Johnson, K. N., F. Swanson, M. Herring, and S. Greene (eds.), Bioregional assessments: Science at the crossroads of management and policy, Island Press, Washington, D.C.

II. INTRODUCTION

2.1 Why Conduct Rapid Ecoregional Assessments?

> The gap between conservation at the species and community level and planning at the landscape level has not been bridged.
>
> — Noss 1987

Rapid Ecological Assessments (REAs) are a product of the Bureau of Land Management's evolution toward a landscape approach to land and resource management. Using the landscape approach, the BLM hopes to integrate available scientific data and information from BLM field offices, other federal and state agencies, and public stakeholders to develop shared responses and collaborative management efforts across administrative boundaries. Another objective of the REAs is to assess the current status of selected ecological resources (conservation elements) at the ecoregional scale and to investigate how this status may change in the future across several time horizons. For these assessments, *status* represents the current condition of the various conservation elements resulting from all stressors and changes imposed on a prior historical condition or benchmark reference condition. The stressors are defined as change agents—natural phenomena or human activities that influence the status of conservation elements. REA results identify areas with high ecological integrity and high biological and ecological value—conservation areas, biological hotspots, and wildlife corridors—to provide a better understanding of key ecosystem processes and the potential impacts of future changes. REAs are timely in supporting planning, management, and mitigation strategies for impacts anticipated from various climate change scenarios as well as rapidly developing issues related to renewable energy development, the spread of invasive species, and changing fire regimes.

The knowledge gained from these assessments will inform future management planning across multiple spatial scales and jurisdictional boundaries. Part of the reason for the continuing decline in many species of concern relates to the scale at which many of our land management practices occur. Because of the pattern of ownerships and administrative districts across a region, management actions directed at any particular issue or species are often implemented in piecemeal fashion. To successfully maintain rangewide species and habitat viability requires managers to coordinate local efforts at a regional scale by practicing cross-jurisdictional planning, involving federal and state management agencies, non-governmental organizations, and citizen working groups. For example, whether a regional species issue is desert bighorn, desert tortoise, sage grouse, or northern spotted owl, pooling information across ownerships is necessary to prioritize resource uses, allow access to species' seasonal habitats and migration corridors, and provide connectivity between productive and less productive populations.

Rapid ecoregional assessments assist regional management by compiling, organizing, and maintaining a comprehensive source of regional datasets and analyses and making them available to land managers and the public to query and reassemble in issue- and project-specific ways. REAs are not meant to allocate resource uses or make management decisions. One of the more important components of the REA process is data compilation in topical areas that are regionally important. REAs, being *rapid* assessments, do not involve original research, but they use existing data, modeling, and GIS analyses to answer a broad range of management questions. The intensive data collection required to conduct an REA reveals knowledge gaps and highlights areas for future ecosystem monitoring and research. REAs also provide a baseline condition from which to evaluate the results of adaptive management and to characterize potential trends in resource condition both in the near-term (2025)—as a consequence of development activities—and in the long-term (2060) as a result of climate change. While REAs are scaled at the ecoregional level, they provide conceptual and geoprocessing models that can be reworked at the state or field office levels using more refined data.

2.2 The Spatial Nature of REAs

2.2.1 Mapping and Modeling

Because an REA is a rapid assessment, not research, the analyses and results are limited by available spatial data. The REA effort provides a baseline of information and results built on spatial data that were publicly available during the 2010–2012 time frame. The intensive collection and organization of spatial data in itself provides value to the BLM to serve as a library or atlas of spatial data for use in future agency investigations. In addition, the use of the spatial information to produce analyses explaining the association of native species, aquatic and terrestrial resources, and environmental change agents across the whole ecoregion provides BLM with another scale of consideration beyond the field office level that will assist in the coordination of regional issues among various BLM Field Offices (and between the BLM and other state and federal agencies dealing with the same issues). Regional-scale information and assessment analyses on current and future condition will be used by the BLM to assist with land use planning, developing best-management practices, authorizing uses, and establishing conservation and restoration priorities.

To digest the vast amount of material produced by the assessment, it is important to become familiar with the spatial analysis and modeling tools that made up the core of the REA. As a starting point, conceptual models were created for each conservation element and change agent (i.e., natural or human-influenced disturbance) to aid in our understanding of complex interactions between each specific subject and the relevant natural drivers and human-induced changes. To assist in the replication of analyses, process analytical models were developed that detail actual mapping and modeling steps. The more complex analyses required logic modeling to help organize and communicate the process and findings. While most analyses were carried out using ArcGIS Model Builder or python scripts, additional specialized software was utilized, including FRAGSTATS (to evaluate habitat fragmentation), MaxEnt (to build probability surfaces), NetCDF Climate Operator software (to manage climate input data), and MAPSS (Mapped Atmosphere-Plant-Soil System to predict vegetation and runoff response to climate variables).

Although the REA focused on the ecoregion extent, data collection had to be conducted within political boundaries, most prominently at the state level. For example, the Sonoran Desert ecoregion included areas inside two different states—California and Arizona. Significant differences existed between the states in what features were routinely mapped, the regularity of mapping techniques used, and attributes assigned to spatial datasets leading to inconsistencies along political boundaries in both geometry and content. For the entire ecoregion, all data collection, analysis, and reporting was conducted within the outer boundary of all 5th level hydrologic units (HUC5s) that intersected the Sonoran Desert ecoregion boundary. This buffer was created to mitigate edge effects during spatial analyses and provide an area of overlap for edge-matching between data layers generated for REAs in neighboring ecoregions. All datasets were projected to USA Contiguous Albers Equal Area projection (USGS version) for mapping and modeling.

Assessments of species status, ecological integrity, and potential for change due to change agents were performed using landscape reporting units. These units provide a uniform framework for summarizing detailed information to a higher level that allows integration across multiple disparate factors. The reporting units used for this REA were 1) a 4 km X 4 km grid for current and near-term status and potential for change of terrestrial conservation elements, terrestrial intactness, long-term climate potential for change, and current, near-term, and long term development change; and 2) 5th level hydrologic units (HUC5s) for ecological integrity and current and near-term status and potential for change of aquatic conservation elements. The 4 km^2 grid was selected as the finest resolution that could be accomplished consistent with the scale of the several hundred datasets, including climate change.

2.2.2 Using Existing Data and Determining Data Gaps

One of the overarching requirements of the REA was to use pre-existing data as inputs to the modeling process. Data acquisition, review, and pre-processing occurred throughout the REA process, even though the original intent of the REA was to identify and evaluate all relevant datasets prior to the onset of modeling. Acquisition of existing datasets presented a number of challenges:

- Existing, centralized, and easily accessible datasets are often older, whereas very recently developed datasets often require significant outreach effort to discover and obtain.
- Datasets actively used for BLM planning often became obsolete as soon as they were acquired (e.g., renewable energy priority projects), necessitating multiple acquisitions over the course of this REA.
- Data developed by BLM field offices were generally not available for this REA, including data recently developed for Resource Management Plans.
- Existing data on particular themes (e.g., wildlife habitat) tend to vary widely in data quality, coverage, accuracy, methodology, thematic resolution, and timeliness across sources, which make it quite difficult to create a seamless dataset across the ecoregion of uniform quality.

For example, although grazing was selected as a change agent in the Sonoran Desert, a lack of consistent data limited assessment products related to grazing. After some discussion, the consensus of Workshop 1 participants was that 1) grazing should be addressed as a change agent that includes all herbivores; 2) grazing data sources should be evaluated; and 3) the Assessment Management Team (AMT) would compile a set of grazing questions. The grazing management questions were added and remained until the end of Pre-assessment Task 3 (March 2011) when the BLM determined that no region-wide, readily available spatial data existed for grazing on federal or private land and that the timeframe of the assessment precluded converting BLM's hard-copy records for their grazing allotments into electronic spatial data. As a result, although grazing remained as a change agent and is included in literature review where applicable throughout the assessment report, the grazing management questions were not specifically addressed and were deferred as a possible post-REA sub-assessment. Lack of consistent, region-wide, quality data affected the REA in this and other resource areas, such as recreation and off highway vehicle (OHV) routes.

Each source dataset went through a thorough eleven point evaluation for data quality: outstanding issues were noted and a decision made on its utility. Many more datasets were pre-screened and evaluated than were actually used in modeling, because it was often necessary to compare several datasets for a particular theme to determine those that were most appropriate for the modeling effort. In total, 169 data layers were used to create final derived results and maps for the Sonoran Desert REA.

Several key data gaps became apparent during this REA:

- High quality, locally-accurate, and seamless data across the entire ecoregion for most themes.
- High quality and uniform wildlife habitat maps across state boundaries for the species evaluated in this REA.
- Current and detailed grazing allotment use and status datasets for federal and private lands.
- Uniform projections of urban growth, change in agriculture area, and potential development of oil, gas, and renewable energy sources.
- Existing assessments of where species have been surveyed for presence/absence.
- Uniformly developed, detailed maps of soil characteristics (datasets exist but are not complete within ecoregion)
- Consistent recreation data, including OHV routes.

- Although the Border Fence and its associated infrastructure and activity create a barrier to ecological connectivity, it was not assessed because of lack of data on the ecoregional effects of the Border Fence on both sides of the international boundary.

The modeling method used to answer conservation element management questions depended on the data available for species occurrence locations and environmental predictors. Because of the short time frame of the REAs and the stipulation to avoid research, existing models were considered most appropriate. Where quality models did not currently exist, various potential methods were proposed for addressing the issue. An order of preference for modeling was agreed on by participants in the REA process to use 1) existing high quality models that cover the full ecoregional extent or that can be readily be extended from a portion of the assessment region to cover the desired areal extent; 2) a modeling approach such as MaxEnt (or related software) if enough occurrence data were available, and 3) southwest regional gap analysis (SW ReGAP) models if both existing models and occurrence data were lacking. Adequate occurrence data for MaxEnt modeling were not available for any species in the Sonoran Desert ecoregion. State wildlife distribution data were generally more detailed than SW ReGAP models, which typically overestimate species distributions; however, in an ecoregion composed of multiple states, edgematching disparate state data at state boundaries was a common problem. Since correcting or updating datasets was beyond the scope of the REA, any gaps in distribution data are reflected in the results. For example, the distributions of the four species of invasive plants selected as change agents in the Sonoran Desert were under-represented in the data, leading to a decision to combine the results for invasive species distributions. Where more detailed state data were not available, or where edgematching issues in data from multiple states could not be resolved, SW ReGAP models were used. With SW ReGAP models, which are typically based on vegetation classes and elevation, distributions for species like mountain lion were generalized to cover a broad area of the ecoregion.

Regional spatial datasets are constantly evolving; rarely is a dataset of proper extent and quality that exactly fits a project's needs available to pluck off the shelf. At various points in the REA process, participants and the BLM in particular were required to make choices and decisions about various data layers—for example, to allow the use of a dataset with limited extent but high value or one of a coarser scale than specified in the Statement of Work. Typically, if a dataset required a significant amount of alteration or correction or if it existed as hard-copy records only, it was excluded from this rapid assessment and treated as a data gap.

2.2.3 Assessing the Present-Projecting the Future

Assessment of the current status and future condition of the ecoregion's natural resources occurs by examining the relationships between a set of *conservation elements* and disturbance factors or *change agents.* Selected core conservation elements may be biotic elements (wildlife and plant species or assemblages) or abiotic factors (e.g., soils, water resources) of regional significance in major ecosystems and habitats of the ecoregion. REAs assess current status—or the existing state resulting from all past changes imposed on the prior historical condition—for each of the conservation elements. Because of the spatial nature of the REAs, describing status for various conservation elements and resource values requires that specific characteristics of that resource can be identified and mapped.

REAs also assess for each conservation element the potential for change from four change agents selected by the BLM: fire, development, invasive species, and climate change. Potential for change predicts how status may change in the future in direction, magnitude, likelihood, and certainty. Assessment output products documenting potential-for-change demonstrate how current evidence of cumulative impacts may be projected into the future to identify potential trade-offs, alternatives, and mitigation strategies for BLM planning purposes. A development-related REA product of interest to BLM is the location of areas with high

potential for renewable energy development—REA results contain current and potential development data layers that were merged with mapped distributions for the various conservation elements to identify the elements that may be affected by various renewable energy development forecasts.

In summary, REAs establish baseline ecological data to gauge the effect and effectiveness of future management actions. In this way, REAs provide a foundation for an adaptive management approach that enables implementation strategies to be adjusted for new information and changing conditions. REAs assess both the current and future scenarios by:

- identifying and answering important regional management questions;
- documenting key resource values, or conservation elements, with a focus on regionally-significant terrestrial habitats, aquatic habitats, and species of concern;
- describing current and projected future influences from four environmental change agents: climate change, wildfire, invasive species, and development;
- identifying and mapping key opportunities for resource conservation, restoration, and development;
- identifying science gaps and data needs; and
- providing a baseline to evaluate and guide future management actions.

The regional scope of the Sonoran Desert REA, its many conservation elements and their interactions with change agents, produced a massive volume of results that can only be summarized within the constraints of a report of reasonable length. The body of this Sonoran Desert REA report contains highlights of major topics and case studies of key individual conservation elements. Appendices provide more detailed information on methods and models and specific results for all conservation elements and change agents.

Access to a data portal to examine the results in greater detail is available at the BLM website: http://www.blm.gov/wo/st/en/prog/more/climatechange.html.

2.3 REA Process and Workflow

An Assessment Management Team (AMT) composed of BLM managers, partner agencies and technical specialists from within the ecoregion monitored the progress of each REA. At the beginning of the REA process, other federal and state agencies were invited as partners to the Assessment Management Team, including representatives of the Western Governors Association and Landscape Conservation Cooperatives. Members of the U.S. Geological Survey were retained as peer reviewers of REA products. The AMT guided the assessment and directed the work of the contractors.

REAs progress in two phases (Figure 2-1). In the first phase, the *pre-assessment*, participants refined the management questions, identified the data available for analysis, and agreed to methods and modeling approaches. The *assessment* phase followed agreement on the formal terms of a workplan; in the assessment phase, the contractors conducted the analyses and prepared the assessment report, maps, and supporting documents. The BLM, recognizing the importance of participation and input from agency partners and stakeholders, planned workshops near the end of each task for an interdisciplinary group to discuss and review the REA products. A peer review panel of USGS scientists monitored and commented on REA products at the completion of each task. For the review, a private group was established on the data portal, Data Basin (Conservation Biology Institute, http://databasin.org/), where analyses and map results were posted weekly over a three month time period. Teams of reviewers viewed maps, component data layers, process models, and attachments, and entered review comments for products within their topical area of expertise. Thus, the REA was monitored and reviewed externally at regular intervals rather than solely at the end of the project, resulting in a product with a high degree of oversight, collaborative input, and consensus.

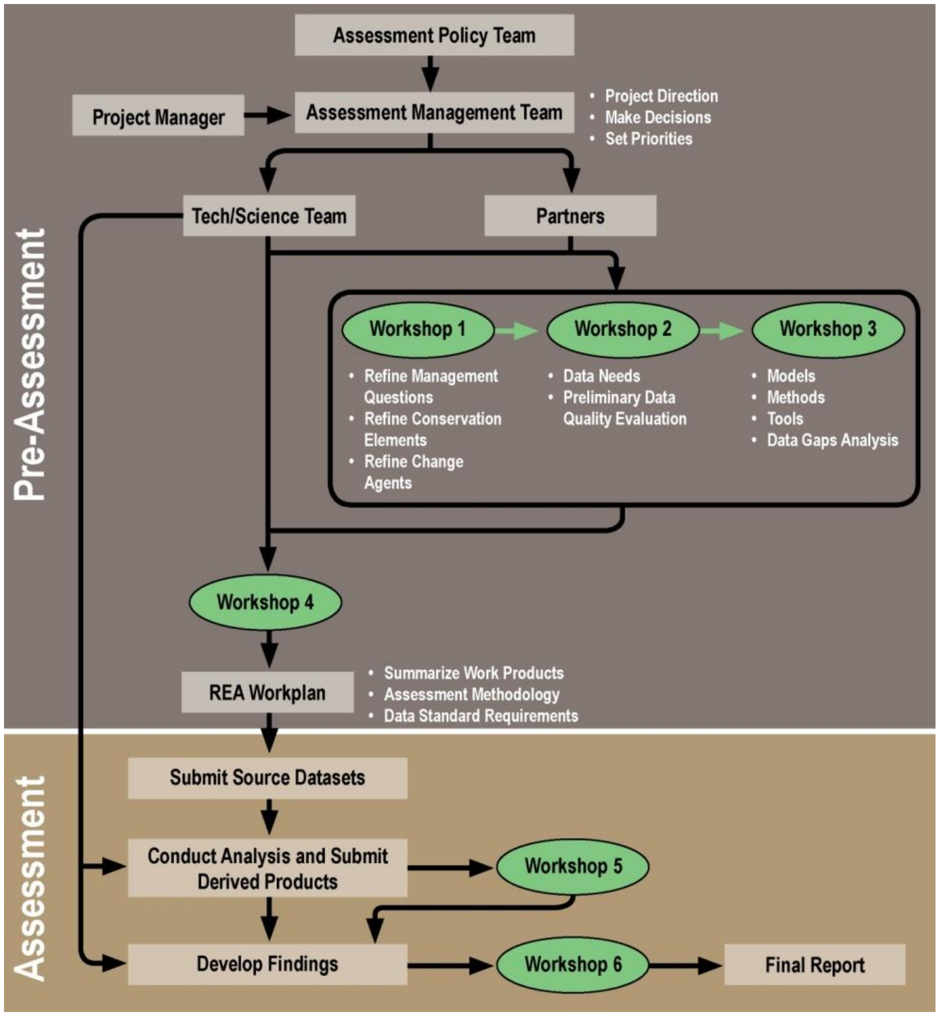


Figure 2-1. REA workflow divided into pre-assessment and assessment phases with regular workshops. Contents of each of the first three workshops listed beneath each workshop symbol in white text. Workshop 4 marked the preparation of a workplan with formal timelines, workflow, and review process. Workshops 5 and 6 provided forums for presenting analyses and products described in the final report.

2.4 REA Elements

2.4.1 Management Questions

BLM land managers provided a broad range of management questions to the REA to frame regional issues and data needs for land use planning, refining best management practices, and setting priorities for conservation, development, and restoration. Management questions are the foundation and catalyst for the REAs in that they determine the scope of data requirements and analyses. The management questions developed for each ecoregion match the scale of the assessment because the issues captured by the questions are considered regionally significant. The management questions prepared for the Sonoran Desert REA refer to native and invasive flora and fauna, significant sites and ecological functions and services, and disturbance factors or change agents that affect present and future resource status.

Throughout the Pre-Assessment phase, BLM staff, REA contractors, and workshop participants weighed the time and resource requirements needed to address the full complement of management questions in the short time frame of the REA and in a manner that would have utility for BLM for future planning purposes. All participants suggested revisions, clarifications, and additions to the core list of management questions. USGS peer reviewers evaluated the questions with reference to the clarity of the language and the availability of data required to answer them. After the evaluation, 32 management questions remained in 10 topical classes (e.g., wildlife, invasive species, wildfire, and development) for the Sonoran Desert REA (Table 2-1).

Table 2-1. Final AMT-Approved Sonoran Desert REA Management Questions. There are 32 management questions; labels out of order indicate deletion of various questions from redundancy or lack of adequate data. A number of management questions are addressed in the body of the report; they are repeated along with remaining management questions and their results in Appendix A.

A. SOILS, BIOLOGICAL CRUSTS, AND FORAGE MANAGEMENT

MQ A1. Where are soils susceptible to wind and water erosion?

MQ A2. Where are sensitive soils (including saline, sodic, gypsiferous, shallow, and low water holding capacity) and highly productive (higher clay content, hydric) soils?

MQ A3. Which HMAs and allotments may experience significant effects from change agents, including climate change?

B. SURFACE AND GROUNDWATER MANAGEMENT QUESTIONS

MQ B1. Where are lotic and lentic surface waterbodies and livestock and wildlife watering tanks and artificial water bodies?

MQ B2. Where are perennial streams and stream reaches?

MQ B3. Where are the alluvial aquifers and their recharge areas (if known)?

MQ B4. Where are aquatic systems listed on 303d with degraded water quality or low macroinvertebrate diversity?

MQ B6. What is the location/distribution of these aquatic biodiversity sites?

MQ B7. What are the seasonal maxima and minima discharges for the Colorado River and major tributaries at gaging stations?

C. ECOLOGICAL SYSTEMS MANAGEMENT QUESTIONS

MQ C1. Where are existing vegetative communities?

MQ C2. Where are vegetative communities likeliest to be vulnerable to change agents in the future?

MQ C3. What change agents have affected existing vegetation communities?

D. SPECIES CONSERVATION ELEMENT MANAGEMENT QUESTIONS

MQ D1. What is the most current distribution of available occupied habitat (and historic occupied habitat if available), including breeding, seasonal habitat, and movement corridors and bottlenecks (as applicable)?

MQ D4. Where are potential areas to restore connectivity?

MQ D5. What is the location/distribution of terrestrial biodiversity sites?

MQ D6. What aquatic and terrestrial species CEs and high biodiversity sites and movement corridors are vulnerable to change agents in the near term horizon, 2025 (development, fire, invasive species) and a long-term change horizon, 2060 (climate change)? Where are these species and sites located?

MQ D8. Where are HMAs located?

E. WILDFIRE MANAGEMENT QUESTIONS

MQ E1. Where are the areas that have been changed by wildfire between 1999 and 2009?

MQ E2. Where are the areas with potential to change from wildfire?

MQ E3. Where are fire-adapted communities?

F. INVASIVE SPECIES MANAGEMENT QUESTIONS

MQ F1. Where are tamarisk, buffelgrass, red brome, Sahara mustard, quagga and zebra mussel, and Asiatic clam present?

MQ F2. Where are the areas of potential future encroachment from this invasive species?

G. FUTURE DEVELOPMENT MANAGEMENT QUESTIONS

MQ G1. Where are current locations of these development types?

MQ G2. Where are areas of planned development (e.g., plans of operation, urban growth, transmission corridors, governmental planning)?

MQ G3. Where are areas of potential development (e.g., under lease), including renewable energy sites and transmission corridors and where are potential conflicts with CEs?

H. RESOURCE USE MANAGEMENT QUESTIONS

MQ H1. Where are high-use recreation sites, developments, roads, infrastructure or areas of intensive recreation use located (including boating)?

MQ H2. Where are areas of concentrated recreation travel (OHV and other travel) located?

MQ H3. Where are allotments and type of allotment?

I. AIR QUALITY MANAGEMENT QUESTIONS

MQ I3. Where are Class I PSD areas?

J. CLIMATE CHANGE MANAGEMENT QUESTIONS

MQ J1. Where/how will the distribution of dominant native plant and invasive species be vulnerable to or have potential to change from climate change in 2060?

MQ J2. Where are areas of species (conservation elements) distribution change between 2010 and 2060?

MQ J3. Where are aquatic/riparian areas with potential to change from climate change?

Although the management questions selected for the REAs were regionally significant, there were times when the scale of the data available to answer the questions did not match the scale of the questions. That is, the management questions were conceived by BLM managers, but field office data were not available to the REA effort, which was limited to publicly-available data with national data standards. Often, publicly-available data gathered at the state or ecoregional scale did not match the detail necessary to answer some of the management questions. In many cases, data of the proper extent and detail to address the wildlife species and management issues found in Resource Management Plans at the field office level were not available at all. Although this was a limitation, it was also a revelation in that it revealed the limitations and gaps in the myriad data sources available to a project of this kind.

2.4.2 Conservation Elements

Coarse Filter Elements. The BLM planned that condition assessments within the REA framework follow a coarse-filter/fine-filter approach. A coarse filter approach employs elements such as vegetation communities,

ecosystems, or land classes for planning and management across landscape- and regional-level management units (Noss 1987, Haufler et al. 1996, Desmet and Cowling 2004). Vegetation communities compose the habitat that supports the region's wildlife species. An assumption of the coarse filter approach is that blocks of naturally functioning communities will protect a diverse collection of flora and fauna. Within this paradigm, a top-down or "umbrella" approach is considered a more realistic and economical management system than one that attempts to address a host of species individually. The Nature Conservancy planned that its state-by-state coarse filter heritage network would preserve 85–90% of a state's species (Noss 1987). Noss (1987) noted, however, that coarse filter frameworks are typically based on dominance or homogeneity and that an optimal coarse filter would also incorporate food webs, species seasonal use, disturbance regimes, and hydrology. The REAs included some of these additional elements, such as seasonal use and disturbance regimes (e.g., for fire), where spatial information was available.

Table 2-2. ECOLOGICAL SYSTEMS	**% OF ECOREGION**
Sonoran-Mojave Creosotebush-White Bursage Desert Scrub	42.4%
Sonoran Paloverde-Mixed Cacti Desert Scrub	33.5%
TOTAL AREA	75.9%

Characteristic vegetation communities of the Sonoran Desert, specifically the vegetation types (Ecological Systems, Table 2-2) defined in the Southwest Regional GAP Analysis Project (SWReGAP, Prior-Magee et al. 2007), represented the coarse-filter component of the REA. The two major vegetation communities selected as coarse-filter conservation elements, the Sonoran-Mojave Creosotebush White Bursage Desert Scrub and the Sonoran Palo Verde-Mixed Cacti Desert Scrub, together cover 76% of the land area of the Sonoran Desert ecoregion. Vegetation-related management questions and mapped results for the two major communities addressed their current distribution, the effects of change agents on particular vegetation types, and areas where communities may be vulnerable to change agents in the future.

Although the coarse filter-fine filter approaches are meant to be complementary, limitations in species distribution datasets often force the use of coarse-filter surrogates to assess condition (Desmet and Cowling 2004). Because vegetative cover provides wildlife habitat, it can serve as a surrogate to estimate the status of species that are dependent on those habitats. As stated previously, status is the current condition of various conservation elements resulting from all stressors and changes imposed on a prior historical condition or benchmark reference condition. To express present status in terms of a gradient of condition requires describing how far a conservation element has departed from a model of its minimally-disturbed reference condition and thus from a state of ecological or biological integrity (Frey 1977, Karr and Dudley 1981). Since spatial information for the presettlement distribution and abundances of various wildlife species is lacking, coarse filter vegetation communities must be used instead to estimate changes over time. However, using vegetation communities to estimate historical reference condition requires a spatial dataset that is continuous across the entire ecoregion. While current vegetation conditions can be expressed using either the NatureServe national landcover dataset (version 2.7, 2009) or the LANDFIRE Existing Vegetation Type data (EVT; revised 2011, www.landfire.gov), the only dataset that maps (or models) reference condition over the entire region is the LANDFIRE Biophysical Settings (BpS) dataset. LANDFIRE BpS models the vegetation communities that may have been dominant on the landscape prior to Euro-American settlement. All vegetation communities are mapped using a combination of vegetation plot data, biophysical gradients, and vegetation dynamics models, which describe the primary succession classes (e.g., post-fire vegetation, old growth forest) and their state-transition probabilities, including rates of fire that would most likely have occurred under pre-settlement conditions.

The current distribution of existing vegetation communities was presented using both the NatureServe National Landcover and LANDFIRE existing vegetation (EVT) datasets because REA participants had definite

preferences for one dataset or the other. However, to show change over time, LANDFIRE BpS was used for historic reference condition to compare with LANDFIRE EVT ("apples to apples"), an approach that minimized errors of comparison since both products were produced using similar input data and methods.

Fine Filter Elements The fine filter approach is meant to complement the coarse filter by targeting species with requirements that will not be met through the broad brush of dominant vegetation communities—rare, threatened or endangered species, wildlife species of management interest, or those species that consistently use ecotones or multiple habitats on a diurnal or seasonal basis. Two variants of the fine filter approach are the focal species and landscape species approaches. Under the focal species approach, species are grouped according to susceptibility to regional threats or disturbances and the species with the highest sensitivity needing the most comprehensive management response is selected for each threat category; the rationale for species selection is that if the most sensitive species' requirements are met, then so will the needs of the full complement of species dependent on the ecosystem in question (Lambeck 1997, Noss et al. 1999, Hess and King 2002).

Table 2-3. WILDLIFE SPECIES CONSERVATION ELEMENTS

Mountain lion (*Puma concolor*)
Mule deer (*Odocoileus hemionus*)
Desert bighorn sheep (*Ovis canadensis nelson*i)
Golden eagle (*Aquila chrysaetos*)
Lucy's warbler (*Oreothlypis luciae*)
Southwestern willow flycatcher (*Empidonax traillii extimus*)
Le Conte's thrasher (*Toxostoma lecontei*)
Bell's vireo (*Vireo bellii*)
Lowland leopard frog (*Lithobates yavapaiensis*)
Mojave desert tortoise (*Gopherus agassizii*)
Sonoran desert tortoise (*Gopherus morafkai*)

Landscape species, on the other hand, are chosen according to a scoring system that incorporates multiple criteria (Sanderson et al. 2002, Coppolillo et al. 2004). The BLM suggested that the landscape species approach of Coppolillo et al. (2004) be used for landscape species selection for the Sonoran Desert REA. Using this approach, species are selected that capture a range of important attributes characterizing their environment, such as heterogeneity in habitat use, large home range area, vulnerability to anthropogenic disturbance, functional contributions to the ecological system, and relative socio-economic importance (Coppolillo et al. 2004). Species are ranked by aggregate scores for each of these attributes and selected based on the highest aggregate score and minimum overlap in the major vegetation communities (Ecological Systems) used, until all Ecological Systems are accounted for. A cross check is then made to ensure that all change agent threats are accounted for as well. A set of 25–30 species from the State Wildlife Action Plan lists were selected and scored in addition to the core species identified by the BLM. The screening process resulted in ten wildlife species with the highest scores representing the minimum overlap in habitats. Those species identified by the BLM that were of management interest but did not score high enough to make it on the final landscape species list were retained and included in the assessment (Table 2-3).

The Statement of Work requested an objective screening process to select wildlife species conservation elements, or landscape species. It was also apparent that to provide the best representation of status and condition at the ecoregional level with respect to habitat alteration, displacement, and human stressors, it was important to select species that were vulnerable to the selected change agents. Thus, although the group at Workshop 1 agreed to a species selection process based on Coppolillo et al. (2004) that produced an initial list of landscape species, REA participants continued to suggest additional wildlife species of unrepresented taxa or habitats throughout Tasks 1, 2, and 3 of the pre-assessment phase.

In addition to the list of wildlife landscape species, the selection of fine filter elements also included 1) special status plant or animal species (sensitive, threatened and endangered) enumerated by 5th level hydrologic unit and mapped as species richness or species diversity hotspots and 2) a range of terrestrial and aquatic sites of conservation concern (Table 2-4) and ecological functions and services (Table 2-5).

The terrestrial and aquatic sites of conservation concern range from Nature Conservancy portfolio sites, National Parks, Wildlife Refuges, National Conservation Areas, and wilderness areas, all of which have various levels of protection (Table 2-4). Both current and future threats were assessed for these sites. Mapping the sites with surrounding ownership status will provide opportunities for interagency cooperation in management. Some of these sites may lose the function or features for which they were designated as a result of interactions among climate change and other change agents such as fire and invasive species. Are there cross-jurisdictional opportunities to create an additional buffer of protection around sites of conservation concern? Establish corridors between sites? Plan for future refugia from climate change? Are diverse ecosystems at all elevations well-represented? These questions can be addressed by the BLM through ecoregional direction (see Chapter 1).

Table 2-4. SITES OF CONSERVATION CONCERN

Terrestrial Sites

- TNC portfolio sites
- Important bird areas (Audubon)
- Historic and Nationally Designated Trails
- Wilderness Areas
- Wilderness Study Areas
- Historic Districts
- National Wildlife Refuges
- Monuments
- National and State Parks
- National Conservation Areas
- BLM Areas of Critical Environmental Concern
- Forest Service Research Natural Areas
- State Wildlife Management Areas
- Wild and Scenic Rivers
- Designated Recreation Management Areas

Aquatic Sites

- TNC portfolio sites

The list of ecological functions and services focuses on aquatic features such as springs, seeps, and riparian areas, recognizing the importance of water availability in an arid environment (Table 2-5); REA participants added the terrestrial function of soil stability to the list of ecosystem functions and services.

Table 2-5. ECOSYSTEM FUNCTIONS AND SERVICES

Terrestrial Functions of High Ecological Value:

- Soil stability

Surface and Subsurface Water Availability:

- Aquatic systems (streams, lakes, ponds)
- Springs/seeps/wetlands
- Riparian areas
- High quality and impaired waters
- Groundwater aquifers

2.4.3 Change Agents

An assessment of the status of conservation elements must be conducted with reference to both natural and anthropogenic disturbance factors. The status or condition of various conservation elements cannot be discussed without examining the risks that these resources experience from a collection of regional disturbances or change agents. Human disturbances represent the change agents of interest in the REA process (Table 2-6). Although the same change agent may threaten one organism and benefit another, the change agents selected for the REAs typically affect habitat negatively and degrade the productivity and sustainability of the selected conservation elements

Many effects of change agents are directly apparent, representing changes in land use during development, agriculture, resource extraction, such as logging and mining, and energy development. While normally not as destructive as urbanization, various forms of recreation are expanding throughout the region each with a unique set of impacts, from increased hiking and mountain biking to OHV use, which can result in habitat fragmentation, connectivity loss, soil erosion, and wildlife disturbance (Papouchis et al. 2001, Belnap 1995, Brooks and Lair 2005, Ouren et al. 2007).

Other effects are more diffuse, such as the changes in plant species dominance created by prolonged grazing (Belsky and Gelbard 2000, Krueper et al. 2003, Miller et al. 2011), or the synergy of livestock grazing, invasive species introduction, and fire (D'Antonio and Vitousek 1992, Brooks and Pyke 2001, Brooks et al. 2004). Fire, while it is a natural disturbance agent, when it deviates from expected frequencies, it can be considered a form of anthropogenic change agent. Fire often deviates from its characteristic regime, through fire suppression, increased ignition frequencies, and changes in characteristic fuels and fuel loads (D'Antonio and Vitousek 1992, Brooks and Pyke 2001, Keane et al. 2002, Brooks et al. 2004). Perhaps the most overarching and profound change agent of all is climate change. As indicated by recent evidence and robust predictive models, climate change has the potential to change the landscape over the near term (i.e. 50 years) in fundamental ways with tremendous direct impacts on natural systems while exacerbating many effects of the other change agents. For example, climate change influences fire regimes, alters invasive plant species competition, affects hydrologic regimes and water yields, and changes basic soil properties (Seager et al. 2007, Munson et al. 2012).

Table 2-6. CHANGE AGENTS

- Wildland Fire
- Invasive Species
- Land and Resource Use (Development)
    - Urban and Roads Development
    - Oil, Gas, and Mining Development
    - Renewable Energy Development (i.e., solar, wind, geothermal, including transmission corridors)
    - Agriculture
    - Grazing: Livestock, wild horse and burro, wildlife
    - Groundwater and Surface Water Extraction, Development, and Transportation
    - Recreational Uses
    - Pollution (Air Quality)
- Climate change

2.4.4 Index of Ecological Integrity

The concept of ecological integrity is complex and a great deal has been written about it in the literature (Angermeier and Karr 1994, Pimentel et al. 2000). Other terms often used interchangeably with integrity include ecosystem health, resilience, resistance, and stability. In almost all treatments of ecological integrity, the focus has been on the 'ecosystem' not specific species or communities. As Karr and Dudley (1981) described it—ecological integrity is the sum of all physical, chemical, and biological integrity. Karr and Chu (1995) later defined integrity as, "the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, metapopulation processes) expected in the natural habitat of a region." More simply stated ecological integrity is the degree to which all ecosystem components and their interactions are represented and functioning.

A number of strategies have been devised to conduct assessments of ecological condition, from data-driven indices of biological integrity or IBIs, to more qualitative, conservation guidance approaches such as those discussed by Parrish et al. (2003) and Unnasch et al. (2008). Approaches such as these differ in rigor and defensibility, and they also differ in terms of their potential application in products such as Rapid Ecoregional Assessments. Indices of biotic integrity (IBIs), as developed over the last 3 decades for aquatic ecosystems, use systematically-collected species abundance data to develop metrics representing taxonomic richness, trophic categories, or sensitivity to disturbance. Candidate metrics are screened for responsiveness to disturbance, low variability, and lack of redundancy (Hughes et al. 1998, Mebane et al. 2003, Whittier et al. 2007). Metric values at minimally- or least-disturbed sites serve as a reference model against which to

compare indicator metric values at disturbed sites (Hughes et al. 1986, Hughes 1995, Whittier et al. 2007). Few indices of *terrestrial* ecological integrity have been developed using the approach described above. Development of terrestrial integrity indices present even greater challenges than aquatic indices of biointegrity, and terrestrial applications of indices of biotic integrity are limited in the scientific literature (O'Connell et al. 1998, Bradford et al. 1998, Bryce et al. 2002, Bryce 2006, Mattson and Angermeier 2007).

The development of data-driven indicators of ecological integrity is beyond the scope of the REA process because it would require a major research effort. REAs are defined in the Statement of Work as "assessments only, evaluating status and potential changes in status for selected core conservation elements." Thus, the approach to regional ecological integrity within the REAs represents an early iteration of a process that will continue to evolve. Concurrently with these first REAs, BLM and agency partners have considered various more qualitative approaches to characterize landscape-level ecological integrity or condition based on existing geospatial data.

For this REA, the group agreed to emphasize the mapping of ecological condition by focusing on intactness, an attribute that could be defensibly supported by existing geospatial datasets and reasonably tracked through time. No place on Earth remains unaffected by modern humans (Vitousek et al. 1997), but some regions have been more directly and severely affected than others. Natural landscapes lose components and functionality as human uses expand and continue over time. Some ecosystem changes can be quite gradual (e.g., loss of interior forest habitat over time), while others are punctuated (e.g., loss of a keystone species). Intactness is not a binary (yes/no) quality, but one of degree: a continuum of intactness from a pristine environment on one end to a totally developed environment on the other. Quantifiable and replicable indices and scales of measurement are needed to score landscapes on this continuum. Although significant progress is being made (Anderson 1991, Angermeier 2000), this area of applied research remains quite young. Nevertheless, although ranking natural landscapes by relative intactness may be imperfect, it need not be arbitrary.

> Intactness is a quantifiable estimate of naturalness according to the level of anthropogenic influence based on available spatial data.

The origin of the intactness concept can be traced to the concept of naturalness. Machado (2004) provides a thorough review of the history and use of the term "naturalness" and how it has been applied to conservation planning throughout the world. There has been a mostly philosophical and semantic debate regarding the concept of naturalness as it pertains to a conservation value. Less confusion and debate has been levied against the concept as it applies to its use as a parameter or state descriptor of ecosystems (Grumbine 1994) although there are many different ways it has been studied and applied (Machado 2004). The term "landscape intactness", which is used as a quantifiable state descriptor, has been largely applied to forested landscapes (Lee et al. 2002, Heilman et al. 2002, Strittholt et al. 2006, Potapov et al. 2008), but many of the same principles apply to any natural landscape. The state (or condition) of the natural ecosystem may be viewed and quantified as the ecological stage upon which the actors (species) and the play itself (ecological processes) are carried out over time. Intactness is a quantifiable estimate of naturalness according to the level of anthropogenic influence based on available spatial data. Intactness considers an assemblage of spatially explicit indicators that helps define the condition of the natural landscape. Different species may possess different tolerances to these conditions, but natural assemblages of species and natural patterns and processes are increasingly compromised as human influences intensify. For this REA, terrestrial and aquatic intactness models were created for the entire ecoregion (see Methods, Chapter 3) and served as the foundation against which conservation element status was assessed based on current condition as well as future projections.

Presence or absence of particular species, species richness, or species rarity did not factor into any metric of integrity. First and foremost, high species richness or concentration of rare or endemic species is not indicative of high ecological integrity. Areas with high species endemism or high species richness may be important from a conservation or management perspective, but regions with these species are not necessarily better from an ecological integrity perspective. Species do not naturally arrange themselves equally across the landscape even under pristine conditions. Natural concentrations of species are driven by many factors. For example, vertebrate species richness is often higher at middle elevations (McCain 2003, McCain 2007) or in warmer river and stream systems (Mebane et al. 2003, Hughes et al. 2004). Species numbers typically increase with moderate disturbance (Odum et al. 1979, Odum 1985). Ecosystem condition can sometimes even decline as species diversity (even native species diversity) increases (Scott and Helfman 2001). Areas with high species endemism or high species richness should be evaluated separately from ecological condition or integrity; maps of species hotspots were requested in the REA Statement of Work and they are presented and evaluated separately in Chapter 6. The BLM acquired richness-function data from NatureServe that enumerates and displays G1–G3 species and threatened and endangered species by 5th level HUC for the Sonoran Desert. In Chapter 6, this heritage data for species hotspots is combined with mapped concentrations of conservation elements in an example of step-down planning for species of concern.

2.5 REA Assumptions and Limitations

As previously stated, the REA was not intended to be a research project; however, at numerous times throughout the project, that is what was needed in order to generate a useful assessment. There was inadequate time and funding to allow full development of every topic identified by the assessment team or outside reviewers, however, some major areas were explored that could be classified as work beyond what was required. Of all the issues and management questions addressed, significant research time was dedicated to the following topics that enhanced the utility of the results:

- using logic models to help aggregate and synthesize large concepts using numerous, disparate data inputs
- refining the concept of intactness and how it could be used to assess current and future status in a repeatable and scientifically defensible fashion
- instituting the 4km resolution as one of the primary reporting units
- including natural habitat fragmentation as an important metric for assessing intactness
- modification and improvement of fire modeling
- utilization of both LANDFIRE EVT v 1.1 and NatureServe Landcover v 27 in the assessment
- integration of STATSGO and SURRGO soils data in assessing a variety of soils management questions
- inclusion of MAPSS in the climate change component of the project to extend our understanding of vegetation responses to predicted changes in temperature and precipitation
- inclusion of seasonality in climate change projections

The REA was also not a specific planning exercise, which typically requires higher levels of project definition with measurable goals and objectives against which a rigorous analytical treatment is devised and carried out. The REA took on a much broader approach focusing more on how many topics could be addressed at once rather than an in-depth exploration of a smaller subset of the issues. It was the intent of the BLM to use the REA to obtain a regional context with analyses that would help them later prioritize or focus on particular areas of need or special interest in a series of step-down efforts.

With any spatial analysis, especially for a large geographic area such as an ecoregion, there are many limitations and assumptions. The most fundamental limitation for these types of assessments is the availability and quality of the spatial data. Even after exhaustive searches and time-intensive data compilations, acquiring and assembling useful spatial datasets to address specific issues or management questions often proved challenging. The inability to acquire datasets such as specific point locations for species, OHV tracks, recreation areas, and grazing history and current intensity either limited our ability to address specific questions or prevented us from meaningfully addressing them at all.

For most issues, the scale/resolution of acquired datasets allowed for a reliable coarse level assessment, but the datasets were generally insufficient to allow for site-specific management applications (e.g. restoration of invasive grass patches). However, for the purposes of a regional ecoregional assessment, the datasets assembled and analyzed resulted in very useful contextual information on top of which local analyses and management prescriptions could be explored and implemented.

Spatial data accuracy (geometry and attribution) was highly variable for different themes and often between subregions (e.g. states) for the same theme. Even for the most authoritative datasets, errors are commonplace. For example, the National Hydrography Dataset stream flow status attribute currently has a high rate of error in arid ecoregions. In a recent stream survey (2000–2004) conducted by the Environmental Protection Agency (Stoddard et al. 2005), many streams identified as perennial were in fact not perennial when visited in the field. Both LANDFIRE EVT v1.1 and NatureServe Landcover v2.7 are recognized as authoritative, yet significant differences occur between them. In reality, they both possess errors, meaning that more detailed vegetation data are needed to carry out site-specific planning and management.

With data inputs of variable quality, analyzing complex ecological systems, and trying to forecast into the future, the spatial modeling conducted possesses a fairly high degree of uncertainty. The original plan was to produce an accompanying map with each result to help the user identify places on the map with varying levels of uncertainty. This proved to be too difficult and time-consuming to include with each of the hundreds of REA results. The chapter on climate change modeling does have an uncertainty section and Appendix E provides detailed tabular assessments of the uncertainties associated with source datasets and model results that give each a confidence rating based on expert judgment and project experience.

Throughout the project, the data portal Data Basin (www.databasin.org) was used to solicit regular feedback from outside reviewers on the data inputs, analytical approaches conducted, and final results through a private working group created in the online system. Customized commenting tools helped reviewers pose spatially explicit or general comments and questions. Having all of the spatial datasets and attached processing models and notes easily available via the Internet, Data Basin enhanced numerous webinars for subsets of reviewers to explore specific topical areas or problem areas. Although generating batches of mapped results on a regular schedule for posting on Data Basin created more work than the original scope of work outlined, Data Basin proved to be an extremely valuable tool for managing the review process, improving the assessment in numerous ways through an improved suite of products and better overall understanding.

2.6 References Cited

Anderson, J.E. 1991. A conceptual framework for evaluating and quantifying naturalness. *Conservation Biology* 5(3):347–352.

Angermeier, P.L. 2000. The natural imperative for biological conservation. *Conservation Biology* 14(2):373–381.

Angermeier, P.L., and J.R. Karr. 1994. Biological integrity versus biological diversity as policy directives: Protecting biotic resources. *BioScience* 44(10):690–697.

Belnap, J. 1995. Surface disturbances: Their role in accelerating desertification. *Environmental Monitoring and Assessment* 37:39–57.

Belsky, A.J., and J.L. Gelbard. 2000. Livestock grazing and weed invasions in the arid west. Oregon Natural Desert Association. Bend, Oregon.

Bradford, D.F., S.E. Franson, A.C. Neale, D.T. Heggem, G.R. Miller, and G.E.Canterbury. 1998. Bird species assemblages as indicators of biological integrity in Great Basin rangeland. *Environmental Monitoring and Assessment* 49:1–22.

Brooks, M.L., C.M. D'Antonio, D.M. Richarson, J.B. Grace, J.E. Keeley, J.M. DiTomaso, R.J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54(7):677–688.

Brooks, M.L., and B. Lair. 2005. Ecological effects of vehicular routes in a desert ecosystem. Report prepared for the United States Geological Survey, Recoverability and Vunerabilty of Desert Ecosystems Program, U.S. Geological Survey, Las Vegas, Nevada. 23 pp.

Brooks, M.L., and D.A. Pyke. 2001. Invasive plants and fire in the deserts of North America. Pages 1–14 *in* Galley, K.E.M. and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, Florida.

Bryce, S.A. 2006. Development of a bird integrity index: Measuring avian response to disturbance in the Blue Mountains of Oregon, USA. *Environmental Management* 38(3):470–486.

Bryce, S.A., R.M. Hughes, and P.R. Kaufmann. 2002. Development of a bird integrity index: Using bird assemblages as indicators of riparian condition. *Environmental Management* 30(2):294–310.

Coppolillo, P., H. Gomez, F. Maisels, and R. Wallace. 2004. Selection criteria for suites of landscape species as a basis for site-based conservation. *Biological Conservation* 115: 419–430.

D'Antonio, C.M., and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics* 23:63–87.

Desmet, P., and R. Cowling. 2004. Using the species–area relationship to set baseline targets for conservation. *Ecology and Society* 9(2): 11. http://www.ecologyandsociety.org/vol9/iss2/art11

Frey, D. 1977. Biological integrity of water: An historical approach. Pages 127–140 *in* Ballentine, R.K., and L.J. Guarraia (eds.), The integrity of water: Proceedings of a symposium, March 10–12, 1975, U.S. Environmental Protection Agency, Washington, D.C.

Grumbine, R.E. 1994. What is ecosystem management? *Conservation Biology* 8:27–38.

Haufler, J.B., C.A. Mehl, and G.J. Roloff. 1996. Using a coarse-filter approach with species assessment for ecosystem management. *Wildlife Society Bulletin* 24(2):200–208.

Heilman, G.E., J.R. Strittholt, N.C. Slosser, and D.A. DellaSala. 2002. Forest fragmentation of the conterminous United States: Assessing forest intactness through road density and spatial characteristics. *Bioscience* 52(5): 411–422.

Hess, G.R., and T.J. King. 2002. Planning open spaces for wildlife: Selecting focal species using a Delphi survey approach. *Landscape and Urban Planning* 58(1):25–40.

Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. Pages 31–47 *in* W.S. Davis and T.P. Simon (eds.), Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers, Boca Raton, Florida.

Hughes, R.M., S. Howlin, and P.R. Kaufmann. 2004. A biointegrity index (IBI) for coldwater streams of western Oregon and Washington. *Transactions of the American Fisheries Society* 133:1497–1515.

Hughes, R.M., P.R. Kaufmann, A.T. Herlihy, T.M. Kincaid, L. Reynolds, and D.P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1618–1631.

Hughes, R.M., D.P. Larsen, and J.M. Omernik. 1986. Regional reference sites: A method for assessing stream potentials. *Environmental Management* 10(5):629–635.

Karr, J.R., and D.R. Dudley. 1981. Ecological perspective on water quality goals. *Environmental Management* 5:55–68.

Karr, J.R., and E.W. Chu. 1995. Ecological integrity: Reclaiming lost connections. Pages 34–48 *in* L. Westra and J. Lemons (eds.), Perspectives in Ecological Integrity, Kluwer Academic, Dordrecht, Netherlands.

Keane, RE, T. Veblen, K.C. Ryan, J. Logan, C. Allen, and B. Hawkes. 2002. The cascading effects of fire exclusion in the Rocky Mountains. Pages 133–153 *in* Rocky Mountain futures: An ecological perspective, Island Press, Washington, DC.

Krueper, D. J. Bart, and T.D. Rich. 2003. Response of vegetation and breeding birds to the removal of cattle on the San Pedro River, Arizona, USA. *Conservation Biology* 17(2): 607–615.

Lambeck, R.J. 1997. Focal species: A multi-species umbrella for nature conservation. *Conservation Biology* 11(4):849–856.

Lee, P., D. Aksenov, L. Laestadius, R. Nogueron, and W. Smith. 2002. Canada's large intact forest landscapes. Global Forest Watch Canada, Edmonton, Canada. http://www.globalforestwatch.org/english/canada/pdf/Canada_LIFL-Text_Section.pdf

Machado, A. 2004. An index of naturalness. *Journal of Nature Conservation* 12(2004):95–110.

Mattson, K.M., and P. L. Angermeier. 2007. Integrating human impacts and ecological integrity into a risk-based protocol for conservation planning. *Environmental Management* 39:125–138.

McCain, C.M. 2003. North American desert rodents: A test of the mid-domain effect in species richness. *Journal of Mammology* 84:967–980.

McCain, C.M. 2007. Could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and Biogeography* 16:1–13.

Mebane, C.A., T.R. Maret, and R.M. Hughes. 2003. An index of biological integrity (IBI) for Pacific Northwest rivers. *Transactions of the American Fisheries Society* 132:239–261.

Miller, M.E., R.T. Belote, M.A. Bowker, and S.L. Garman. 2011. Alternative states of a semiarid grassland ecosystem: Implications for ecosystem services. *Ecosphere* 2(5):art55. doi:10.1890/ES11-00027.1

Munson, S.M., R.H. Webb, J. Belnap, J.A. Hubbard, D.E. Swann, and S. Rutman. 2012. Forecasting climate change impacts to plant community composition in the Sonoran Desert region. *Global Change Biology* 18:1083–1095.

Noss, R.F. 1987. From plant communities to landscapes in conservation inventories: A look at The Nature Conservancy (USA). *Biological Conservation* 41:11–37.

Noss, R.F., J. Strittholt, K. Vance-Borland, C. Carroll, and P. Frost. 1999. Conservation plan for the Klamath-Siskiyou ecoregion. *Natural Areas Journal* 19(4):392–411.

O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 1998. A bird community index of biotic integrity for the mid-Atlantic highlands. *Environmental Monitoring and Assessment* 51(1-2):145–156.

Odum, E.P., J.T. Finn, and E.J. Franz. 1979. Perturbation theory and the subsidy-stress gradient. *BioScience* 29(6):349–352.

Odum, E.P. 1985. Trends expected in stressed ecosystems. *BioScience* 35(7):419–422.

Ouren, D.S., C. Haas, C.P. Melcher, S.C. Stewart, P.D. Ponds, N.R. Sexton, L. Burris, T. Fancher, and Z. Bowen. 2007. Environmental effects of off-highway vehicles on Bureau of Land Management lands: A literature synthesis, annotated bibliographies, extensive bibliographies, and internet resources. U.S. Geological Survey, Open-File Report 2007-1353, U.S. Geological Survey, Reston, Virginia. 225 p.

Papouchis, C.M., F.J. Singer, and W.B. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. *Journal of Wildlife Management* 65(3):573–582.

Parrish, J.E., D.P. Braun, and R.S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. *BioScience* 53:851–860.

Pimentel, D., Lach, L., Zuniga, R. & Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. *Bioscience* 50(1):53–65.

Potapov P., A. Yaroshenko, S. Turubanova, M. Dubinin, L. Laestadius, C. Thies, D. Aksenov, A. Egorov, Y. Yesipova, L. Glushkov, M. Karpachevskiy, A. Kostikova, A. Manisha, E. Tsybikova, and I. Zhuravleva. 2008. Mapping the world's intact forest landscapes by remote sensing. *Ecology and Society*, 13(2): http://www.ecologyandsociety.org/vol13/iss2/art51/

Prior-Magee, J.S., K.G. Boykin, D.F. Bradford, W.G. Kepner, J.H. Lowry, D.L. Schrupp, K.A. Thomas, and B.C. Thompson (Eds). 2007. Southwest Regional Gap Analysis Project final report. U.S. Geological Survey, Gap Analysis Program, Moscow, Idaho.

Sanderson, E.W., K.H. Redford, A. Vedder, P.B. Coppolillo, and S.E. Ward. 2002. A conceptual model for conservation planning based on landscape species requirements. *Landscape and Urban Planning* 58(1):41–56.

Scott, M.C., and G.S. Helfman. 2001. Native invasions, homogenization, and the mis-measure of integrity of fish assemblages. *Fisheries* 26(11):6–15.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316:1181–1184.

Stoddard, J.L., D.V. Peck, S.G. Paulsen, J. Van Sickle, C.P. Hawkins, A.T. Herlihy, R.M. Hughes, P.R. Kaufmann, D.P. Larsen, G. Lomnicky, A.R. Olsen, S.A. Peterson, P.L. Ringold, and T.R. Whittier. 2005. An ecological assessment of western streams and rivers. U.S. Environmental Protection Agency, EPA 620/R-05-005, Washington, D.C.

Strittholt, J.R., R. Nogueron, M. Alvarez, and J. Bergquist. 2006. Mapping undisturbed landscapes in Alaska. World Resources Institute, Washington, DC. http://www.globalforestwatch.org/english/us/pdf/GFW-Alaska_report_final.pdf .

Unnasch, R.S., D.P. Braun, P.J. Comer, and G.E. Eckert. 2008. The ecological integrity assessment framework: A framework for assessing the ecological integrity of biological and ecological resources of the National Park system, version1.0. Unpublished report to the National Park Service.

Vitousek, P.M., J.D. Aber, R.W. Howarth, G.E. Likens, P.A. Matson, D.W. Schindler, W.H. Schlesinger, and D.G. Tilman. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. *Ecological Applications* 7(3):737–750.

Whittier, T.R., R.M. Hughes, J.L. Stoddard, G.A. Lomnicky, D.V. Peck, and A.T. Herlihy. 2007. A structured approach for developing indices of biotic integrity: Three examples from streams and rivers in the western USA. *Transactions of the American Fisheries Society* 136:718–735.

Photo: Rattlesnake, Joshua Tree National Park, National Park Service.

III SUMMARY OF METHODOLOGY

3.1. Data Management

The majority of data processed for this REA were handled according to the BLM Data Management Plan (DMP), except in specific cases where guidance was not sufficiently detailed, not feasible according to schedule and budget constraints, or where specific characteristics of the data or processing required a special approach. In nearly all cases, additional guidance was provided by the NOC Data Management Team and the AMT to address these specific cases. In particular, the data processing workflow specified by the DMP required substantial modification during this REA. While it was originally intended by the REA workflow that data would be acquired, fully evaluated, and approved by the AMT prior to the modeling phases, this proved infeasible, and it resulted in the early acquisition and evaluation of many datasets that subsequently were not used for modeling. Instead, a workflow more tightly coupled to the modeling process was adopted, which included acquisition and pre-evaluation of datasets as part of the modeling effort. As such, dataset collection activities were targeted to very specific themes and pre-screened to determine appropriateness for a particular analysis. Additional datasets were identified during workshops and the iterative review process managed using the data portal, Data Basin (www.databasin.org). Thus, although initially over 400 datasets were collected and considered for the REA, 169 datasets were ultimately used in analyses for the Sonoran Desert. After source datasets were successfully used in modeling efforts, they were evaluated according to 11 criteria as specified in the DMP; these included criteria such as non-duplication, spatial accuracy, and thematic accuracy. Data were scored using narrative descriptions for each criterion to highlight potential data quality issues; earlier efforts to use a numeric scoring system proved too time-consuming and less informative.

The analytical extent for this ecoregion was the outer boundary of all 5th level hydrologic units (HUCs) that intersect the Environmental Protection Agency's (EPA's) Level III Ecoregion boundary of the Sonoran Desert (CEC 1997, Figure 3-1). All datasets were clipped to this extent and re-projected to USA Contiguous Albers Equal Area Projection (USGS Version) as specified by the DMP. Prior to delivery to BLM, all spatial data were standardized into ArcGIS File Geodatabase Feature Class and ArcGRID file formats. This included conversion of quasi-spatial datasets (e.g., spreadsheets with coordinates, print maps) into these formats through format conversion and digitization. Digitization of published materials was used as a last resort for essential datasets when original spatial data could not otherwise be obtained.

Climate data were developed at a 4km resolution from the native 15km resolution for the Western US, and processed primarily in NetCDF format due to the temporal nature of such data (NetCDF is a file format ideal for climate data because it can accommodate multiple dimensions in a single file). The outer extent of all 4km grid cells within the ecoregion/5th level watershed boundary was used as the analytical extent for these data. Derived results, such as annual average temperature for 2015–2030, were extracted into ArcGRID format.

All datasets required development of FGDC compliant metadata per BLM specifications. In many cases, full FGDC metadata were not available for all original source datasets, and often available information was insufficiently detailed to achieve all BLM desired metadata elements. The Dynamac team exerted considerable effort to populate missing metadata elements. The substantial effort involved in achieving full compliance with FGDC and BLM metadata standards deterred delivery of any datasets to BLM other than those used directly in the modeling and analysis process; thus, several datasets of potential interest but no direct application in this REA were excluded.

Most datasets were processed using ArcGIS ModelBuilder and python scripts delivered as ArcGIS tools, per BLM requirements. Many of these models were developed in such a way as to permit other users beyond this REA to modify the input and processing methods and rerun the tools. Specifically, the terrestrial and aquatic

intactness models are likely to be of high value to end-users. A few non-ArcGIS analysis tools were used to generate some of the results developed in this REA, including MaxEnt and FRAGSTATS.

A number of data-related issues were encountered during this REA:

- some existing thematic data were not available for use by the Dynamac team due to proprietary restrictions (e.g., Natural Heritage data);
- data may have existed in digital form for some published materials (e.g., maps presented in a report), but data was not always obtainable in a timely fashion from authors. In specific cases, this required that the Dynamac team digitize these data directly from the published materials;
- some data specifically developed by the BLM and other agencies as part of their planning processes were not available to the Dynamac team, for example BLM Field Office data; BLM had asked that field office data not be gathered that was not already in national datasets because of consistency, data standards and level of effort;
- versioning of datasets for continually updated themes (e.g., BLM renewable energy projects datasets) presented challenges by becoming available late in the REA or requiring rectification as new versions became available;
- many source datasets were developed at the state level (e.g., wildlife habitat), and presented numerous challenges when combining these at the ecoregion level, such as edge-matching between states, thematic resolution, spatial scale, attribution, and data standards.

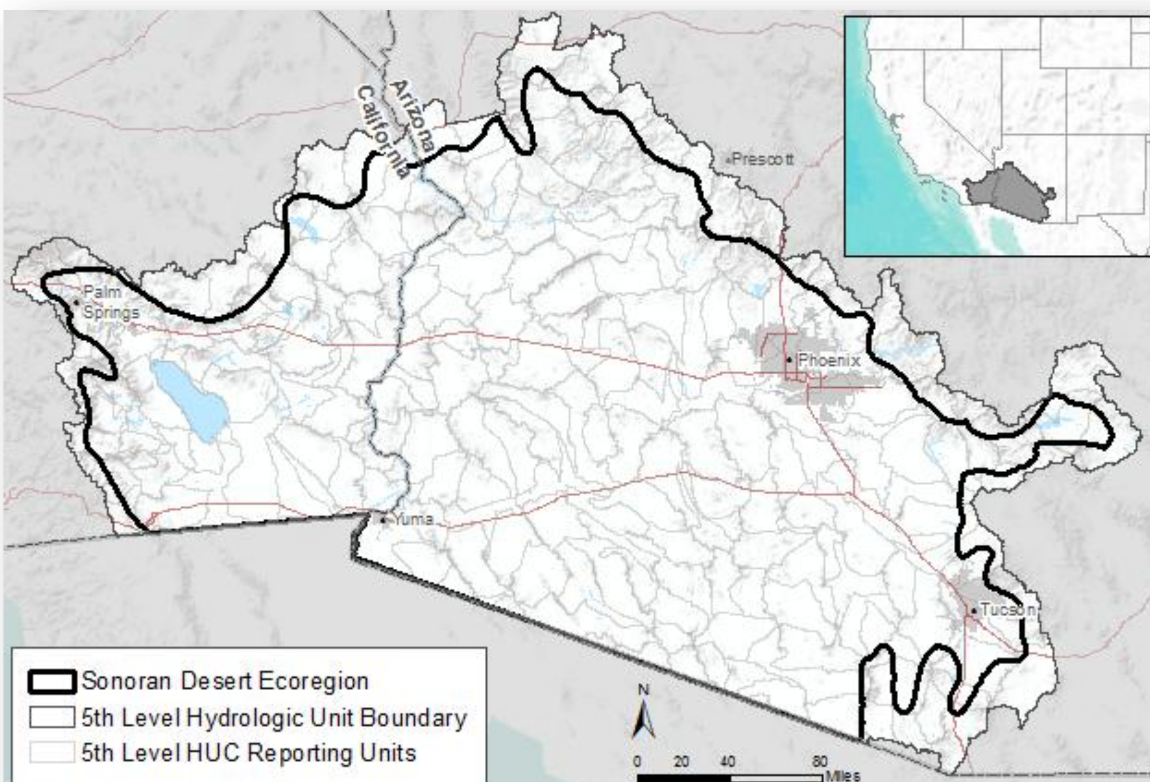


Figure 3-1. Map of the Sonoran Desert ecoregion showing hydrologic unit boundaries and analytical extent.

3.2. Models, Methods, and Tools

Throughout the REA process, numerous types of models were developed and analysis tools used to address the various management questions and overarching issues of interest. This section discusses the development of ecological conceptual models, process and logic models, and habitat fragmentation, connectivity, fire, and climate change modeling.

3.2.1 Conceptual Models

Conceptual models graphically depict the interactions between a conservation element, the biophysical attributes of its environment, and the change agents that drive ecosystem character. The boxes and arrows that make up the conceptual model represent the state of knowledge about the subject and its relationships to these attributes (Figure 3-2). Conceptual models are also supported and referenced by scientific literature. REA conceptual models were developed at three levels. At the ecoregion level, an overarching model was developed that outlined the interactions of the major ecological features, processes, and change agents. Since change agents are a major focus of the REAs, a comprehensive change agent conceptual model was also produced. Finally, individual conceptual models were created for each conservation element with particular attention paid to the potential impacts from the various change agents.

Conceptual models for conservation elements were standardized by including all change agents (yellow boxes, Figure 3-2) and natural drivers (cyan boxes) with close attention paid to those attributes and indicators that could be used to help assess current and future status. Specifics regarding some of the components (when known) are presented in blue text. Arrows represent relationships between the various change agents and natural drivers acting on the conservation element from the standpoint of the natural community or habitat as well as on one or more individual species. Specific information about the flows between components is provided in orange text. It is important to note that not all of the relationships identified in the conceptual models lend themselves well to measurement or monitoring because adequate spatial data do not exist in many cases or because there is a lack in scientific knowledge to intelligently quantify a particular indicator. In spite of this shortcoming, all important components are included as they aid in our general understanding of complex interactions.

Unlike many published conceptual models, thicknesses of the arrows in our models **DO NOT** represent degree of importance. Rather, bold lines represent those factors that are tracked or modeled to varying degrees of certainty throughout the REA analysis. The conceptual models as presented in this report, therefore, provide information in several ways—they provide information on: (1) ecological interactions; (2) what spatial data are available to track changes over time; and (3) where there are spatial data gaps.

In the conceptual model for Sonoran-Mojave Creosotebush-White Bursage Desert Scrub (Figure 3-2), there are five primary natural drivers (cyan boxes) for this ecological system including topography, erosion, soil characteristics, precipitation, temperature, and animal herbivory. Specific details on the various environmental conditions characterizing this system (blue text) are provided by NatureServe (2009) and LANDFIRE (2007). Sonoran-Mojave Creosotebush-White Bursage Desert Scrub is a matrix community dominated by the long-lived creosotebush (*Larrea tridentata*). Creosotebush is a generalist that does occur outside of the low elevation basins of the Colorado Desert at higher elevations in the Arizona Upland, although it is not dominant there. White bursage (*Ambrosia dumosa*), on the other hand, does not grow on the rockier ground of bajadas; it is replaced by triangleleaf bursage (*Ambrosia deltoidea*) outside of the low elevation basins (Turner and Brown 1994). Other constituents of the community are determined by

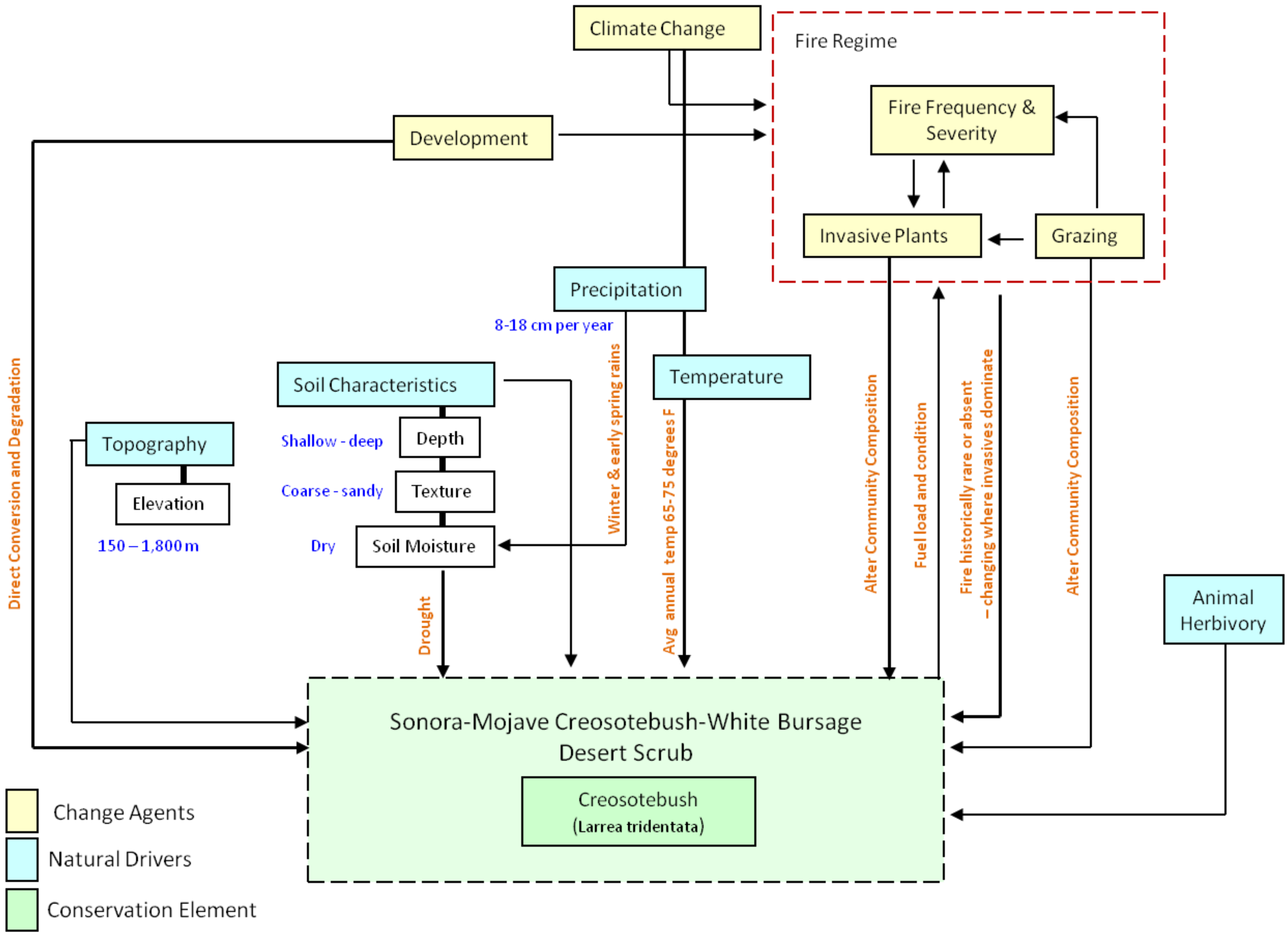


Figure 3-2. Conceptual model diagram for Sonora-Mojave Creosotebush-White Bursage Desert Scrub in the Sonoran Desert ecoregion. Note: Thicknesses of the arrows do not represent degree of importance, but those factors that are tracked or modeled throughout the REA analysis.

landform, local soil moisture, depth, and salinity, and interspecific competition for water, which dictate the distance between shrubs of both species. Livestock grazing and periodic drought are implicated in the expansion of creosotebush into former C_4 desert grasslands over the last century (Grover and Musick 1990, Van Auken 2000, Sayre 2005, Nellessen 2012). Multiple disturbances have allowed the invasion of exotic annual grasses and forbs such as red brome *(Bromus rubens* subsp. *madritensis*), buffelgrass (*Cenchrus ciliaris*, syn. *Pennisetum ciliare*), and Sahara mustard (*Brassica tournefortii*) into desert ecosystems; these species create expanses of fine fuels among the desert shrubs, carrying recurrent fire in an ecological system that rarely burned. Species like creosotebush are intolerant of fire and the system recovers slowly after a burn (Brown and Minnich 1986, Esque and Schwalbe 2002).

Besides fire and invasive species, development is another change agent affecting this ecological system that is covered in the REA process (based on current and projected future extent of urban land cover); overall landscape intactness, which includes development from all sources (urban, agriculture, energy, and roads), invasive species, and habitat fragmentation, is used to describe the status of this ecosystem type. Climate change projections (including precipitation and temperature changes as well as MAPSS modeling outputs) are also used to predict where the current Sonoran-Mojave Creosotebush-White Bursage Desert Scrub may be under significant climate stress. Following this model format, select conceptual models are presented in later sections in this document and all conceptual models for each of the conservation elements are provided in Appendices A, B, and C. Some conceptual models were adapted from Miller (2005) and Miller et al. (2010).

3.2.2 Process Models

With conceptual models in-hand to inform the relationships between components, drivers, and processes, individual process model diagrams were generated to address each stated management question. *Process models* are diagrams that map out data sources, GIS analyses, and workflow. These models were not intended to attempt to replicate all of the interactions of the conceptual models. Rather, they were created to inform the user about the spatial analysis details to address each management question, providing important analytical transparency and allowing for repeatability of the same or similar model in the future (perhaps including new input data for a key variable). Each model could be viewed as the analysis recipe including information about data sources, specific GIS operations, and data and map workflows highlighting all intermediate and final map results.

Some management questions required only a series of simple GIS operations (see Figure 3-3 for an example). More sophisticated analyses required developing a more complex, customized approach through the construction and implementation of Model Builder/Python scripts and, in some cases, the inclusion of non-ArcGIS software (e.g. MaxEnt, MAPSS, and FRAGSTATS). A separate process model is provided in Appendix A for each management question.

3.2.3 Logic Models

For the most complex questions such as assessing terrestrial landscape intactness, aquatic intactness, cumulative development, and summarizing climate modeling results, logic models were constructed to help communicate how the various data inputs were used in a spatial modeling environment. A *logic model* is a cognitive map (Jensen et al. 2009) that presents networks of various spatial data components and their logical relationships to explain the process used to evaluate a complex topic such as landscape intactness. For this REA, the EMDS (Ecosystem Management Decision Support) modeling approach (Reynolds 1999, Reynolds 2001) was replicated, but all of the modeling operations were conducted using ArcGIS Model Builder and Python scripts with additional inputs provided by approved outside analyses such as FRAGSTATS.

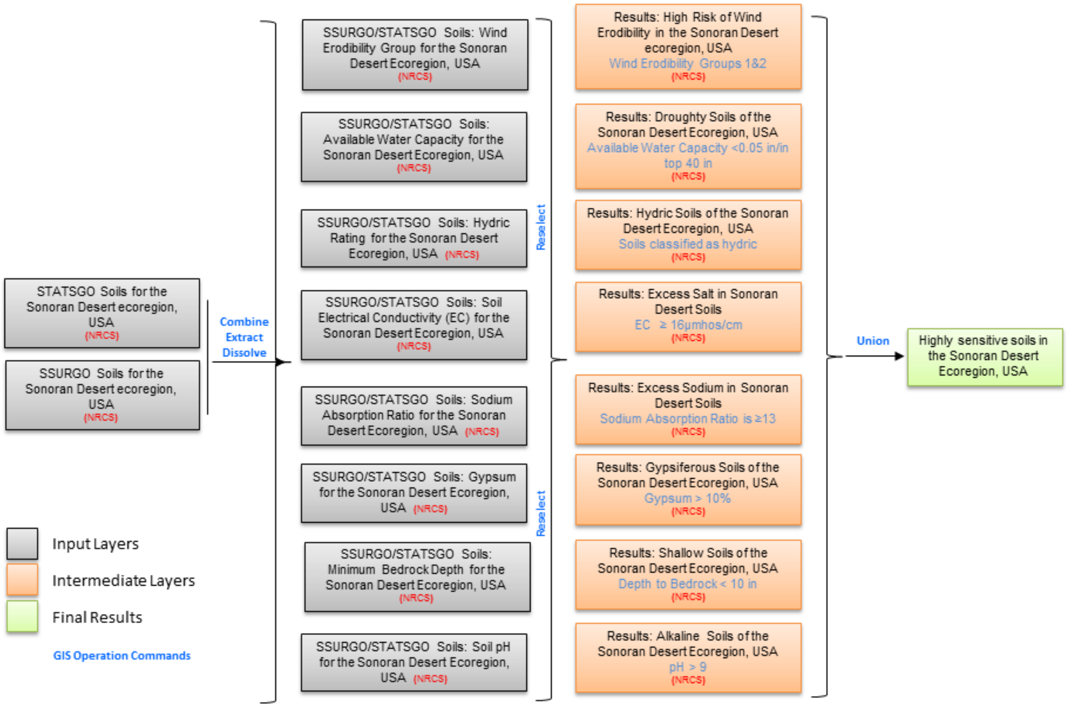


Figure 3-3. Process model diagram for soil sensitivity in the Sonoran Desert ecoregion: Management Question, *Where are sensitive soils (including saline, sodic, gypsiferous, shallow, and low water holding capacity)?*

Logic models were constructed in a hierarchical fashion relying on symbols, colors, labels, and the physical arrangement of components to communicate how a series of spatial datasets were assembled and analyzed to answer a particular question. Using terrestrial landscape intactness as an example (Figure 3-4), logic models rely solely on spatial data layers that are arranged in a hierarchical fashion to answer a primary question that is located at the top of the diagram. In this case, what is the level of terrestrial landscape intactness for the ecoregion? Data and analysis flows from the bottom up. Note that uncertainty assessments for data sources and logic model results can be found in Appendix E.

Unlike conventional GIS applications that use Boolean logic (1s and 0s) or scored input layers, logic models rely on fuzzy logic. Simply put, fuzzy logic allows the user to assign shades of gray to thoughts and ideas rather than being restricted to black (false) and white (true) determinations. All data inputs (regardless of the type—ordinal, nominal, or continuous) are assigned relative values between -1 (false) and +1 (true) up to six decimal places. There are many advantages of this modeling approach: (1) it is highly interactive and flexible; (2) it is easy to visualize thought processes; (3) the logic components are modular making it easy to include or exclude pieces of the logic design; (4) the logic can be managed using a number of different mechanisms; and (5) numerous, diverse topics can be included into a single integrated analysis. Raw spatial data source inputs (gold boxes) are populated by one or more GIS data layers (indicated by the stack of gray files). Moving up the diagram, these data are arranged and analyzed to form intermediate map products (purple boxes), which are then arranged and analyzed to generate the final results (green box). One way the user controls the logic of the information is the arrangement of the various data inputs and intermediate products—the higher up in the diagram, the greater the influence on the final result.

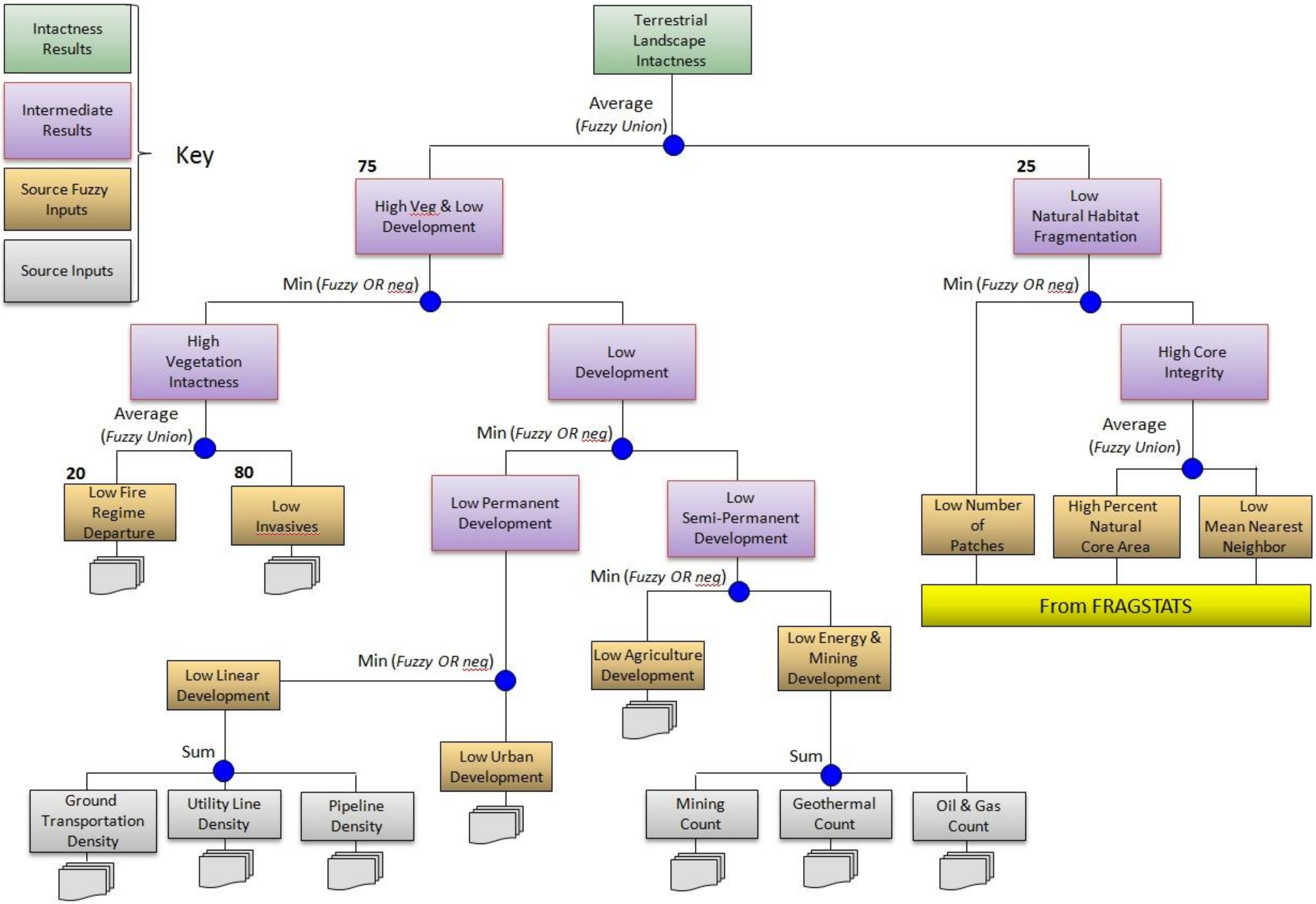


Figure 3-4. Logic model for terrestrial landscape intactness for the Sonoran Desert ecoregion.

Using fuzzy logic as the core modeling principle, logic model performance is achieved in several ways. For every spatial data input, the user determines how to assign the range of values along a truth continuum. When trying to determine and map the most suitable habitat from the standpoint of road density for wildlife—the greater the road density, the greater is the risk to wildlife through habitat degradation and direct mortality. In our example, road density ranges from 0 km/km^2 to 24.5 km/km^2. To assign a fuzzy logic continuum for this range of values, one could assign a -1 to the high value (this value is totally harmful for wildlife or false) and a +1 to the lowest value (this value is totally beneficial for wildlife, or true, red line in Figure 3-5). However, mountain lion research has shown that mountain lion populations have a low probability of persistence in areas with road densities > 0.6 km/km^2 (Van Dyke et al. 1986). A more meaningful alternative then for setting fuzzy thresholds for this parameter would be that a road density of > 0.6 km/km^2 is totally false (-1) and 0 remains totally true (+1, green line in Figure 3-5). Of course, not all wildlife species have the same sensitivity to roads, but this example illustrates how the logic in the model can be altered for known thresholds.

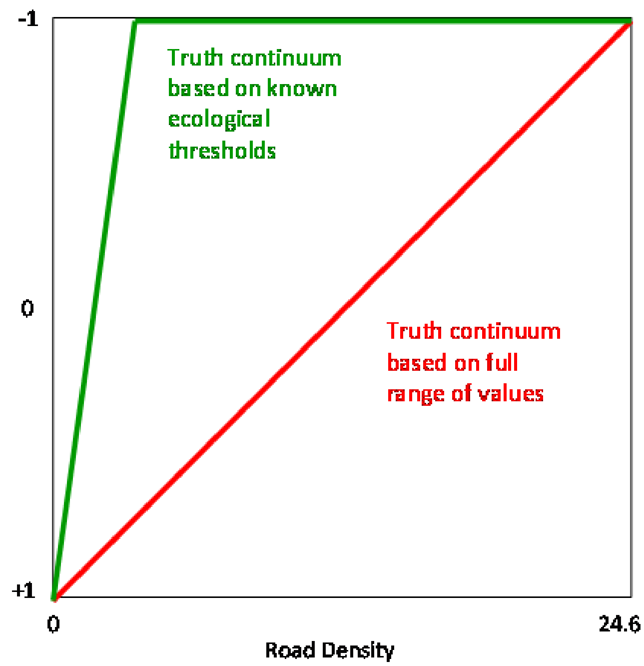


Figure 3-5. Diagram of two treatments of road density in fuzzy logic modeling illustrating important model control options, one based on a full range of values (red line) and the other based on a known threshold for road density (> 0.60 km/km^2 is totally false [-1], green line).

Individual thresholds used for each component in the terrestrial landscape intactness logic model shown in Figure 3-4 are provided in Table 3-1. In this example, there are 12 primary inputs to the model, but two components (Low Linear Development and Low Energy & Mining Development) were created by summing several input values together before applying any fuzzy thresholds. Taking this into account, only nine primary inputs in the logic model required threshold setting.

Table 3-1. List of data inputs for the terrestrial landscape intactness logic model for the Sonoran Desert ecoregion showing data type, range of values, and true and false modeling thresholds for each item at the 4 km x 4 km resolution.

Item	Data Type	Data Range	True Threshold	False Threshold
Fire Regime	Percent Area	0-100	7[1]	100
Invasive Grasses & Tamarisk	Percent Area	0-88	0[3]	33
Linear Development	Density	0-18	0[1]	2.5
Urban Percent	Percent Area	0-99	0[3]	15
Agriculture Percent	Percent Area	0-90	0[3]	20
Energy & Mining Development	Number	0-37	0[2]	1.25
Number of Patches	Number	1-1,455	0[4]	850
Mean Nearest Neighbor	Distance	60-272	59[1]	180
Percent Natural Core Area	Percent Area	.56-95	100[3]	20

1. Used full range or full range with outliers ignored; 2. Skewed data range: 1 Standard Deviation from the mean;
3. Skewed data range: 2 Standard Deviations from the mean; 4. Skewed data range: 2.5 Standard Deviations from the mean.

Spatial data are integrated together using one of several logic 'operators', including Sum, Average (or *Fuzzy Union*), Minimum (or *Fuzzy Or neg*), and Maximum (or *Fuzzy Or*). The Sum operator simply combines similar data into a single file before assigning fuzzy thresholds. For example, Low Linear Development is the fuzzy expression of three linear feature densities—ground transportation, utility lines, and pipelines. Average (or *Fuzzy Union*) simply averages all of the fuzzy inputs to form a new output. Minimum (or *Fuzzy Or neg*) causes the lowest value to dominate in the resultant map between two or more inputs. For example, in producing the High Veg and Low Development intermediate file, cells that are the lowest in either input get reflected in the resulting map.

Lastly, the logic models produced for the REA contain some weighting of inputs. In the example provided, weighting was used in two places. The High Vegetation Intactness intermediate layer is influenced differentially—80% is from the Low Invasives input and 20% from the Low Fire Regime Departure input. The other place where weighting was used was in the final combination of High Veg and Low Development and Low Natural Habitat Fragmentation inputs, 75% and 25% respectively. Weighting can be considered subjective and thus responsible for introducing uncertainty into the model. However, weighting may be justified where the relative dominance of various factors is known in theory or in practice. In this case, weighting was applied to keep less important factors from dominating the resulting model. If all factors are considered of equal influence, weights may be avoided altogether, or weights can be applied and adjusted on successive model runs to balance the components and test the outcome. In any case, whether or not weights are used, the resulting model should be evaluated to test its relevance to real-world knowledge and expectations. An uncertainty assessment for each logic model appears in Appendix E.

All intermediate and final map results are rendered as fuzzy outputs, which range from -1.000000 (totally false) to +1.000000 (totally true). Interpretation of the range of values for a given map can be organized and interpreted in many ways using standard GIS binning such as Natural Breaks or Equal Area. For the terrestrial landscape intactness results, where an estimate of ecologically meaningful results was attempted using a careful selection of operators, thresholds, and input data, a modified EMDS classification was used to characterize intactness and assigned six classification descriptions—Very Low, Low, Moderately Low, Moderately High, High, and Very High (Table 3-2). This way, the degree of intactness could be evaluated against multiple conservation values and easily compared to potential future conditions based on updated raw inputs (e.g. new urban development projections) using the same scale.

Table 3-2. Intactness value ranges and legend descriptions. Fuzzy output map results range from -1.000000 (totally false) to +1.000000 (totally true) in six intactness classes from Very Low to Very High intactness.

Intactness Value	Legend
-1.000 to -0.750	Very Low
-0.750 to -0.500	Low
-0.500 to 0.000	Moderately Low
0.000 to 0.500	Moderately High
0.500 to 0.750	High
0.750 to 1.000	Very High

3.2.4 Habitat Fragmentation Modeling

The three inputs to the Natural Fragmentation component in the terrestrial landscape intactness logic model (number of patches, average mean nearest neighbor, and percent natural core area) were generated using FRAGSTATS (McGarigal and Marks 1995). FRAGSTATS produces a series of metrics that are focused at the individual patch, class, and landscape levels. All three fragmentation indicators chosen were class-level metrics. Prior to running FRAGSTATS, the entire landscape was mapped into one of three classes—natural vegetation, invasive species, and other (including developed, agriculture, and water, Figure 3-6). For this exercise, spatial details on fragmentation of different natural communities were not of primary interest, meaning that differentiating various vegetation communities (e.g. sagebrush shrubland from woodlands) was not needed. Two classes would have sufficed—natural vegetation cover and un-natural vegetation cover (developed land, agriculture); however, having a third class of fragmentation information on invasive species may prove useful in the future as part of a step-down assessment. See specific details on how the master layer was generated in Appendix E.

Two of the functions (Percent Natural Core Area and Average Mean Nearest Neighbor) were averaged together to create an intermediate layer called High Core Integrity. This intermediate layer was then combined with the Number of Natural Patches using a *Min* (or *fuzzy Or neg*) operator to generate the final Low Natural Habitat Fragmentation component in the model (Figure 3-7).

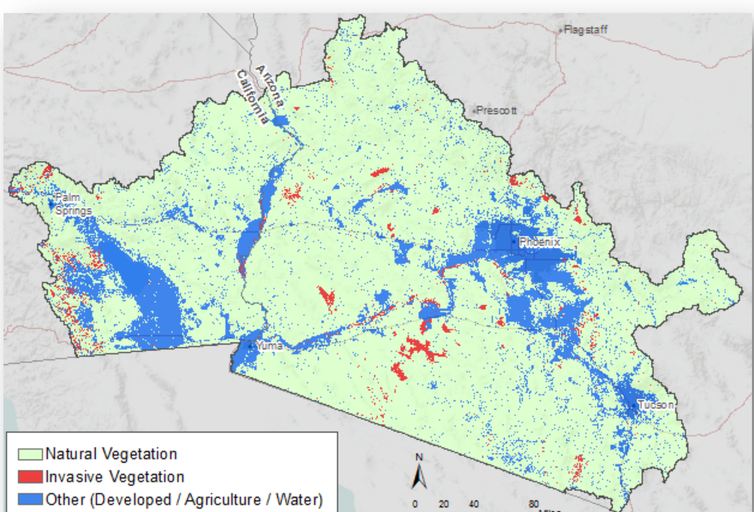


Figure 3-6. Prior to running FRAGSTATS, the entire landscape was mapped into three classes: natural vegetation, invasive species, and other (including developed, agriculture, and water).

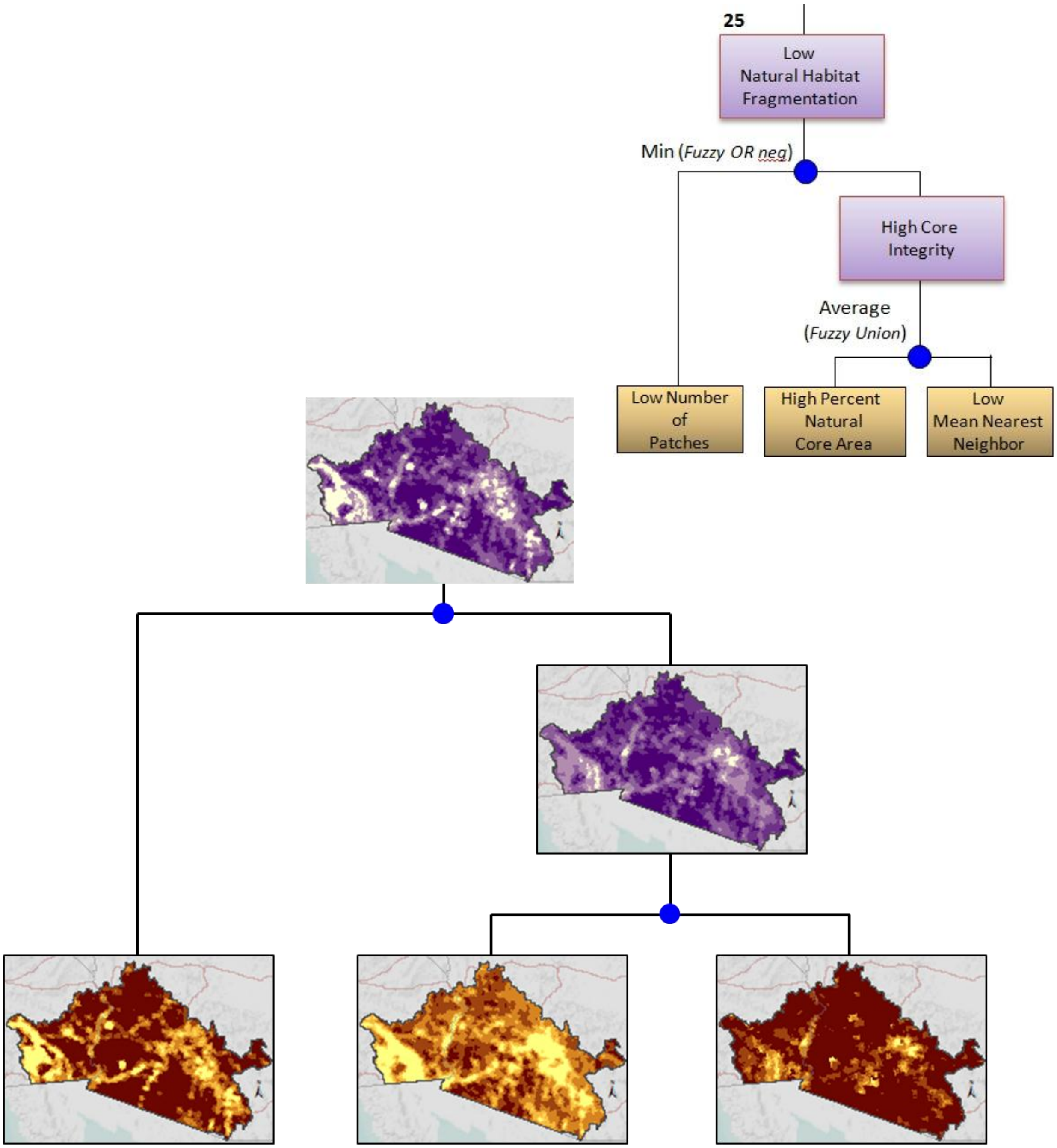


Figure 3-7. FRAGSTATS-based fragmentation inputs into the terrestrial landscape intactness model at 4km resolution for the Sonoran Desert ecoregion. Two of the FRAGSTAT functions (Percent Natural Core Area and Average Mean Nearest Neighbor) were averaged together to create an intermediate layer called High Core Integrity. This intermediate layer was then combined with the Number of Natural Patches to generate the final Low Natural Habitat Fragmentation component in the model.

3.2.5 Invasive Vegetation Modeling

Existing landcover classifications (LANDFIRE Existing Vegetation Type, NatureServe National Landcover, and Integrated Landscape Assessment Project Current Vegetation) were used to identify areas dominated by invasive vegetation types. However, it was determined during review and analysis of these products that they likely significantly underestimate the distribution of invasive vegetation within the ecoregion. One invasive species in particular, Sahara mustard (*Brassica tournefortii*), has significantly expanded its distribution within the ecoregion in recent years and was not adequately captured by existing products. To better capture its likely distribution, a MaxEnt (Elith et al. 2011) model was developed based on occurrence data from a number of sources (Figure 3-8, 1,539 occurrence records), and predictive surfaces based on elevation, soil characteristics (percent sand, available water capacity), surficial geology, distance to roads, and climate parameters. Fifteen percent of samples were held out (without replacement) as a validation test. High probability areas were incorporated from the MaxEnt model into the predicted current distribution of major invasive species. The near-term future (2025) distribution of Sahara mustard was estimated by applying the model (developed on current climate) to future climate estimates from RegCM3 using ECHAM5 boundary conditions.

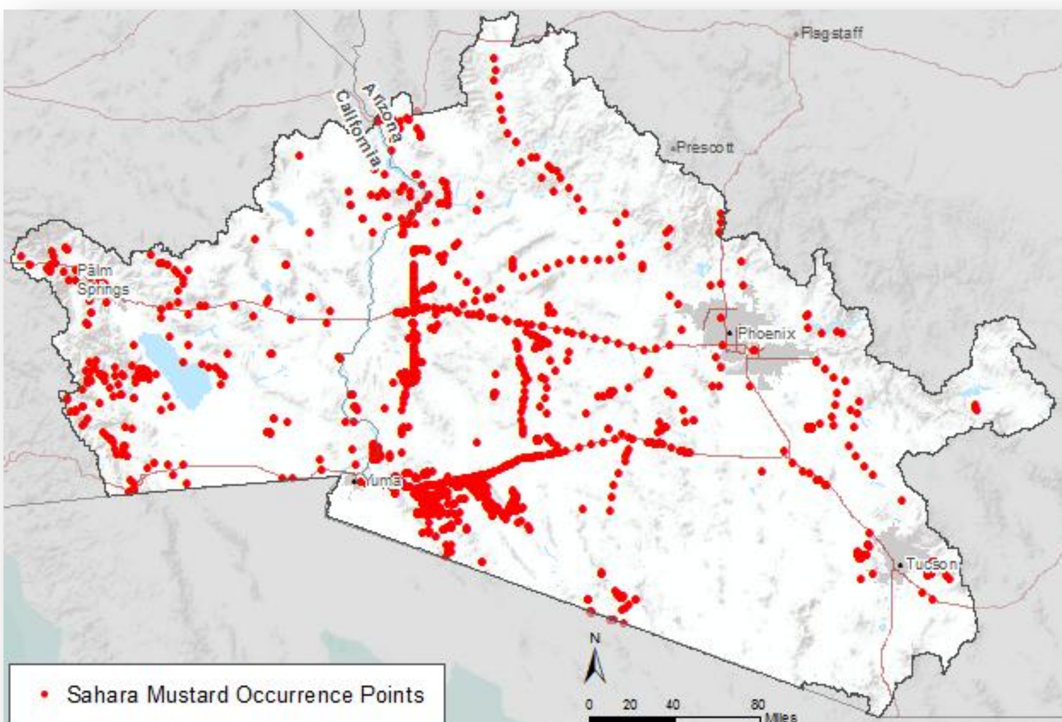


Figure 3-8. Sahara mustard (*Brassica tournefortii*) in the Sonoran Desert ecoregion. A MaxEnt (Elith et al. 2011) model was developed based on occurrence data from a number of sources (1,539 occurrence records), and predictive surfaces based on elevation, soil characteristics (percent sand, available water capacity), surficial geology, distance to roads, and climate parameters. Fifteen percent of samples were held out (without replacement) as a validation test.

This model has several sources of uncertainty. The model is based on occurrence data that likely have sampling bias (most are along major highways) and occurrence records are lacking for notable areas where Sahara mustard is known to be present (T. Esque and J. Weigand, BLM, pers. comm., 2011). The model is based on coarse-grain estimates of climate conditions and soil characteristics and on relationships to landscape factors; it does not directly account for causal factors such as site-level disturbance or seed dispersal. Thus, the results may both over-predict Sahara mustard in areas where it is unlikely to occur and under-predict it where it is known to occur but has not been sufficiently sampled.

3.2.6 Fire Modeling

To assess areas changed by fire (1999–2010), fire location and severity from LANDFIRE Disturbance layers (1999–2008) and wildland fire perimeters (2000–2010) were extracted for the Sonoran Desert ecoregion. The degree to which vegetation changed during this period could not be assessed due to the lack of accurate pre- and post-fire vegetation maps. Instead, the focus was on highlighting the severity of the fires, where information was available, because the degree of ecological changes likely increases with increasing severity.

To assess areas with potential to change from wildfire, models were developed to predict the probability of human- and naturally-caused fire occurrences. Thirty years of fire occurrence data (Figure 3-9) were used to develop two MaxEnt (Elith et al. 2011) models to predict human and natural fire occurrences. A series of input surfaces were used as the basis for prediction, including elevation, fuel type, vegetation type, climate variables, distance to major roads, distance to all roads and trails, distance to urban areas, and lightning density. Areas of high probability of occurrence were then extracted from the human and natural model results and combined into a single dataset to express areas likely to experience fires due to humans, natural causes, or both.

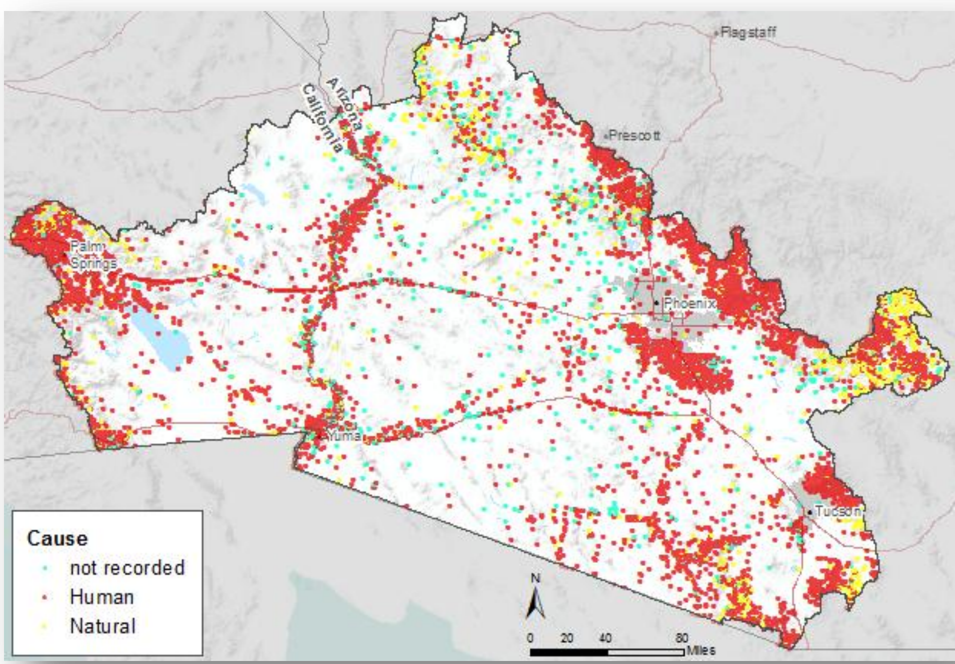


Figure 3-9. Fire occurrences between 1980 and 2010 according to cause of ignition.

A combination of existing data and expert opinion were used to identify areas of high fire regime departure. LANDFIRE Fire Regime Departure Index (v1.0) was used as an estimate of departure of current vegetation conditions compared to reference vegetation conditions. Reference condition vegetation conditions describe the proportions of various successional stages of a given Biophysical Setting that would be expected to occur across space and time under the influence of unaltered disturbance regimes. Current conditions were tabulated from existing vegetation type and structure, and compared to these reference conditions to determine vegetation departure.

Measures of current fire regime (frequency and severity) were obtained from fire experts familiar with the ecoregion for the 40 most extensive Biophysical Settings. These values were compared against reference condition fire regime estimates derived from LANDFIRE Mean Fire Return Interval and Percent Replacement Severity, and calculated measures of fire frequency and severity departure according to FRCC Guidebook (Barrett et al. 2010) methods using the average of the minimum and maximum departure values that could be obtained from comparing each range of fire frequency and severity from current estimates to reference condition estimates. Lastly, the maximum departure between vegetation departure and fire frequency and severity departure were extracted to use as our overall measure of fire regime departure.

To assess areas where fire may be adverse to ecological communities and resources of concern, areas from the LANDFIRE Fire Regime Groups and Succession Classes datasets were extracted to capture the following conditions:

- historically-rare fire systems (fires that occur may result in high severity, and may be uncharacteristically frequent if caused by human ignitions).
- historically-frequent fire systems (fires may produce potentially uncharacteristic fire behavior due to legacy effects of fire suppression).
- uncharacteristic native vegetation composition or structure (fires may produce uncharacteristic behavior due to uncharacteristic fuel conditions).
- invasive vegetation (fire frequency, severity, and size may be altered by presence of invasives, especially annual grasses).

3.2.7 Climate Modeling

The climate change modeling required extensive exploration and several major processing steps best communicated with a diagram (Figure 3-10). Eight major steps were taken to generate a final potential climate change impact map for the ecoregion.

The base input data into the modeling process was RegCM3—a regional climate model run at 15km spatial resolution. Regional Climate Models have been developed based on the concept of one-way nesting, in which large scale meteorological fields from General Circulation Model (GCM) runs provide initial and time-dependent meteorological lateral boundary conditions (LBCs) for high resolution Regional Climate Model (RCM) simulations, with no feedback from the RCM to the driving GCM. The Regional Climate Model system RegCM, originally developed at the National Center for Atmospheric Research (NCAR) in Colorado, is maintained in the Earth System Physics section of the International Center for Theoretical Physics in Italy. The first version of the model, RegCM1, was based on the NCAR-Pennsylvania State University (PSU) Mesoscale Model version 4 (MM4) (Dickinson et al. 1989, Giorgi 1989). Since then the model has undergone major updates including RegCM2 based on NCAR's Community Climate Model version 2 (CCM2, Hack et al. 1993) and the mesoscale model MM5 (Grell et al. 1994). Further development based on the Community Climate Model version 3 (CCM3, Kiehl et al. 1996) gave rise to RegCM2.5 and RegCM3 that include the effect of additional greenhouse gases (NO_2, CH_4, CFCs), atmospheric aerosols, and cloud ice as well as a prognostic equation for cloud water used in the cloud radiation calculations (Giorgi et al. 2003).

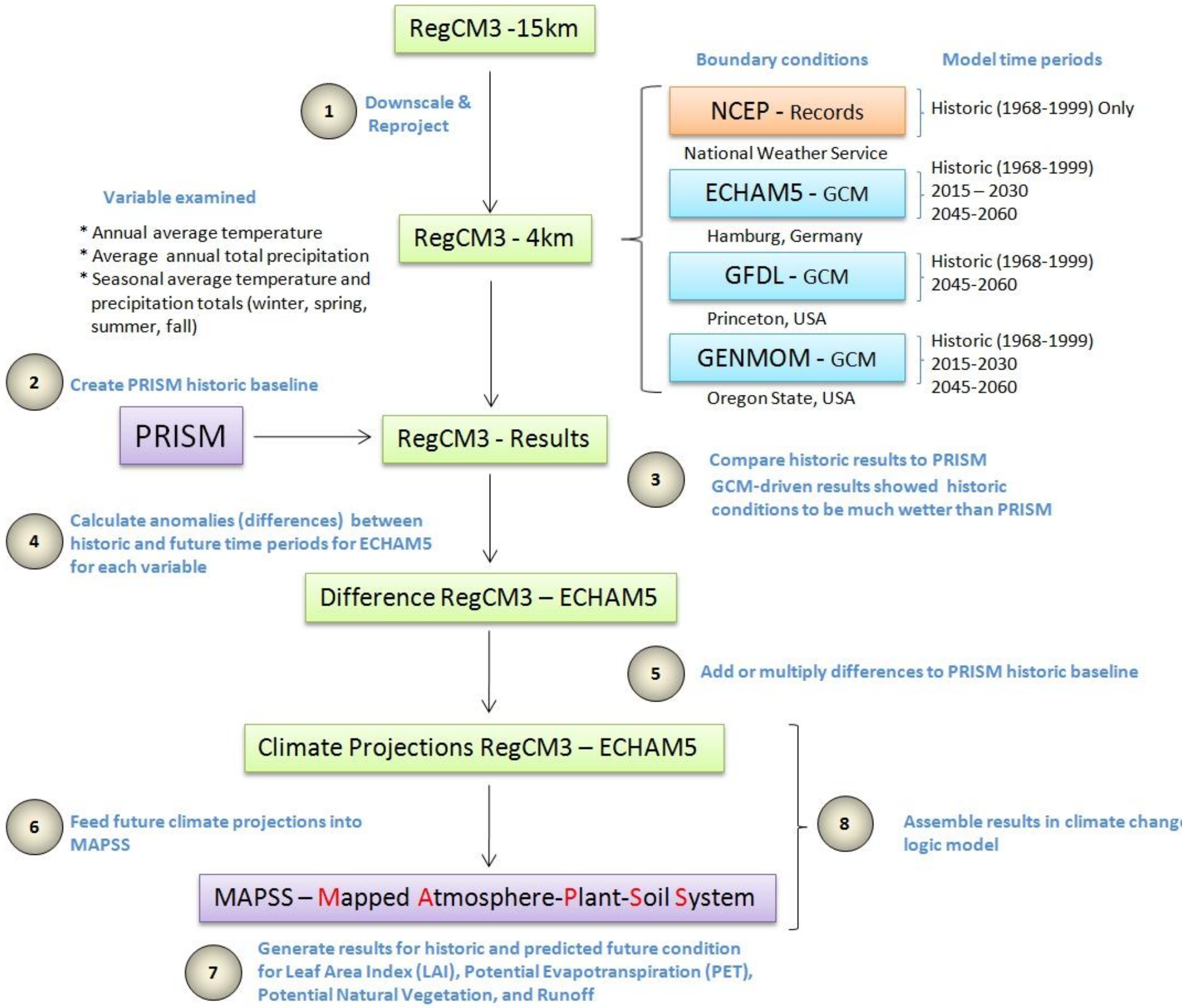


Figure 3-10. Climate change processing workflow.

Dynamically downscaled climate change data were provided by USGS (Hostetler et al. 2011). Three General Circulation Models (GCMs) were used as boundary conditions to drive the RegCM3 model. RegCM3 is a regional climate model that accounts for the North American Monsoon (sometimes called the Arizona Monsoon, Hostetler et al. 2011). One limitation of the regional model that was used for this REA is that its boundary lies on the Arizona/Mexico border, and it is thus affected by coarse ocean conditions simulated by the GCMs and the scarcity of meteorological stations south of the Border, which may affect modeling results for the Sonoran Desert. In these later models, the USGS Global Land Cover Characterization and Global 30 Arc-Second Elevation datasets are used to define topography. In addition, NCEP (National Center for Environmental Protection, part of the U.S. National Weather Service) and ECMWF (European Centre for Medium-Range Weather Forecasts) global reanalysis climate datasets are used for initial and boundary conditions.

Input data was first re-projected to the 4km Albers Equal-Area projection using the proj4 library. Elevation data and anomalies for temperature, precipitation, and vapor pressure were re-projected from the 15km Lambert projection (original RegCM3 resolution and projection) and interpolated using bilinear interpolation.

Variables examined throughout this assessment included annual average temperature, average annual total precipitation as well as seasonal averages for both temperature and precipitation.

A number of boundary conditions were based on NCEP records and three different GCMs (ECHAM5, GFDL, and GENMOM). Historic model runs using the different GCMs were examined to establish a historic baseline and compared to NCEP and PRISM, which rely on observed weather data over the 1968–1999 time period. PRISM was believed to be the more reliable dataset as it takes into account more information such as elevation and other terrain influences. All GCM-influenced historic model runs were found to be wetter than the weather data supported, so the historic baseline was defined using the PRISM-based results. This decision required that anomalies (differences) be calculated between PRISM interpolations of historic and simulated future time steps based on the various GCMs. Final future climate projections were generated by adding (for temperature variables) or multiplying (for precipitation variables) the model differences to PRISM historic baseline. After review of the future output results and after consultation with climate model experts, the ECHAM5-based future potential climate results were selected for this report to assess impacts on the conservation elements. (The other GCM results are available on the data portal for comparison and further analysis.) The ECHAM5-based results were then fed into MAPSS (Mapped Atmosphere-Plant-Soil System modeling software, Neilson 1995). Results from MAPSS and ECHAM5 climate projections were integrated into a fuzzy logic model in order to evaluate potential climate change impacts on conservation elements.

MAPSS (Mapped Atmosphere-Plant-Soil System) is a static biogeography model (Neilson 1995) that projects potential future vegetation distribution and hydrological flows using long-term average monthly climate data (mean monthly temperature, precipitation, vapor pressure, and wind speed) and soils information (texture and depth). MAPSS has been used widely for various climate change assessments including the 2000 National Assessment Synthesis Team's report (NAST 2000) at various spatial scales (10x10 km over the continental U.S. and 50x50km globally) determined by the spatial grain of the available climate inputs. It was partially validated within the U.S. for vegetation distribution, Leaf Area Index (LAI), and runoff (Neilson 1995). Based on a set of climatic thresholds, MAPSS defines as many as 64 potential vegetation types based on different plant functional types (PFTs) such as evergreen needleleaf trees, deciduous broadleaf shrubs, and C_3 grasses. The model uses thresholds of LAI and climatic zone thresholds to identify potential vegetation types composed of various PFT mixtures (Neilson 1995).

MAPSS assumes that vegetation distribution is constrained either by the availability of water or by energy for growth. The energy constraints on vegetation type and LAI are simulated by calculating growing degree-days as a surrogate for net radiation. In temperate latitudes, water is the primary constraint while at high latitudes energy is the primary constraint (exceptions occur particularly in areas that are nutrient limited).

The model simulates infiltration, saturated, and unsaturated percolation. Water holding capacities at saturation, field potential, and wilting point are calculated from soil texture, as are soil water retention curves. Water in the surface soil layer is apportioned to two life forms (woody and herbaceous) in relation to their relative LAIs and stomatal conductance, i.e., canopy conductance, while woody vegetation alone has access to deeper soil water.

Potential evapotranspiration is calculated as a function of temperature, vapor pressure, wind speed, and elevation. It is used as a surrogate for vapor pressure deficit to estimate actual transpiration. Actual transpiration is also constrained by leaf area and stomatal conductance. The model calculates LAI for both woody (either trees or shrubs) and grass life forms competing for light and water in such a way that all soil water available is transpired during the drier months of the year. Site water balance parameters were originally calibrated to be consistent with observed runoff (Neilson 1995).

Elevated CO_2 can affect vegetation responses to climate change through changes in carbon fixation and water-use-efficiency (WUE, carbon atoms fixed per water molecule transpired). The WUE effect is often interpreted as a reduction in stomatal conductance. Since MAPSS simulates carbon/biomass indirectly (through LAI), a WUE effect can be imparted directly as a change in stomatal conductance, which results in increased LAI and usually a decrease in transpiration per unit land area.

Five primary inputs were assembled from the climate change analyses into a logic model to create a potential for climate change map surface that could be applied to each of the conservation elements (Figure 3-11). Two of the variables (degree of runoff change and vegetation change) were products taken from the MAPSS modeling. Three other variables (normalized summer temperature change, normalized winter temperature change, and absolute precipitation relative change) were taken directly from the climate results of future projections based on the ECHAM5 version of the RegCM3 model results. Through a series of logic steps, these variables were assembled to provide a single reasoned classification. The final results for Probability of Change were presented using five classes—Very High, Moderately High, Moderate, Moderately Low, and Low Probability of Change.

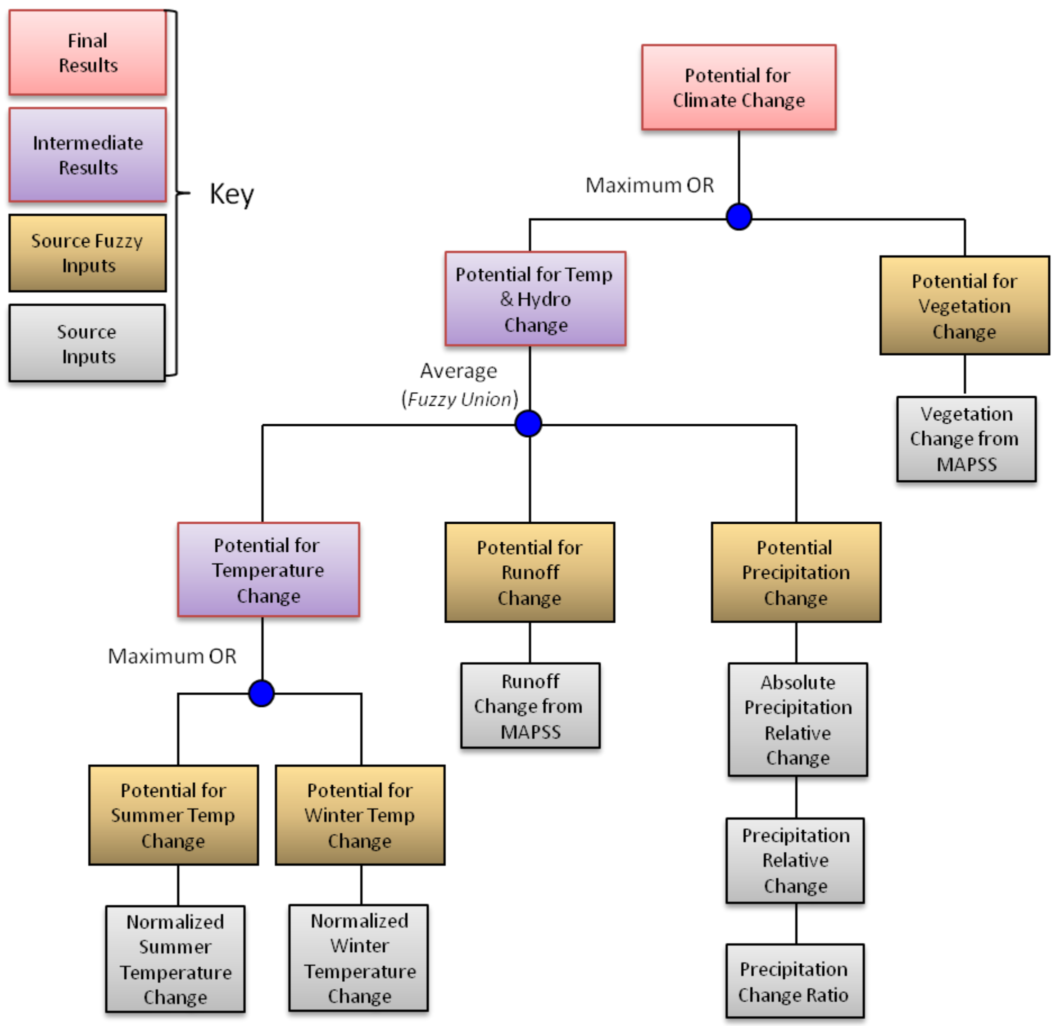


Figure 3-11. Logic diagram assembling key climate variables into an overall potential climate change surface that is applied to each of the conservation elements to project climate change exposure by 2060.

3.2.8 References Cited

Barrett, S., D. Havlina, J. Jones, W. Hann, C. Frame, D. Hamilton, K. Schon, T. Demeo, L. Hutter, and J. Menakis. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0, www.frcc.gov. Accessed 10/15/2011.

Brown, D.E., and R.A. Minnich. 1986. Fire and creosote bush scrub of the western Sonoran Desert, California. *American Midland Naturalist* 116:411–422.

CEC (Commission for Environmental Cooperation). 1997. Ecological regions of North America: Toward a common perspective. Commission for Environmental Cooperation, Montreal, Quebec, Canada. 71 pp. Map scale 1:12,500,000. Revised 2006.

Dickinson, R.E., R.M. Errico, F. Giorgi, and G T. Bates. 1989. A regional climate model for the western United States. *Climatic Change* 15:383–422.

Elith, J., S.J. Phillips, T. Hastie, M. Dudik, Y.E. Chee, and C.J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17:43–57.

Esque, T.C., and C.R. Schwalbe. 2002. Alien annual plants and their relationships to fire and biotic change in Sonoran desert scrub. Pages 165–194 *in* Tellman, B. (ed.), Invasive exotic species in the Sonoran region. Arizona-Sonora Desert Museum and University of Arizona Press, Tucson, Arizona.

Giorgi, F. 1989. Two-dimensional simulations of possible mesoscale effects of nuclear war fires. *Journal of Geophysical Research* 94:1127–1144.

Giorgi, F., R. Francisco, and J.S. Pal. 2003. Effects of a subgrid-scale topography and land use scheme on the simulation of surface climate and hydrology. Part 1: Effects of temperature and water vapor disaggregation. *Journal of Hydrometeorology* 4:317–333.

Grell, G.A., J. Dudhia, and D.R. Stauffer. 1994. Description of the fifth generation Penn State/NCAR Mesoscale Model (MM5). Technical Report TN-398+STR. National Center for Atmospheric Research, Boulder, Colorado. 121 pp.

Grover, H.D., and H.B. Musick. 1990. Shrubland encroachment in southern New Mexico, USA: An analysis of desertification processes in the American Southwest. *Climatic Change* 17(2-3):305–330.

Hack, J.J., B.A. Boville, B.P. Briegleb, J.T. Kiehl, P.J. Rasch, and D.L. Williamson. 1993. Description of the NCAR community climate model (CCM2). Technical Report NCAR/TN-382+STR, National Center for Atmospheric Research, Boulder, Colorado.

Hostetler, S.W., Alder, J.R., and Allan, A.M. 2011. Dynamically downscaled climate simulations over North America: Methods, evaluation, and supporting documentation for users. USGS Open-File Report 2011-1238, U.S. Geological Survey, Reston, Virginia, 64 p.

Kiehl, J.T., J.J. Hack, G.B. Bonan, B.A. Boville, B.P. Breigleb, D. Williamson, and P. Rasch. 1996. Description of the NCAR community climate model (CCM3). Technical Report NCAR/TN-420+STR, National Center for Atmospheric Research, Boulder, Colorado.

LANDFIRE. 2007. Biophysical Setting Model. Wildland Fire Science, Earth Resources Observation and Science Center, U.S. Geological Survey, Sioux Falls, South Dakota.

McGarigal, K., and B.J. Marks. 1995. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. U.S. Forest Service, General Technical Report PNW-GTR-351, U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. 122pp.

Miller, D.M., S.P. Finn, A. Woodward, A. Torregrosa, M.E. Miller, D.R. Bedford, and A.M. Brasher, A.M. 2010. Conceptual ecological models to guide integrated landscape monitoring of the Great Basin, USGS Scientific Investigations Report 2010-5133, U.S. Geological Survey, Reston, Virginia. 134 pp.

Miller, M.E. 2005. The structure and functioning of dryland ecosystems: Conceptual models to inform long-term ecological monitoring. USGS Scientific Investigations Report 2005-5197, U.S. Geological Survey, Reston, Virginia. 73 pp.

NAST (National Assessment Synthesis Team). 2000. Climate change impacts on the United States: The potential consequences of climate variability and change, US Global Change Research Program, Washington DC.

NatureServe. 2009. International ecological classification standard: Terrestrial ecological classifications. NatureServe Central Database, Arlington, Virginia.

Neilson, R.P. 1995. A model for predicting continental scale vegetation distribution and water balance. *Ecological Applications* 5:362–385.

Nellessen, J.E. 2012. *Larrea tridentata*. http://www.fs.fed.us/global/iitf/pdf/shrubs/Larrea%20tridentata.pdf. Accessed 1/12.

Reynolds, K.M. 1999. NetWeaver for EMDS version 2.0 user guide: A knowledge base development system. U.S. Forest Service, General Technical Report PNW-GTR-471, U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Reynolds, K.M. 2001. EMDS: Using a logic framework to assess forest ecosystem sustainability. *Journal of Forestry* 99(6) 26–30.

Sayre, N.F. 2005. Rangeland degradation and restoration in the “Desert Seas”: Social and economic drivers of ecological change between the sky islands. Pages 349–352 *in* Gottfried, G. J., B.S. Gebow, L.G. Eskew, and C.B. Edminster (compilers), Connecting mountain islands and desert seas: biodiversity and management of the Madrean Archipelago II, May 11–15, 2004, Tucson, Arizona. Proceedings RMRS-P-36, U.S. Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 631 p.

Turner, R.M., and D.E. Brown. 1994. Tropical-subtropical desertlands: Sonoran desertscrub. Pages 180–221 *in* Brown, D.E. (ed.), Biotic communities: Southwestern United States and northwestern Mexico. University of Utah Press, Salt Lake City, Utah.

Van Auken, O.W. 2000. Shrub invasions of North American semi-arid grasslands. *Annual Review of Ecological Systems* 31:197–215.

Van Dyke, F.G., R.H. Brocke, H.G. Shaw, B.B. Ackerman, T.P. Hemker, and F.G. Lindzey. 1986. Reactions of mountain lions to logging and human activity. *The Journal of Wildlife Management* 50(1):95–102.