Sonoran Desert

Rapid Ecoregional Assessment Report

U.S. Department of Interior
Bureau of Land Management

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BLM MISSION STATEMENT

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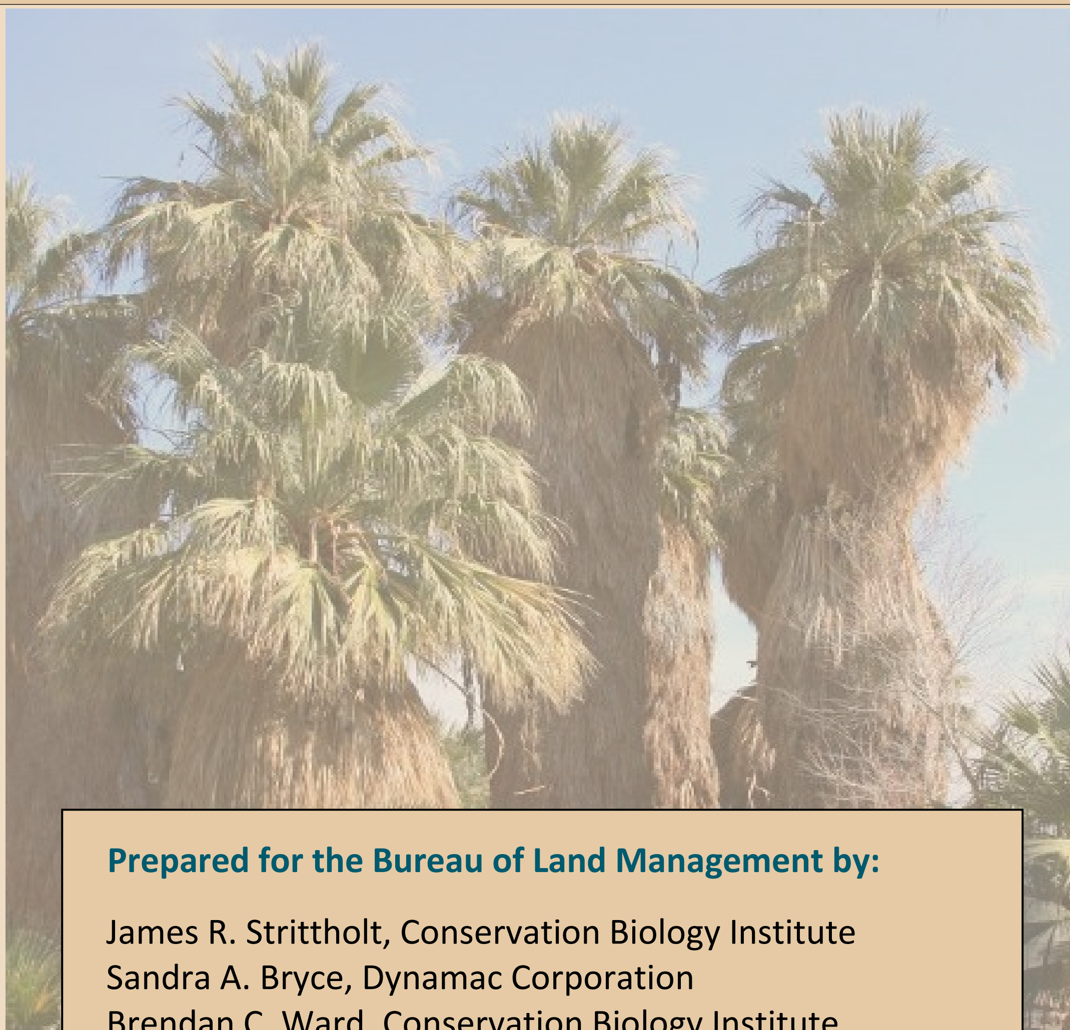

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Photo: Palm oasis near Palm Springs, Gary Burzell

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.

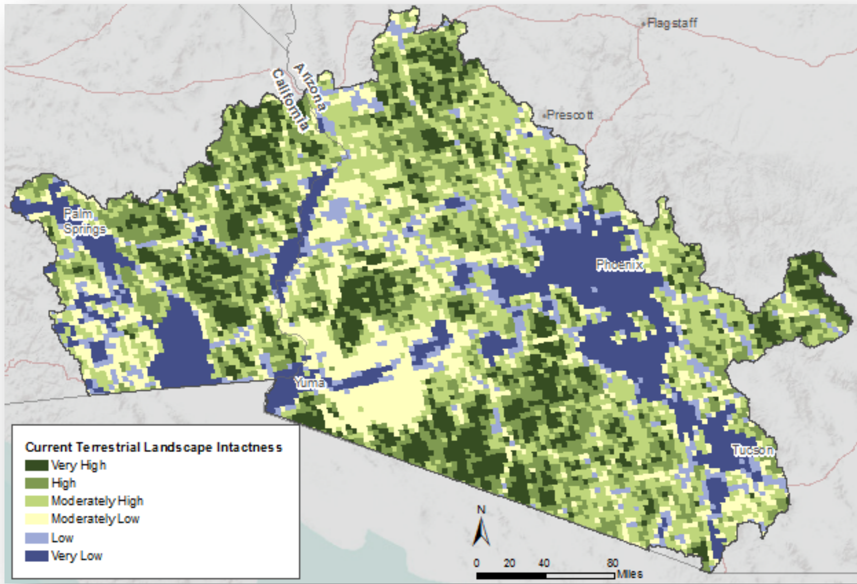

Figure 1. Sonoran Desert terrestrial landscape intactness in six classes from High (relatively undisturbed in dark green) to Very Low (highly disturbed from agriculture, resource development, or urbanization in dark blue) depicted with a 4 km X 4 km grid cell.

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.

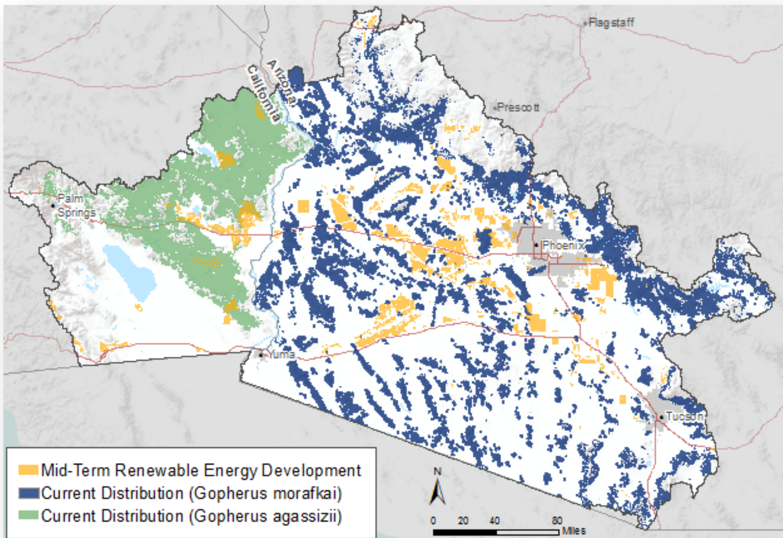

Figure 2. Map shows distribution of two desert tortoise species, the Mojave desert tortoise (in green) and the Sonoran desert tortoise (in blue) relative to mid-term (next several decades) renewable energy development (yellow) in the Sonoran Desert ecoregion.

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.

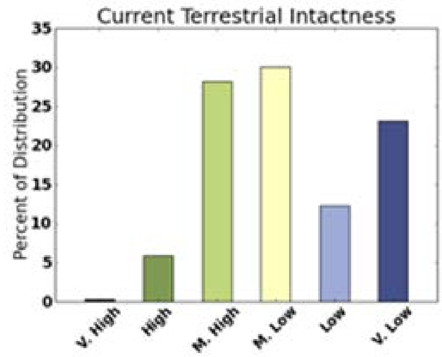

Figure 3. Histogram represents status for southwestern willow flycatcher in 6 intactness classes with about 35% of its distribution in the Low and Very Low intactness classes.

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

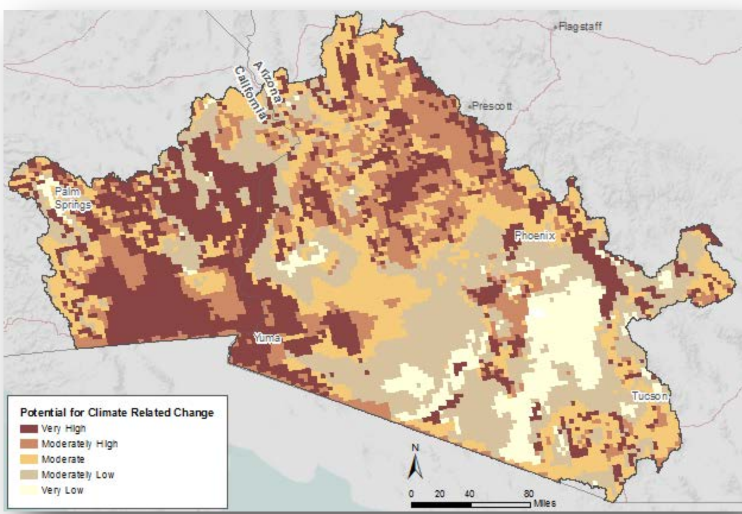

Figure 4. Map shows overall potential for climate change expressed in five classes from Very High (dark red-brown color) to Very Low (off-white). The southwest, west-central, and northeastern portions of the ecoregion have the highest potential for climate change.

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.

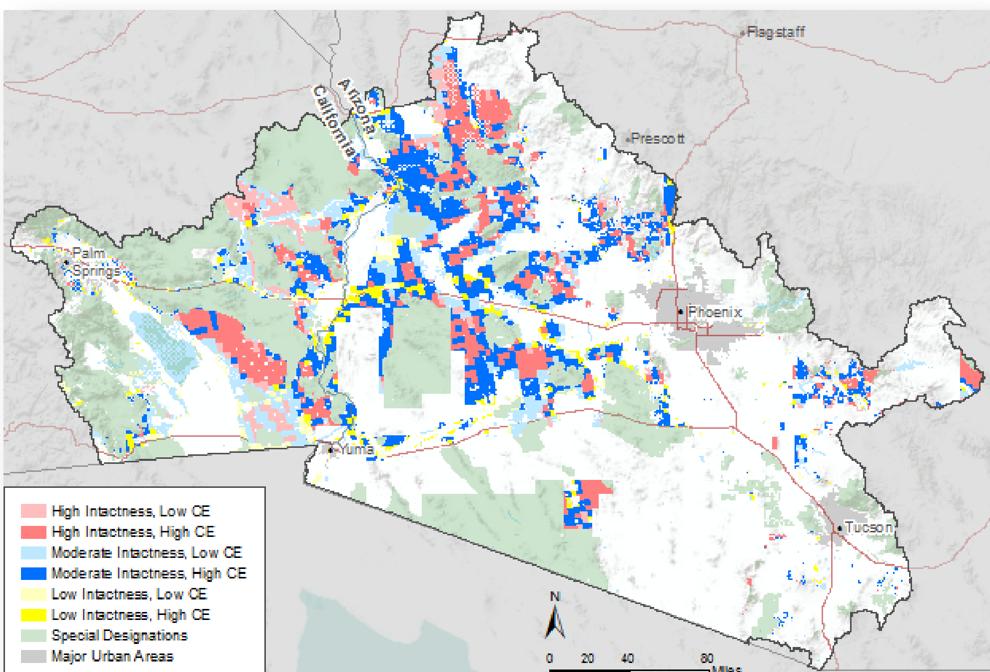

Figure 5. Map shows BLM-managed land areas of various intactness classes in the Sonoran Desert intersected with low and high concentrations of conservation elements (CEs). Designated protected areas are shown in green; white areas are non-BLM lands. Darker pink areas represent the intersection of high 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, 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 uses the information from the REAs and stakeholders to develop a broad scale management strategy for an ecoregion's BLM-managed lands.

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.

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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.

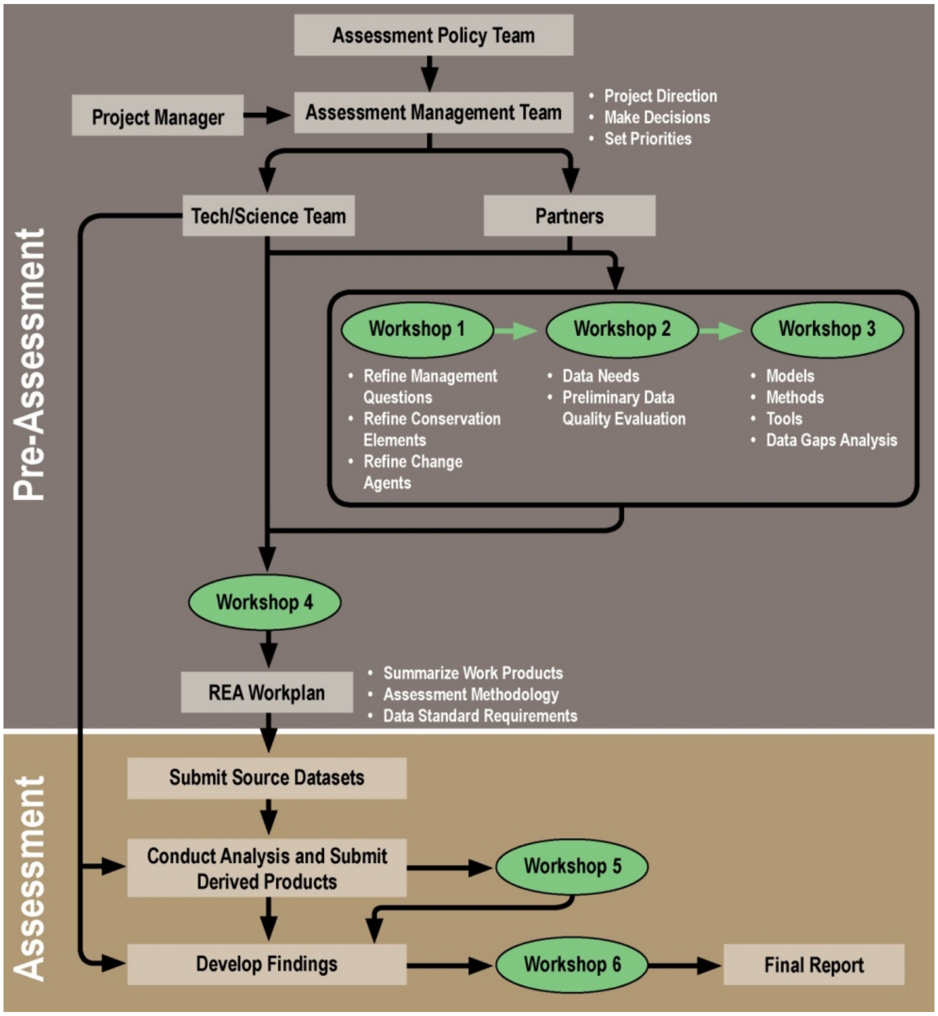

Figure 2-1. REA workflow divided into pre-assessment and assessment phases with regular workshops. Contents of each of the first three workshops listed beneath each workshop symbol in white text. Workshop 4 marked the preparation of a workplan with formal timelines, workflow, and review process. Workshops 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.

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.

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%

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 <u>components</u> and their <u>interactions</u> 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.

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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.

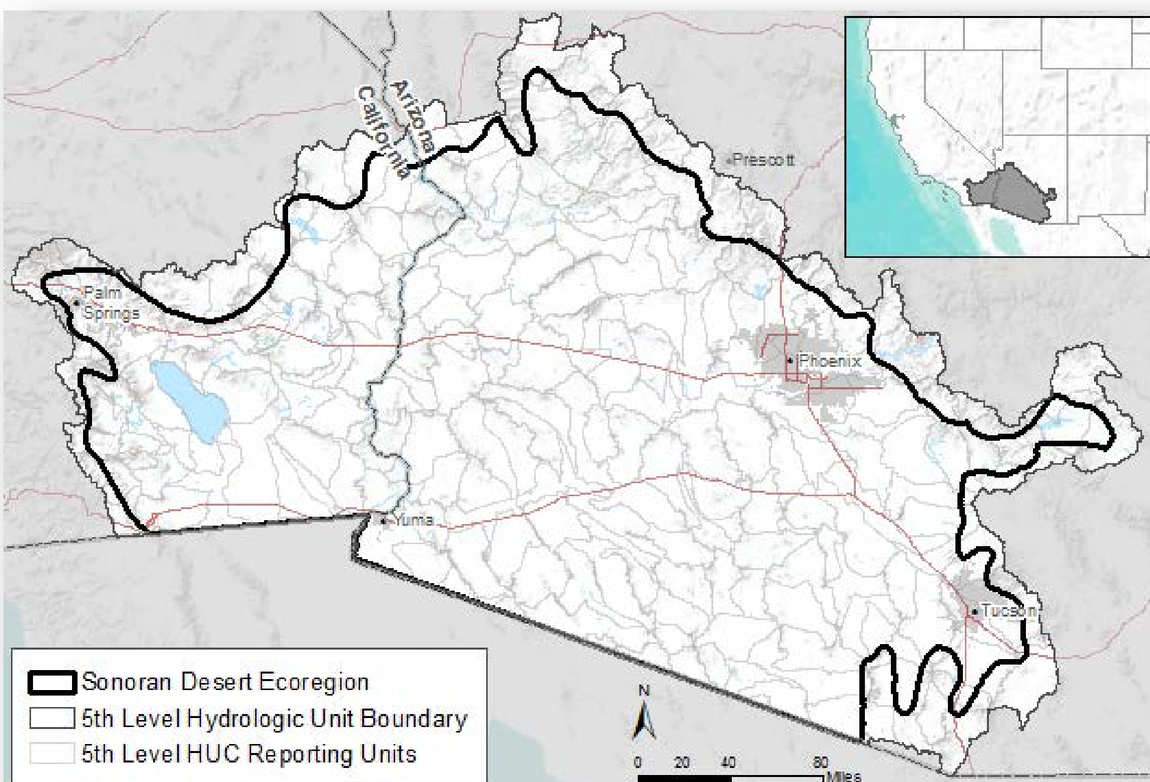

Figure 3-1. Map of the Sonoran Desert ecoregion showing hydrologic unit boundaries and analytical extent.

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

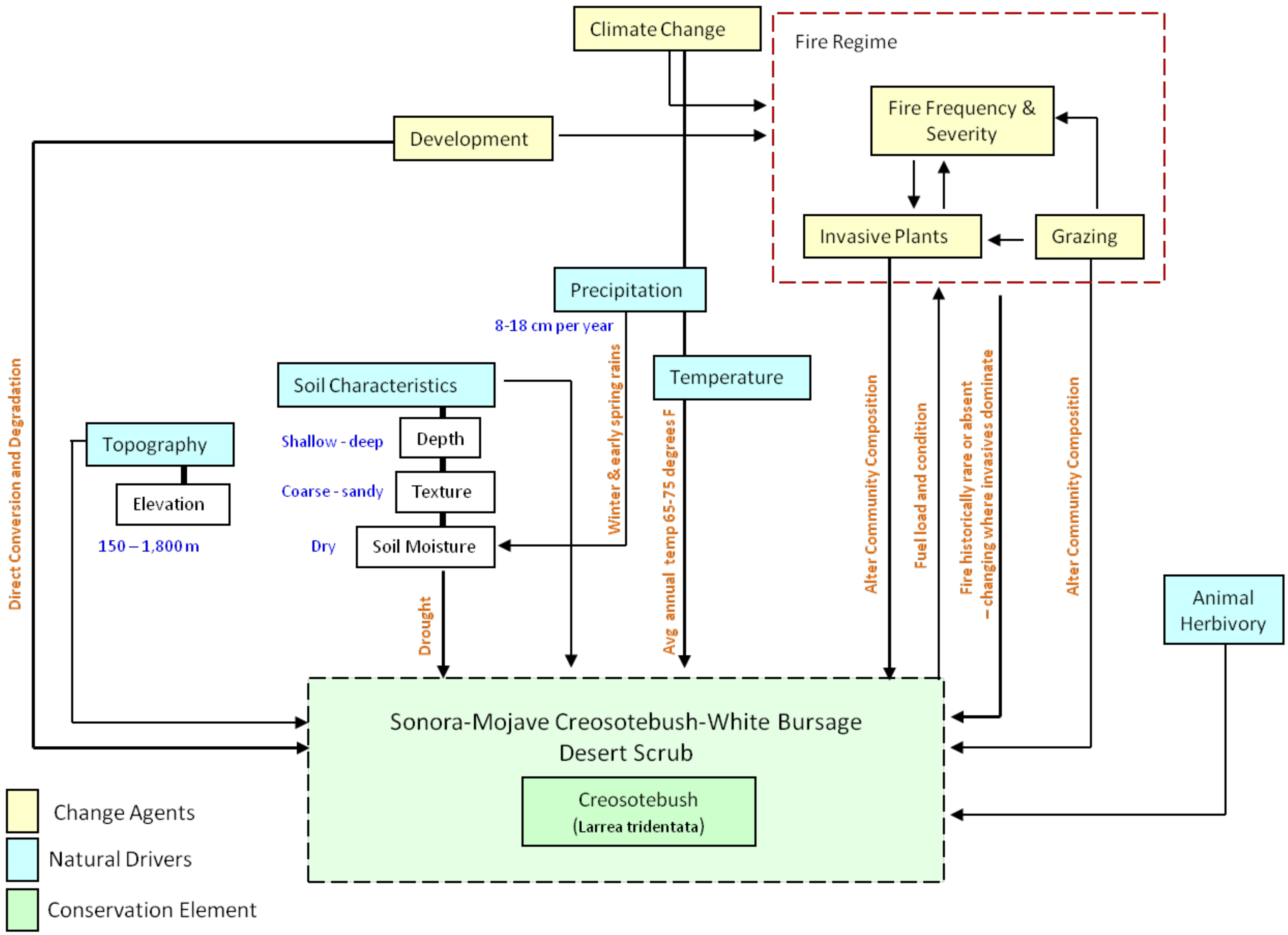

Figure 3-2. Conceptual model diagram for Sonora-Mojave Creosotebush-White Bursage Desert Scrub in the Sonoran Desert ecoregion. Note: Thicknesses of the arrows do not represent degree of importance, but those factors that are tracked or modeled throughout the REA analysis.

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.

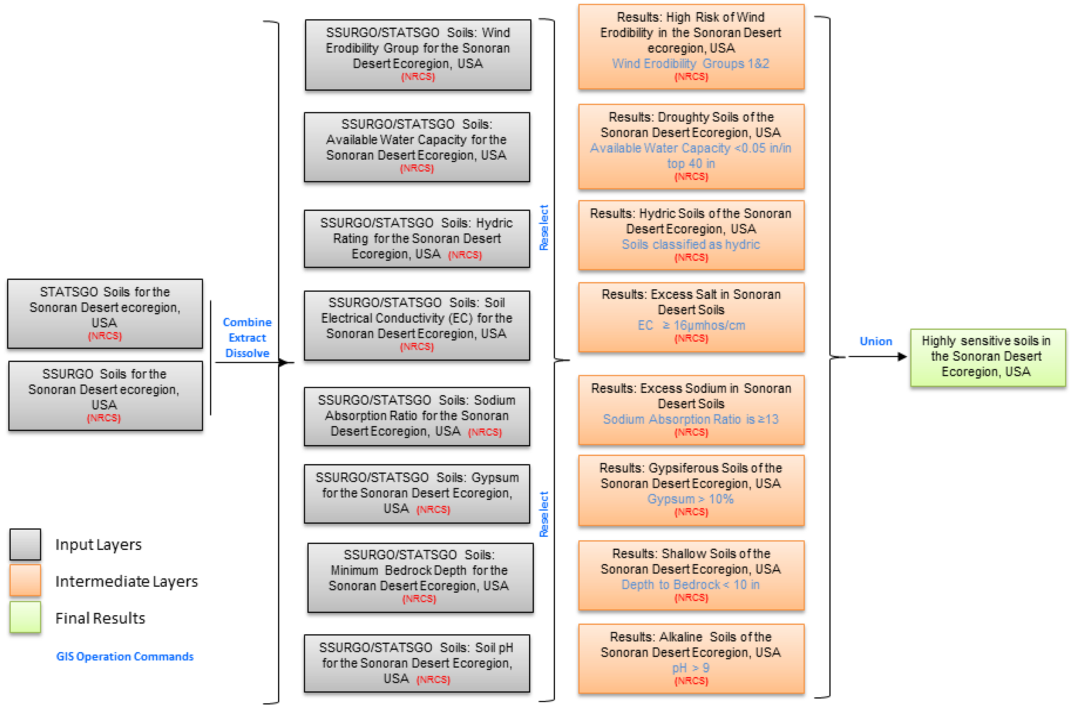

Figure 3-3. Process model diagram for soil sensitivity in the Sonoran Desert ecoregion: Management Question, *Where are sensitive soils (including saline, sodic, gypsiferous, shallow, and low water holding capacity)?*

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 <u>arrangement of the various data inputs and intermediate products</u>—the higher up in the diagram, the greater the influence on the final result.

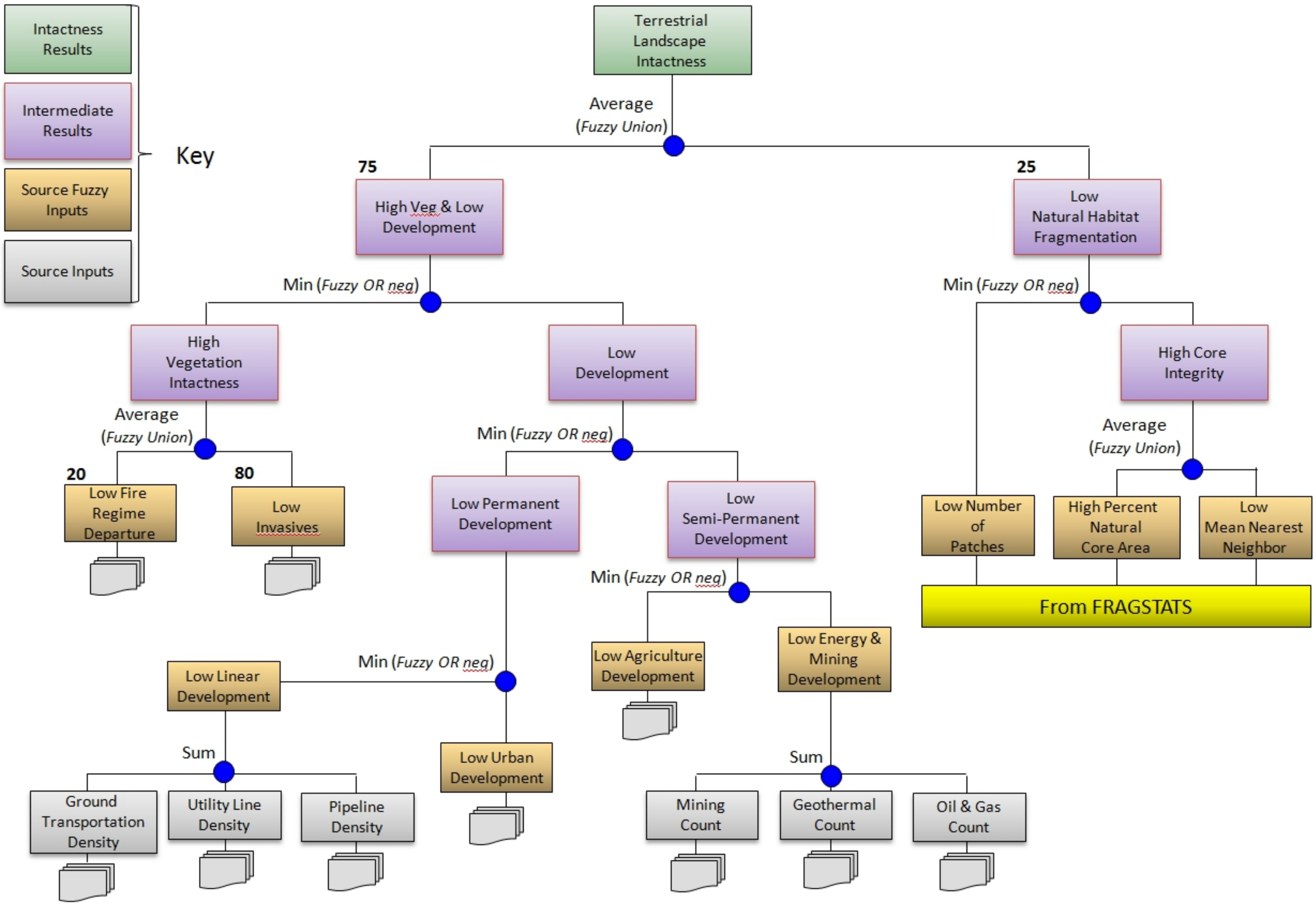

Figure 3-4. Logic model for terrestrial landscape intactness for the Sonoran Desert ecoregion.

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.

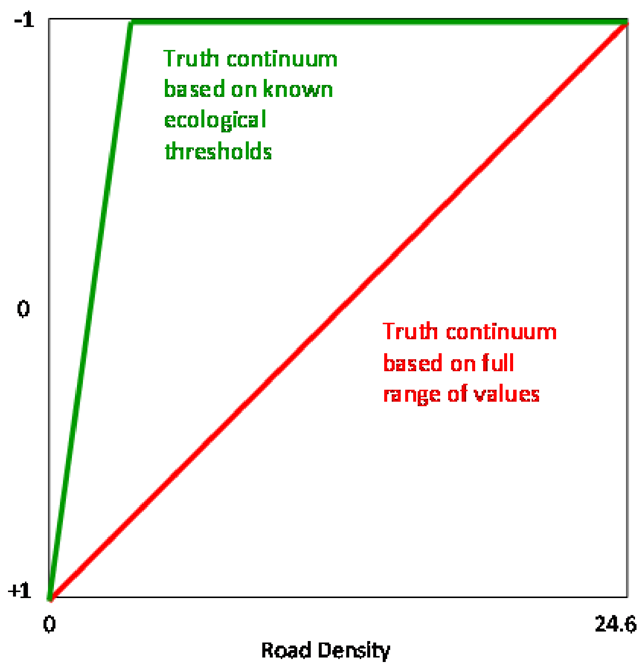

Figure 3-5. Diagram of two treatments of road density in fuzzy logic modeling illustrating important model control options, one based on a full range of values (red line) and the other based on a known threshold for road density (> 0.60 km/km^2 is totally false [-1], green line).

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).

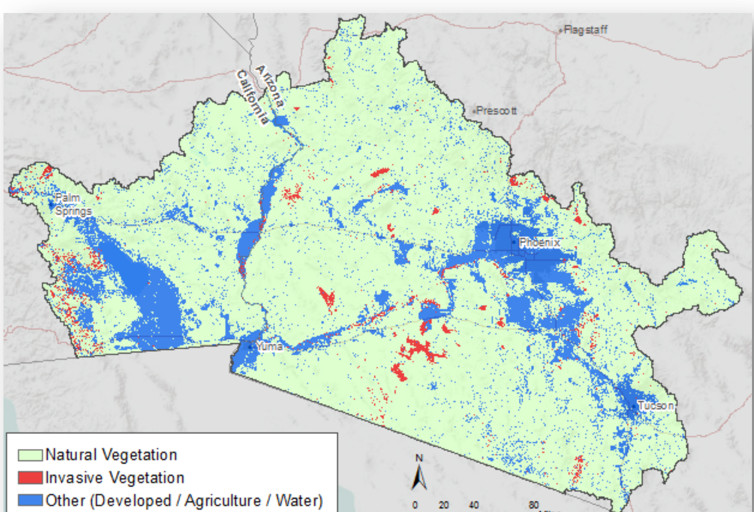

Figure 3-6. Prior to running FRAGSTATS, the entire landscape was mapped into three classes: natural vegetation, invasive species, and other (including developed, agriculture, and water).

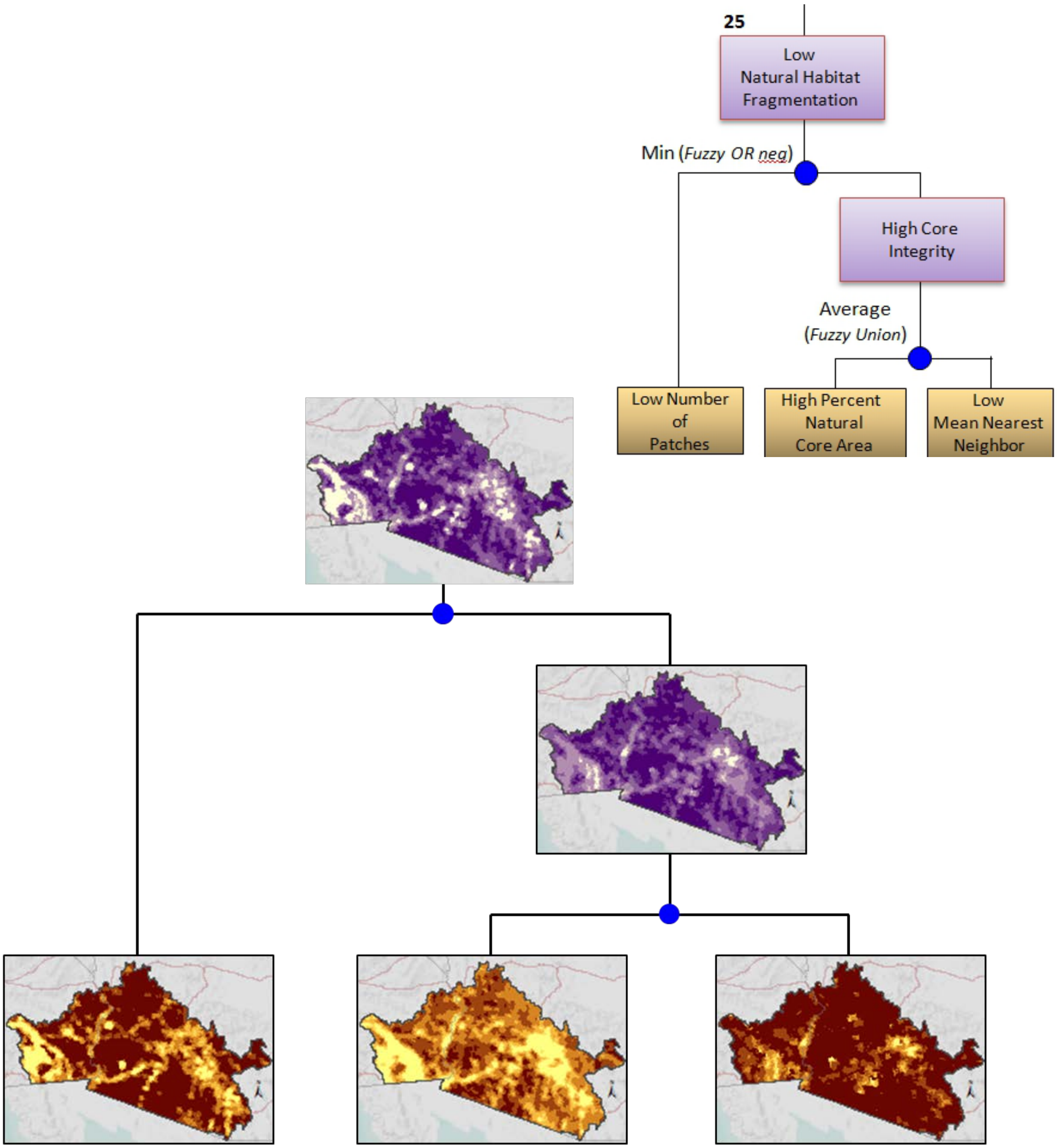

Figure 3-7. FRAGSTATS-based fragmentation inputs into the terrestrial landscape intactness model at 4km resolution for the Sonoran Desert ecoregion. Two of the FRAGSTAT functions (Percent Natural Core Area and Average Mean Nearest Neighbor) were averaged together to create an intermediate layer called 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.

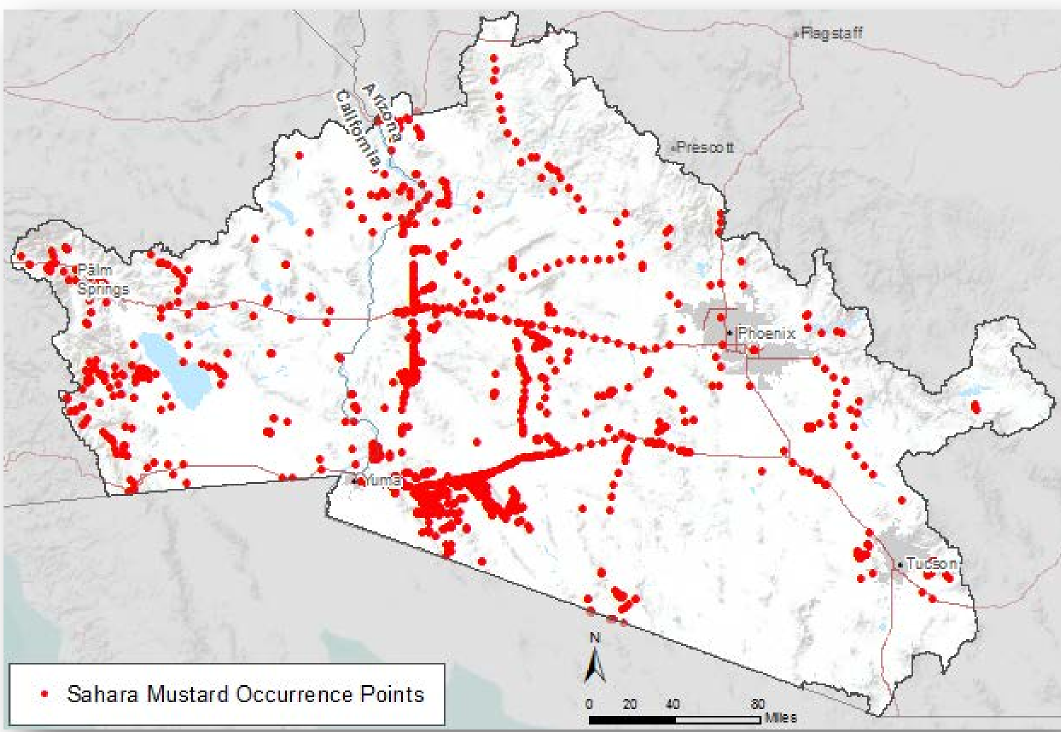

Figure 3-8. Sahara mustard (*Brassica tournefortii*) in the Sonoran Desert ecoregion. A MaxEnt (Elith et al. 2011) model was developed based on occurrence data from a number of sources (1,539 occurrence records), and predictive surfaces based on elevation, soil characteristics (percent sand, available 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.

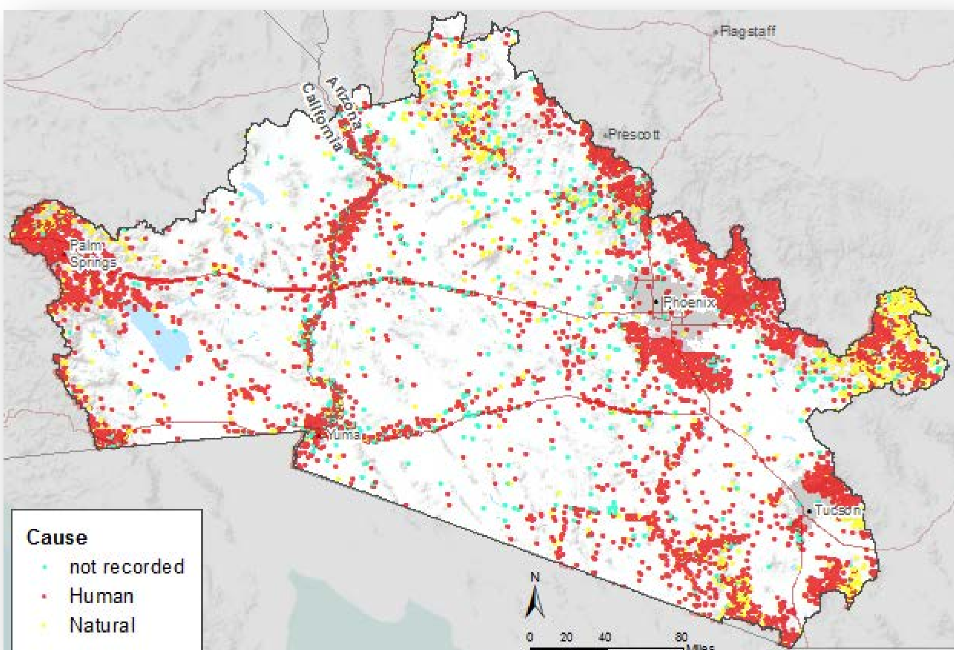

Figure 3-9. Fire occurrences between 1980 and 2010 according to cause of ignition.

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).

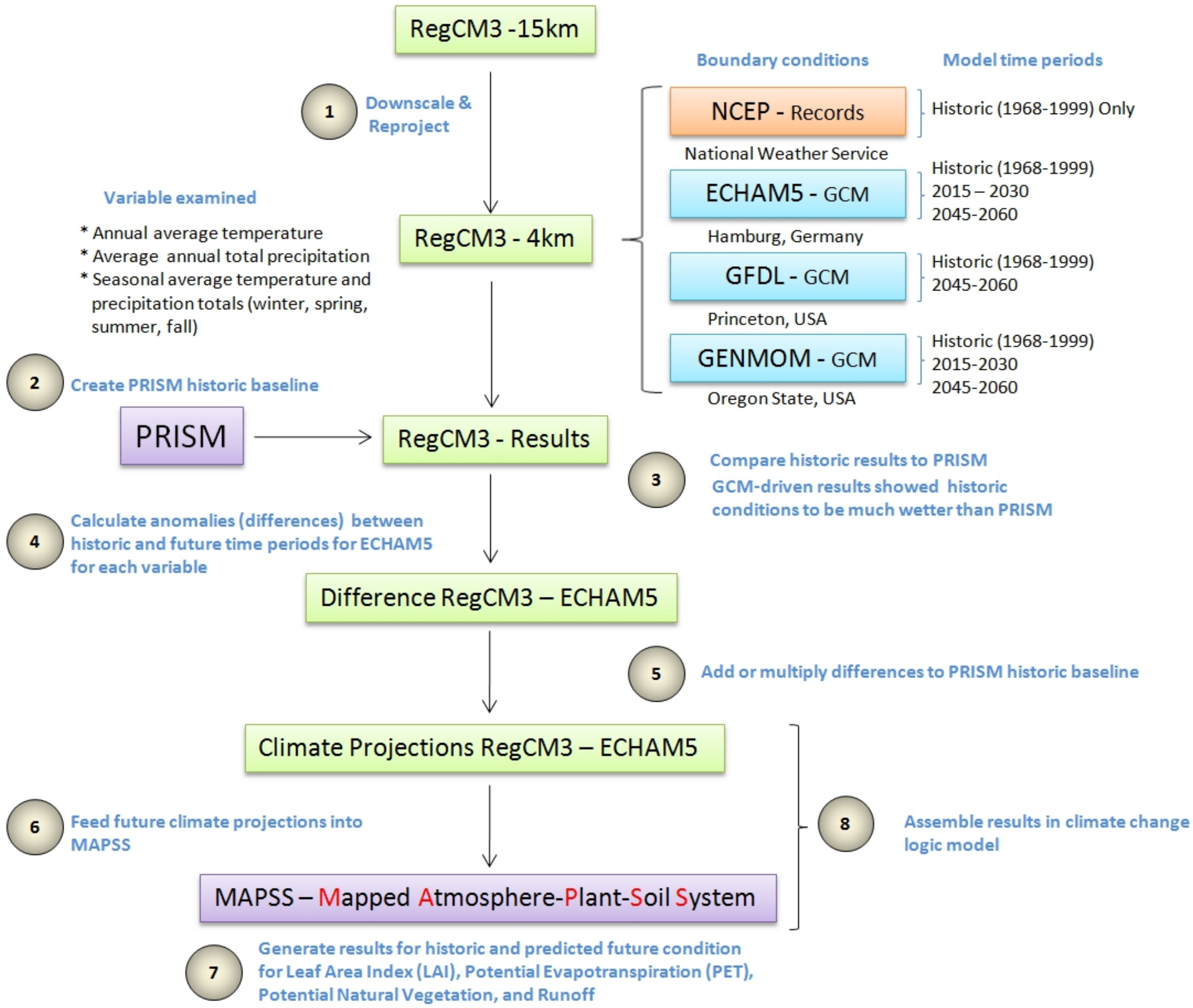

Figure 3-10. Climate change processing workflow.

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.

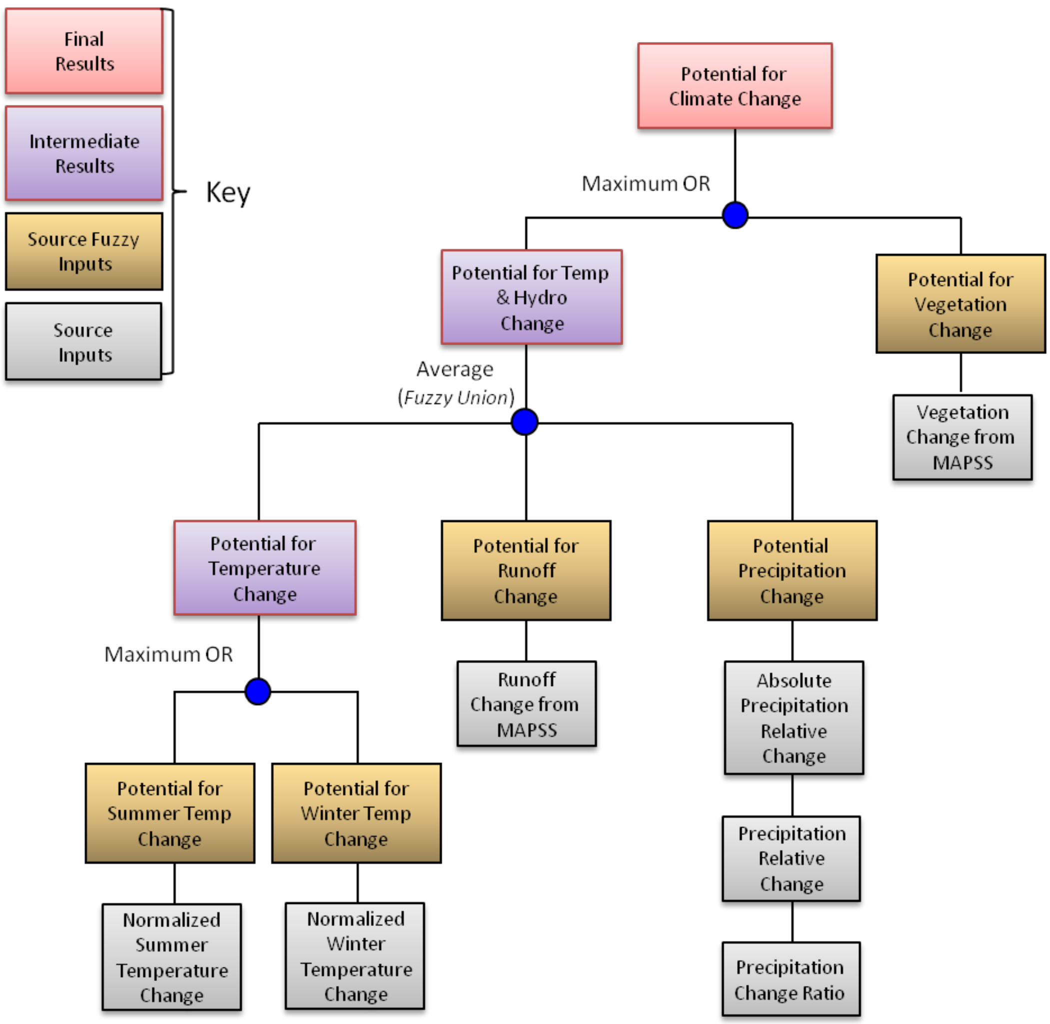

Figure 3-11. Logic diagram assembling key climate variables into an overall potential climate change surface that is applied to each of the conservation elements to project climate change exposure by 2060.

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IV. EXISTING CONDITIONS IN THE SONORAN DESERT

Current conditions in the Sonoran Desert ecoregion are introduced in this chapter with an overview of ecoregion character, terrestrial resources of concern, coarse filter vegetation communities, and aquatic resources (Section 4.1). The regional landscape intactness results for terrestrial and aquatic ecosystems and status for each of the core conservation elements appear in Section 4.2; the major change agents that affect the conservation elements are covered in Section 4.3. Two Case Study Inserts on a key conservation element, the desert tortoise, and the invasive riparian shrub tamarisk (or saltcedar) provide a more detailed discussion of two important regional issues. Since the huge volume of REA results can only be summarized in the body of the report, Appendices A–E (referenced periodically) provide additional information on methods and models and specific results for all conservation elements and change agents.

4.1. Sonoran Desert Resources of Concern

4.1.1 Ecoregion Character

Photo: Waterman Mountain view with transitional East Sonoran Basin (81l on ecoregion map) to Arizona Upland East Sonoran Mountains (81k) vegetation community. M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona

The Sonoran Desert is considered a subtropical desert, somewhat warmer than the adjacent temperate warm deserts—the Mojave and Chihuahuan—that experience more seasonal variability in temperature (Turner and Brown 1994). Topographically, the Sonoran Desert is divided into a lower, drier western section, that includes the Salton Sea basin and the lower Colorado Desert (regions marked 81a, 81b, 81f, 81i, and 81j in Level IV ecoregion map in Figure 4-1) and a higher eastern section, the Arizona Upland, that is somewhat cooler and relatively moist by desert standards (ecoregions 81k, 81l, and 81n).

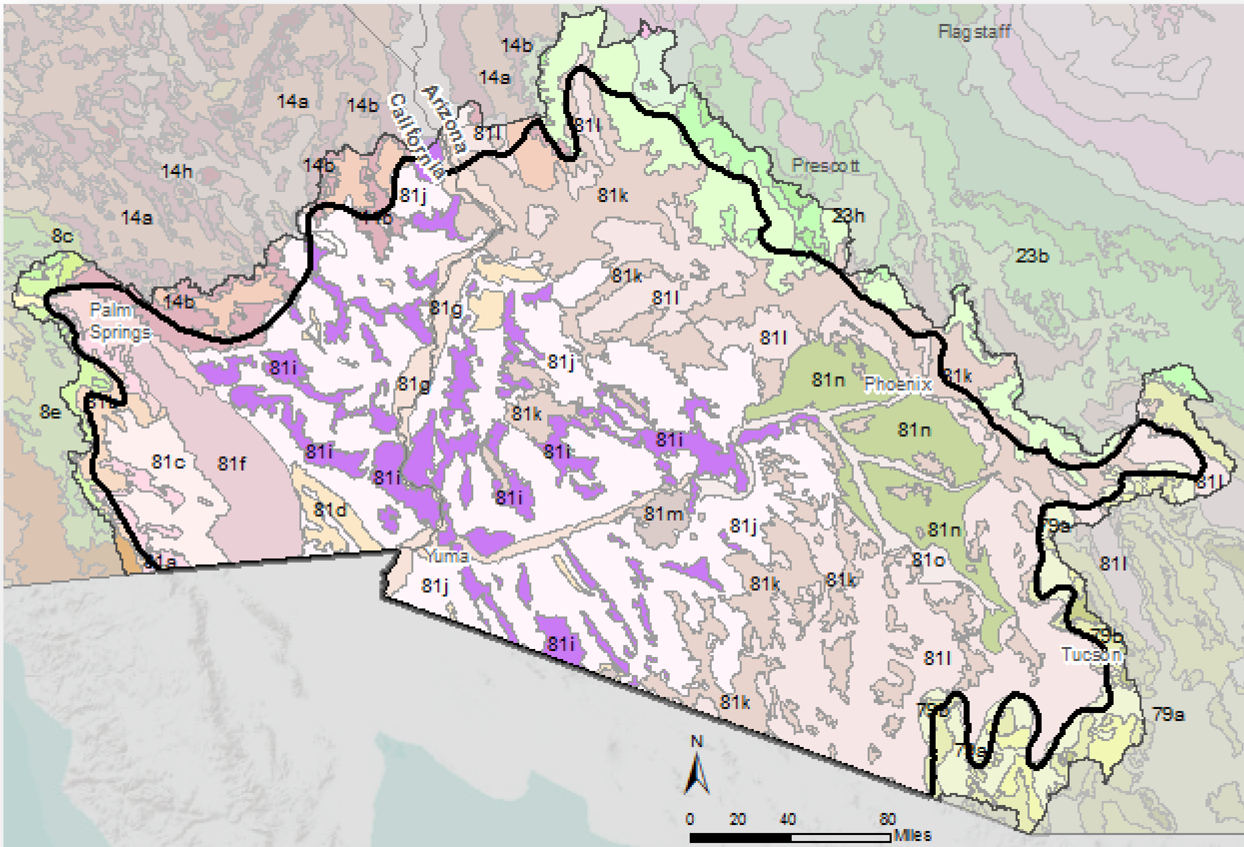


Figure 4-1. Level IV ecoregions of the Sonoran Desert, Griffith et al. (In Preparation a and b).

Across this elevational gradient, from the Salton Sea, at an elevation of 60 m (227 feet) below sea level, to the eastern boundary of the ecoregion at about 900 m (2950 ft.) on the western slope of the Mogollon Rim, precipitation ranges from 75–255 mm (3 to 10 inches). In the desert, a small difference in the amount or seasonality of precipitation can make a dramatic difference in vegetative cover; in the eastern Sonoran Desert a bimodal precipitation pattern supports a more diverse flora than that in other North American deserts (Dimmitt 2000a, Turner and Brown 1994).

Winter rainfall originates from the Pacific Ocean and decreases from west to east, depositing the greater proportion of rainfall in the northwest portion. During the summer monsoon, a shift of wind brings rain from the south beginning in July through September, mostly as localized storm cells (Turner and Brown 1994). Summer rainfall occurs in the opposite pattern, decreasing east to west, with most falling in the southeast portion (providing 30–60% Arizona Upland annual precipitation). Episodic summer storm events send pulses of flood water overland and down ephemeral and intermittent stream channels, prompting the growth of opportunistic summer annuals. The portion of Sonoran desert flora with subtropical origins has evolved with heat and aridity and this summer precipitation pattern, relying on summer rain for germination. Adequate winter precipitation, on the other hand, is necessary to sustain the region's winter annual plants (with a Mojave origin) that germinate in the winter and bloom in early spring (Turner and Brown 1994, Dimmitt 2000b, Van Devender 2000). The desert vegetation that characterizes the Sonoran Desert today has evolved fairly recently during the 9000 years since the end of the Pleistocene, with the northward movement of desert scrub and saguaro into the region followed by foothills palo verde and ironwood (Van Devender 2000).

The Colorado Desert covers the Salton Sea and Lower Colorado River basins eastward to the transition with the Arizona Upland. It is the hottest and driest of the two subregions with annual precipitation levels as low as 0–76 mm (3 in.). The western boundary of the region extends partly up the lower slopes of the California coastal mountains to where winter precipitation increases enough to support coastal chaparral (81b-8e boundary on ecoregion map). The northern boundary with the Mojave Desert follows the southern slopes of the mountain ranges within Joshua Tree National Park. The Colorado Desert is characterized by broad basins and playas punctuated by extremely dry and barren mountain ranges. Creosotebush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) cover an estimated 42% of lower elevations (Prior-Magee et al. 2007). The plants grow regularly spaced in fine-textured soils—their distance apart regulated by water availability and soil water-holding capacity (Dimmitt 2000b, Turner and Brown 1994). Saltbush (*Atriplex* spp.) is a secondary Colorado Desert vegetation community that was historically more widespread in the Gila Valley, Arizona and Coachella Valley, California until it was largely cleared for agriculture (Turner and Brown 1994).

Parts of the region that do not drain directly to the Salton Sea or to the Colorado River are internally drained with a network of anastomosing rills and washes that typically end with water absorbed into a basin or playa floor. The few tree species in the region (such as honey mesquite [*Prosopis glandulosa*], ironwood [*Olneya tesota*], blue palo verde [*Parkinsonia florida*], smoke tree [*Dalea spinosa*] and desert willow [*Chilopsis linearis*]) grow along these drainages or wherever ground water is forced nearer the surface. For example, honey mesquite forms groves or bosques at the scalloped edges of dune fields or where ground water is within reach (Jaeger 1957, Turner and Brown 1994, Barbour et al. 2007).

Photo: Fan palms (*Washingtonia filifera*), Indio Hills, California. M.A. Dimmitt, Arizona-Sonora Desert Museum Digital Library, Tucson, Arizona

Sand dunes and palm oases represent important fine filter communities of the Colorado Desert. Areas of sand dunes, such as the Algodones, Mohawk Valley, and Copper Basin Dunes (81d, ecoregion map), occur southeast of the Salton Sea and along the Colorado River. Forrest Shreve estimated that about 14% of the Sonoran Desert (in the US and Mexico) was in sand plain or dunes (F. Shreve in Jaeger 1957). Fan palm (*Washingtonia filifera*) oases occur in canyons and desert washes north and east of the Salton Sea (e.g. Palm Springs area) and in canyons on the eastern slopes of the San Jacinto and Santa Rosa Mountains (photo left, mountain ranges north and west of 81c on ecoregion map). Both of these ecosystems serve as refugia for a number of endemic and threatened and endangered species.

The transition between the Colorado Desert and the Arizona Upland occurs east of the Colorado River at about 300 m (984 ft.) where elevation and summer rainfall increase and winter temperatures fall (Turner and Brown 1994, Dimmitt 2000b, Griffith et al. In Preparation a). Although the landscape of the Arizona Upland does contain a number of broad valleys, the character of this portion of the ecoregion is defined more by its mountain ranges and bajadas (coalesced alluvial fans). A transitional Colorado Desert community occurs on the toeslopes of alluvial fans and lower bajadas, becoming more characteristic of the Arizona Upland higher upslope where desert trees and cacti become more abundant. At upper elevations of about 900 m (2952 feet), the ecoregion meets characteristic transitional vegetation (grassland or interior chaparral) of cooler and wetter ecoregions to the north and east (Arizona/New Mexico Mountains and Madrean Archipelago, Level III ecoregions 23 and 79, respectively, on ecoregion map).

4.1.2 Ecoregion Conceptual Model

The expression of known relationships in conceptual models forms the basis for the development of management questions and the selection of associated data layers and analyses. The ecoregion conceptual model gives a broad scale overview of the region, denoting important natural drivers and anthropogenic change agents (Figure 4-2). Later in the REA process, more detailed conceptual models were delineated to relate individual conservation elements to topical information gleaned through literature review and to identify what portion of that information was quantifiable and accessible as spatial data. In the ecoregion conceptual model, regional climatic conditions represent the dominant natural change agent. Secondary natural change agents include cyclical drought and the natural fire regime (a minor factor in the Sonoran Desert in presettlement times, but included here to help illustrate recently increasing incidence of fire). Human activities, or anthropogenic change agents, include land and resource use, which covers urban and industrial development, surface and groundwater extraction, recreation, agriculture, grazing, and the introduction of invasive plants.

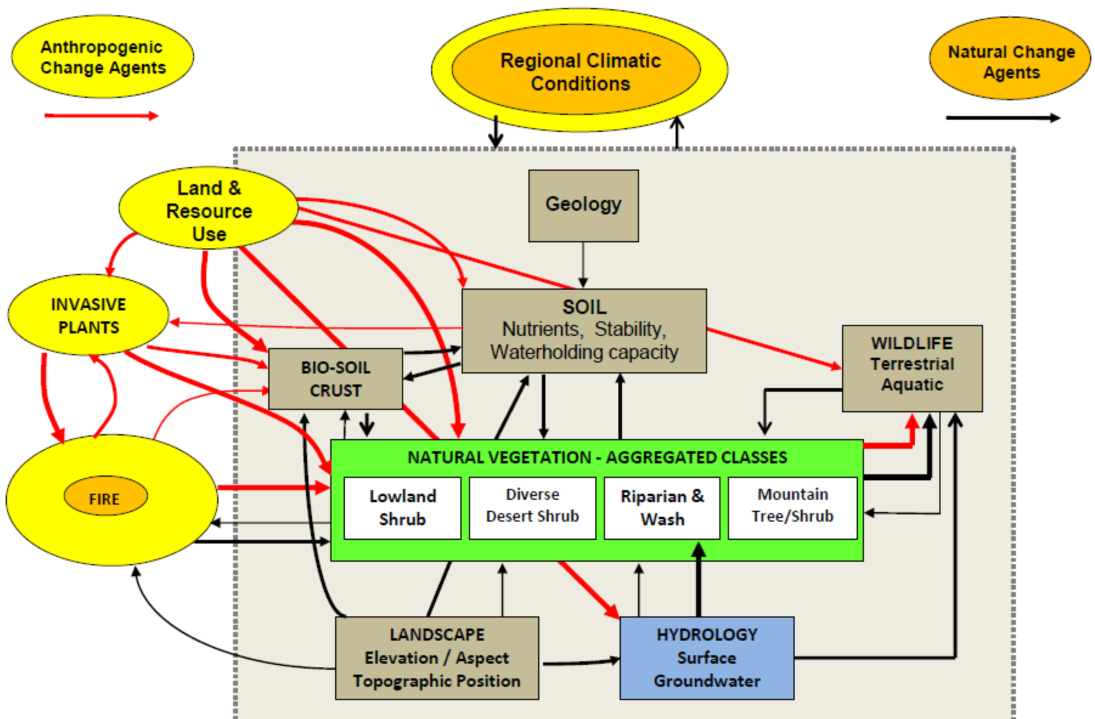


Figure 4-2. Basic ecoregion conceptual model for the Sonoran Desert ecoregion, with both natural and anthropogenic change agents shown. Boxes represent ecosystem components and conservation elements, ovals represent classes of change agents (natural and anthropogenic), and arrows represent the direct and indirect effects of change agents on conservation elements.

The orange and yellow concentric ovals surrounding the change agent *fire* symbolize the change in fire regime in the Sonoran desert in recent decades; historically, fire was not a major influence in the Sonoran desert, but the introduction of invasive annuals such as red brome (*Bromus madritensis L. ssp. rubens*) has been one factor implicated in the increasing incidence of fire (D'Antonio and Vitousek 1997, Esque et al. 2006). Similarly, a yellow concentric oval surrounds regional climate to indicate ongoing human-induced climate change in the region. Across the ecoregion, variability in geology, physiography, elevation, aspect, ground and surface water availability, and soil (texture, depth, and water-holding capacity) is reflected in patterns of vegetation.

Wildlife occurrence and abundance is dependent on interactions with all these abiotic factors (most importantly in the Sonoran ecoregion, temperature regulation and water availability) and the vegetation classes (or major habitats).

Four major natural vegetation (coarse filter) classes are centrally located in the model. The vegetation classes are depicted according to elevational and moisture differences; they represent aggregations of the Southwest Regional Gap Analysis (SW ReGAP) Ecological Systems classes covering more than 1 or 2% of the ecoregion area (Prior-Magee et al. 2007). The *Mountain Tree/Shrub* category is drawn from the Forest and Woodland and upper Shrub/Scrub vegetation classes—represented by small patches of chaparral, broadleaf evergreen, or conifer species in the transition to neighboring ecoregions or at the tops of Sonoran mountain ranges. The box marked *Diverse Desert Shrub* represents the upland Sonoran Paloverde-Mixed Cacti Desert Scrub (that includes saguaro) and the Mojave Mid-Elevation Mixed Desert Scrub (including the Joshua tree anomaly). *Lowland Shrub* corresponds to the Sonora-Mojave Creosotebush-White Bursage Desert Scrub, Sonora-Mojave Mixed Salt Desert Scrub, and the Sonoran Mid-Elevation Desert Scrub classes common to the Colorado Desert in the central and western Sonoran Desert. The box marked *Riparian and Wash Communities* represents the vegetation classes Woody Wetland and Riparian Communities and Emergent Herbaceous Wetlands. Xeroriparian desert wash communities—the North American Warm Desert Riparian Mesquite Bosque and the North American Warm Desert Wash—are also included in this class.

Although biological (cryptogamic) soil crusts might logically fall into several of the coarse-filter vegetation classes, soil crust is pictured separately in the ecoregion conceptual model to highlight its importance. Soil crusts serve as intermediaries between soil and vegetation, with important soil stabilization and nitrogen-fixing roles to play (Belnap and Gillette 1998, Belnap 2002, Housman et al. 2006). Biological soil crusts, composed of algae, lichens, and cyanobacteria, are important to hold the soil surface and to slow the spread of invasive annuals in a region with sparse vegetation. Biological soil crust is easily destroyed by vegetation disturbance of all kinds—clearing, trampling, and OHV traffic—opening the soil to exotic species invasion. Invasive species cover may be 4 times as high on damaged soil as on intact soil with biological soil crust (Wilson et al. 2002).

Photo: Biological soil crust, Saguaro National Park, Rincon Mountains, National Park Service.

In the Sonoran Desert, under hotter and drier conditions, soil crust does not develop as much of a pronounced visible corrugated micro-topography as it does farther north in the colder Central Basin and Range or Colorado Plateau ecoregions where frost heaving is common. In the Sonoran Desert where freezing occurs less often, crusts have a flatter appearance particularly where only cyanobacteria are present (Belnap et al. 2001). Where summer monsoons are consistent, cyanobacteria show greater species diversity and lichen abundance is reduced (fall, winter, spring moisture is optimal for lichen). However, even a thinner soil crust layer fixes nitrogen and binds soil particles together. Although REA participants recognized the importance of soil crust in the Sonoran Desert and initially selected it as a core conservation element, it was deleted as a conservation element during the pre-assessment phase when it became apparent that spatial data were lacking and modeling without adequate occurrence data would not be feasible.

4.1.3 Terrestrial Resources of Concern

4.1.3.1 Soil Stability

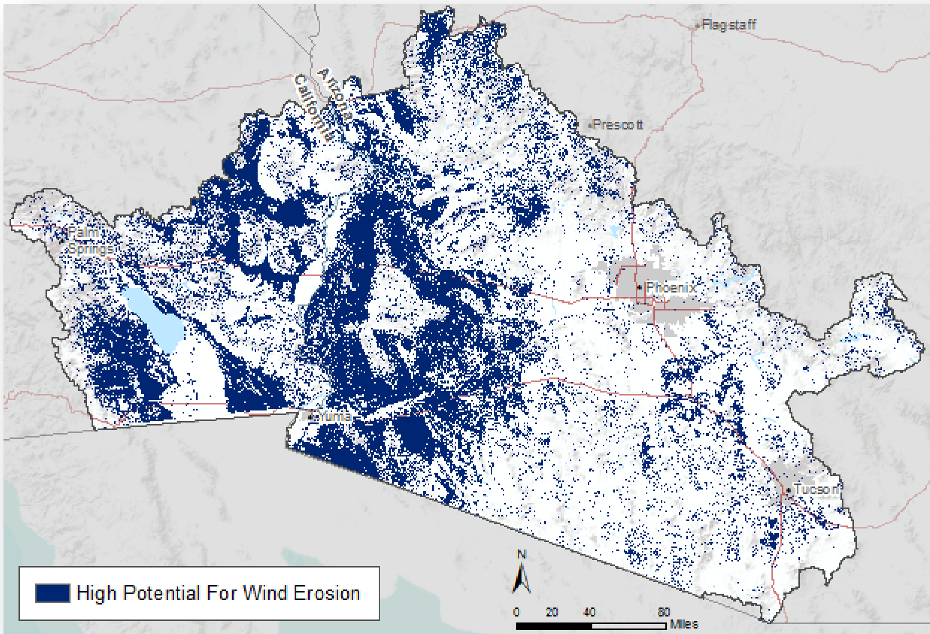
Soils Management Questions

1. Where are soils susceptible to wind and water erosion?
2. Where are sensitive soils (including saline, sodic, gypsiferous, shallow, low water holding capacity)?

Soil stability was selected as a terrestrial function of high ecological value for the Sonoran Desert REA. Sonoran Desert soils contain a high level of soluble salts and low humus content. Aridisol and Entisol soil orders are dominant with thermic and hyperthermic soil temperatures and aridic soil moisture regimes (McAuliffe 1994). Calcium carbonate commonly precipitates out in the soil to produce a *caliche* layer that restricts the downward movement of water (McAuliffe 2000). Sonoran Desert soils are sensitive with sparse vegetative cover and exposed to erosion by a number of natural and anthropogenic change agents. Soils on bajada slopes vary from rocky, colluvial material near the top to finer materials at the base. Finer silts and clays are carried to the basins by wind and water erosion where they have accumulated to 1000s of feet deep (McAuliffe 2000). Persistent wind and wind erosion of soil is a natural phenomenon in desert ecosystems, but human activities including energy and urban development, utility corridors, agriculture, recreation, and grazing all disturb the soil surface, exposing it to erosion. Wind erosion removes nutrients and growing medium from shallow desert soils and semi-arid agricultural areas. Airborne soil particles affect air quality and visibility, nutrient balance, and spring snowmelt in mountainous areas downwind, and blowing dust creates a health and safety hazard for the region's residents (Neff et al. 2008). Evidence suggests that accelerated wind erosion has occurred since Euro-American settlement and may increase in the future with increasing drought predicted under future climate change (Neff et al. 2008).

Photo: Dust storm approaching Phoenix, Arizona, 2003.

REA component maps produced using STATSGO and higher resolution SSURGO data, where available, depict classes of sensitive soils, wind erodibility, and a composite map of sensitive soils in the region (Figure 4-3, See Appendix A for modeling approach, data sources, and component maps).



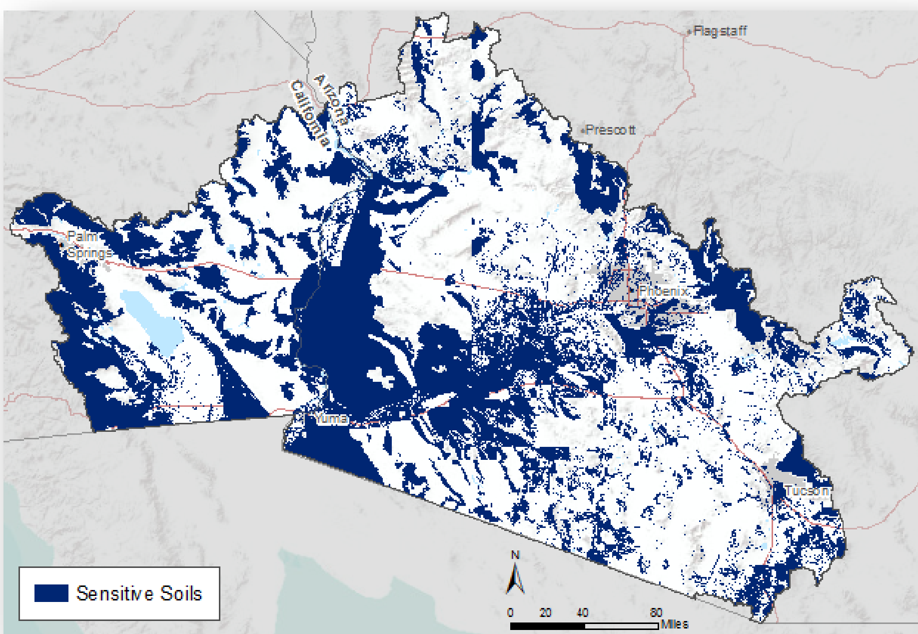


Figure 4-3. Top: Map depicting soils with high risk of wind erodibility in the Sonoran Desert ecoregion. Fine-textured soils susceptible to wind erosion are located mainly in the western and central portion of the Sonoran Desert in the basins of the Colorado Desert. Bottom: Map showing all classes of sensitive soils, including droughty, shallow, hydric, gypsiferous, saline, sodic, and calcareous.

The data for the soil maps were drawn from the 1:24,000 Soil Survey Geographic database (SSURGO) soil surveys and, where SSURGO data were lacking, from the coarser 1:250,000 State Soil Geographic database (STATSGO). The Natural Resources Conservation Service (NRCS) classifies soils into wind erodibility groups; the wind erodibility map depicts the most highly erodible classes 1 and 2 composed of fine-textured soils in the basins of the western and central Sonoran Desert. The second map, sensitive soils, combines soils that are sensitive to erosion or disturbance or that are physically or chemically challenging to vegetative growth. Eight soil classes are represented in the sensitive soils map:

- wind erodible group 1 or 2
- hydric; soils that are sufficiently wet in the upper part to develop anaerobic conditions during the growing season; define wetland conditions, though saturation may be seasonal
- droughty; Available Water Capacity is <0.05 in the top 40 inches of the soil
- calcareous; the CaCO3 content is above 16%
- sodic; with Sodium Adsorption Ratio above 13
- gypsiferous; the gypsum content is above 10%
- shallow; the Rooting Depth is <10 in, or
- highly alkaline, with pH > 9
- saline (chloride)

Sensitive soils have characteristics that make them extremely susceptible to impacts and difficult to restore or reclaim. The classes listed above can serve as thresholds for local soil properties and be used to manage within acceptable ranges to protect vulnerable sites from accelerated erosion, compaction, or invasion by nonnative annual grasses or noxious weeds. Managers have the option to avoid locating disturbances in areas with high-risk sensitive soils and to incorporate best management practices to mitigate negative impacts in areas of low to moderate risk. Awareness of soil types and sensitivity thresholds is also useful for restoration efforts, such as soil crust restoration. Restoration of soil crust in highly disturbed areas is known to be extremely slow, taking as long as 100s of years for recovery (Belnap et al. 2001). Soil crust must go through a succession process with cyanobacteria establishing first and cyanolichens arriving years later after the slow development of the microtopography favorable to lichen recruitment (Belnap et al. 2001). Soil crust species richness is higher in gypsiferous soils, non-calcareous sandy soils, and limestone-derived soils, meaning that restoration efforts are more likely to be successful in those soil types.

4.1.3.2 Coarse Filter Vegetation Communities

Vegetation Management Questions

1. Where are existing vegetative communities?

2. What change agents have affected existing vegetation communities?

The two major vegetation communities selected as coarse filter conservation elements for the Sonoran Desert REA were the Sonoran-Mojave Creosotebush-White Bursage Desert Scrub and the Sonoran Palo Verde-Mixed Cacti Desert Scrub (Prior-Magee et al. 2007). Together these vegetation classes cover 76% of the ecoregion. Mapped results for each vegetation community include 1) current distributions for both SW ReGAP and LANDFIRE existing vegetation, 2) recent disturbances based on disturbance agents drawn from LANDFIRE for 1999–2008, and 3) historic change experienced by each community (agriculture, development, invasive species, and vegetation change) based on a comparison of existing vegetation with a modeled presettlement reference condition (LANDFIRE Biophysical Settings [BpS] dataset [www.landfire.gov]). The creosotebush-white bursage community was introduced in Chapter 3, Section 3.2.1, Conceptual models; a brief introduction to the palo verde-mixed cacti community follows below:

Photo: Arizona Upland, Ragged Top, Ironwood Forest National Monument. M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona

The Palo Verde-Mixed Cacti community is characterized by leguminous trees, such as foothills palo verde (*Parkinsonia microphylla)*, blue palo verde (*P. florida*), and ironwood (*Olneya tesota*), thorn shrubs, succulents and an abundance of cacti: many cholla (*Cylindropuntia* spp.), barrel (*Ferocactus* spp.), and pricklypear (O*puntia* spp.) species. Some of the same woodland species that could grow only in the drainages of the Colorado Desert grow here on the open slopes of coalesced alluvial fans (bajadas) and give this region its subtropical thornscrub character (Turner and Brown 1994). Various associations of these species create a landscape of saguaro cacti (*Carnegia gigantea*) standing in and above a sparse to moderately dense canopy of woodland and shrub species, depending on site conditions, aspect, and elevation (Prior-Magee et al. 2007). Saguaro is the only columnar cactus to be cold hardy enough to survive the winter frosts that regularly occur in the region (Dimmitt 2000b). Two other species of columnar cacti, organ pipe cactus (*Stenocereus thurberi*) and senita (*Pachycereus schottii*), are not as frost hardy and occur in the U.S. only near the Mexican border in Organ Pipe Cactus National Monument and north to Ajo, Arizona. Creosotebush is a generalist and it occurs as a minor element even at higher elevations in the Arizona Upland.

Major threats to ecosystems in the Sonoran region include direct conversion of desert habitats to energy, agricultural, urban, and suburban development, overallocation of water for human consumption, and changes in species diversity and ecosystem character from the increasing incidence of fire and the invasion of exotic annual species. Besides mapping the distribution and status of the selected vegetation communities, REA analyses included both historic and recent changes to the two selected vegetation communities. Historic, cumulative change since presettlement times was expressed spatially for the Palo Verde-Mixed Cacti community by mapping areas of the community that have been converted to a land cover different from that modeled for that community’s reference condition (LANDFIRE BpS). Four major change agents—energy and urban development, agriculture, invasive species predictions in burned areas, and uncharacteristic vegetation composition (derived from the LANDFIRE succession class dataset)—were included in the analysis.

Results for recent disturbances to the Palo Verde-Mixed Cacti community, drawn from LANDFIRE Disturbance datasets for 1999–2008, have been mapped using disturbance agents from four different disturbance categories—fire, mechanical treatment of vegetation communities, insects and disease, and other (herbicide, chemical treatment, or unknown). Fire is the predominant recent disturbance mapped in the Sonoran Desert. Results for historic change and recent disturbances to the two major vegetation communities selected as conservation elements are presented in Section 4.2.

4.1.4 Aquatic Resources of Concern

Surface and Groundwater Management Questions (MQ B1–B7, J3–J4)

1. Where are lotic and lentic surface waterbodies and livestock, wildlife watering tanks and artificial water bodies?
2. Where are perennial streams and stream reaches?
3. Where are the alluvial aquifers and their recharge areas (if known)?
4. Where are aquatic systems listed on (303d) for water quality or having low macroinvertebrate diversity?
5. Where are surface water flows likely to increase or decrease in the near-term, 2025 (development), and long-term, 2060 (climate change)?
6. What is the location/distribution of aquatic biodiversity sites?
7. What are seasonal maxima and minima discharges for the Colorado River and major tributaries at gaging stations?
8. Where are aquatic/riparian areas with potential to change from climate change?
9. Where areas of potential surface water flow change?

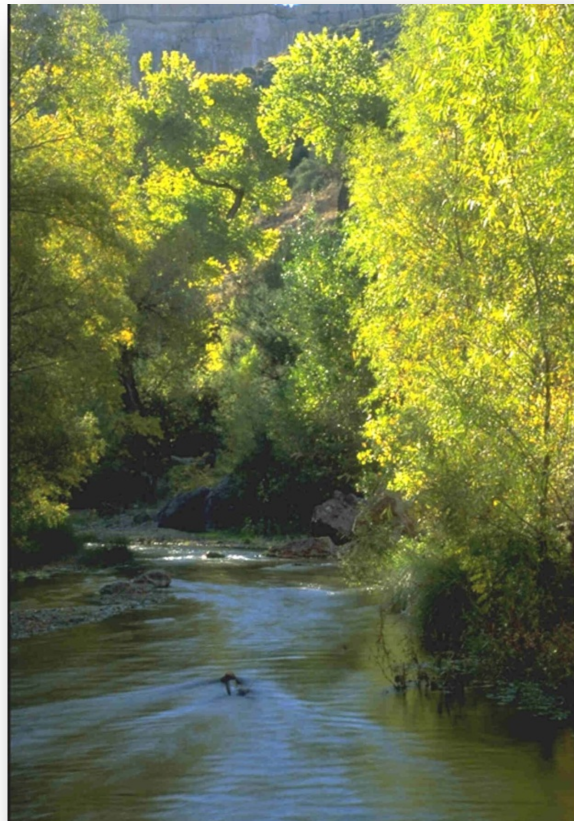


Photo: Aravaipa Creek, Arizona. Arizona BLM

The value of water resources to desert dwellers is obvious and inestimable. The importance of water resources to the Sonoran Desert REA process is reflected in the number of water-related management questions. Management questions 2 and 7 are answered in the body of the text; the rest may be found in Appendix A. Aquatic resources were also represented in REA data and results as aquatic sites of conservation concern, represented by The Nature Conservancy portfolio sites, and ecosystem functions and services—springs and seeps, lakes and artificial waterbodies, wetlands, and riparian areas. Natural lake habitats are limited in the region, but presently, 400 dams and reservoirs on the Colorado River and its tributaries (from headwaters to delta) have created permanent standing water habitat (Pool et al. 2010).

In arid and semi-arid regions, streams experience extreme variations in water flow, permanence, and sediment transport that produce braided, meandering, or anastomosing channels (Hughes et al. 2011). Stream flows range from perennial (mountain source or spring-fed) to spatially intermittent (flowing only where local hydrogeologic conditions raise the water table above the streambed), temporally intermittent (where the water table seasonally supports streamflow), and ephemeral (flowing in response to storms or derived from storm-related bank-storage events). Because of the cumulative impacts of factors such as human water consumption and channel dewatering, climate change, or simple mapping error, >70% of stream length in arid and semi-arid regions in the western U.S. that was historically mapped as permanent is now intermittent or ephemeral (Stoddard et al. 2005b, Figure 4-4, management question B2). Statewide, 66% of California streams and 94% of Arizona streams are intermittent or ephemeral (Levick et al. 2008). Carlisle et al. (2011) also reported, in an assessment of streamflow alteration (1980–2007), that >50% of the stream length in arid U.S. regions experienced reduced base and flood flows. Diminished flow was the primary predictor of biological integrity for aquatic species with the likelihood of impairment increasing as flows diminished. In an assessment of stream resources in 12 western states, Stoddard et al. (2005a) estimated that 50% and 48% of the region's streams had highly disturbed vertebrate and macroinvertebrate biotic condition, respectively. Climate change is projected to result in mean air temperature increases, increased drought conditions, earlier and smaller spring peak flows, and lower summer flows (Cayan et al. 2001, Seager et al. 2007). Although fluctuating flows, high turbidity, and periodic flooding and drought are important natural processes in streams draining arid regions, the increasing amplitude and variability of these processes created by climate change and continued human pressures threaten to reduce and fragment aquatic habitats even further, stressing native species beyond their ability to adapt.

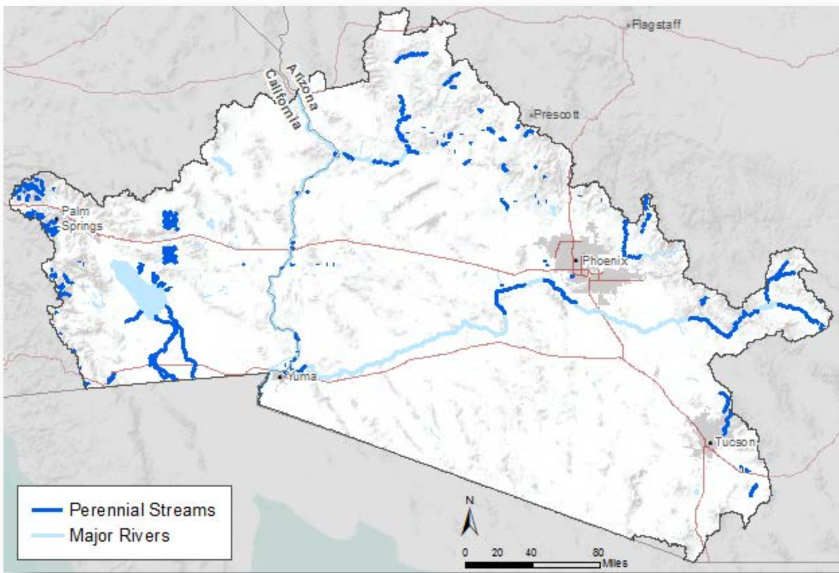


Figure 4-4. Map shows Sonoran Desert perennial streams (management question MQ B2). Mainstem Colorado and Gila rivers are in light blue. Data from the National Hydrography Dataset typically over-represent perennial streams because of mapping error or loss of perennial flow over time (water consumption, climate change).

Because of the region's aridity and high demand for water, most lotic and lentic ecosystems in the Sonoran Desert have been degraded by humans to some degree. About 90% of the region is drained by the Colorado River, one of the most-altered drainages in North America (Ohmart et al. 1988, Hughes et al. 2005). Thirty million people in the upper and lower Colorado River Basin depend on the Colorado River and its tributaries for their water supply; fluctuations in water yield occur from variability in precipitation, runoff, snow pack, and spring snow melt (Table 4-1, management question B3). The river and its tributaries are highly regulated and the water over-allocated. As early as midway into the 20th century, human water demands in the region were three times the amount available from surface waters, resulting in the mining of groundwater for human consumption, mining, industry, and agriculture (Harshbarger 1959). Two thirds of Arizona's available water supply is allocated to irrigated agriculture; this figure is somewhat reduced from that of the mid-20th century (90%) because of losses of agricultural land to urban development and more recent water conservation measures, including a non-expansion rule for groundwater pumping and best management practices for land preparation and water delivery to row crops (Figure 4-5, Bureau of Reclamation, and ADWR 2011). Irrigation tail-water is often reused and any water that is returned to the stream channel is laden with leached salts and agricultural chemicals. In a study examining the effects of agriculture on fish in the western U.S., Moore et al. (1996) reported that the number of fish species listed under the Endangered Species Act per county was positively correlated with the level of irrigated agriculture in that county.

Table 4-1 shows average seasonal maxima and minima for gaging stations on the lower Colorado River and major tributaries recording 12–100 years of records from various gaging stations through 9-30-2010 (Source: http://waterdata.usgs.gov/nwis). Figures in cubic feet/second rounded to the nearest cfs. Table answers management question MQ B3: *What are seasonal maximum and minimum discharges for the Colorado River and major tributaries at gaging stations?*

Gaging Station Location	SPMN	SPMX	SUMN	SUMX	FMN	FMX	WMN	WMX
COLORADO RIVER PARKER DAM, AZ-CA	7145	29691	7243	38777	2440	33405	2502	30791
WHITEWATER RIVER AT INDIO CA	0	4	0	53	0	28	0	500
COLORADO RIVER PALO VERDE DAM, AZ	6149	17167	5763	13332	2978	13119	2562	18403
SALT CREEK NEAR MECCA	2	21	1	50	1	53	3	90
ALAMO RIVER NEAR NILAND CA	683	1290	599	1274	540	1201	389	1133
NEW RIVER NEAR WESTMORLAND CA	469	918	416	1049	414	973	392	932
AGUA FRIA RIVER AT EL MIRAGE, AZ	0	43	0	19	0	15	0	101
VERDE RIVER NEAR SCOTTSDALE, AZ	0	3950	16	1883	6	2473	6	17144
SALT RIVER STEWART MT DAM, AZ	48	7707	147	2638	1	4672	0	19554
GILA BEND CANAL AT GILLESPIE DAM, AZ.	36	170	23	130	1	105	2	171
SANTA CRUZ RIVER NEAR LAVEEN, AZ.	0	56	0	843	0	1081	0	1017
COLORADO RIVER AT NIB	1567	19814	1644	30509	662	28100	920	24144
GILA RIVER NEAR DOME, AZ.	0	13257	0	3344	0	6667	0	15691
SAN CARLOS RIVER NEAR PERIDOT, AZ.	0	477	0	747	0	1276	2	4655
GILA RIVER AT KELVIN, AZ.	7	3034	3	5540	1	5405	14	16062
GILA RIVER AT CALVA, AZ.	1	3039	0	3101	0	9044	15	13905
COLORADO RIVER NEAR SAN LUIS, AZ.	0	15359	0	25060	0	24945	0	20648

SPMN=spring minimum; SPMX=spring maximum; SUMN=summer minimum; SUMX=summer maximum; FMN=fall minimum; FMX=fall maximum; WMN=winter minimum; WMX=winter maximum.

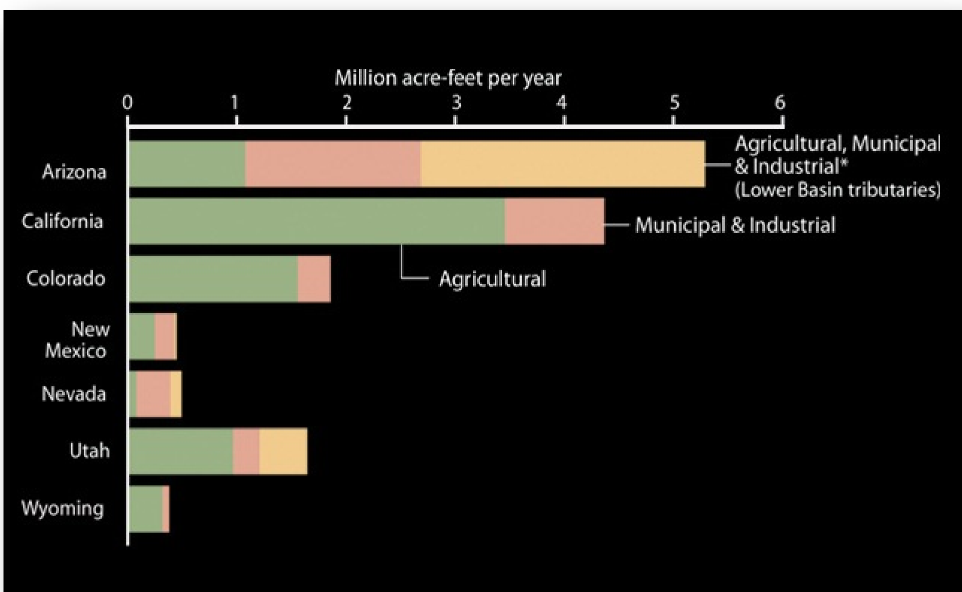
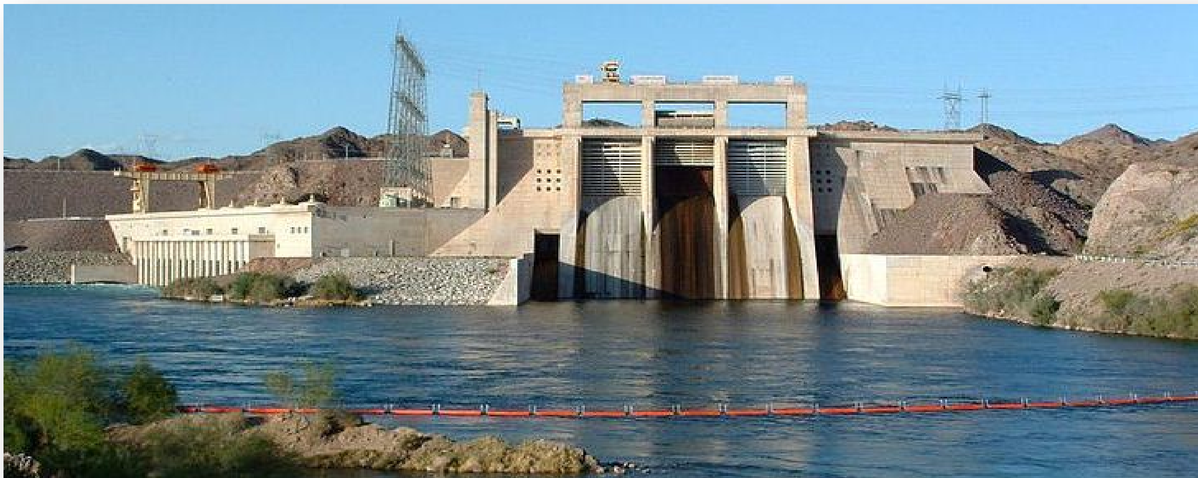


Figure 4-5. Water consumption of states of the upper and lower Colorado River basin for agriculture (green), municipal and industrial use (pink), and all usage from Colorado River tributaries (yellow, data not recorded by usage class). Data from Bureau of Reclamation (National Geographic website http://www.savethecolorado.org/map.php)



Davis Dam, pictured above, together with Hoover and Parker Dams, control the water allotment for the lower Colorado River Basin., Photo: K. Kolb, Wikimedia Commons

Metal mining occurs over relatively small areas of the Sonoran Desert compared to irrigated agriculture; however, mining also requires large quantities of water. Mining increases sediment loads to streams, alters channel structure and flow regimes, and frequently delivers highly toxic effluent to surface waters (Martin and Platts 1981, Woody et al. 2010). Mine effluent, spills, and runoff from exposed tailings may comprise the only flow in naturally temporary streams and the metal concentrations of those flows may exceed criteria for livestock and human consumption.

Besides diminished instream flow in streams, altered flow regimes created by dams, channelization, canal systems, and water withdrawals are associated with increased homogenization of fish assemblages through extirpations of native fishes coupled with increased dominance by non-native fishes (Williams et al. 1985, Stanford 1994, Hughes et al. 2005, Olden et al. 2006, Poff et al. 2007). Native fish species in the region have declined in range and abundance since the early 20th century; during that time, 25 of 31 native fish species in the lower Colorado River Basin have been federally listed as threatened or endangered (Pool et al. 2010). In a study using fish data from 159 watersheds in the lower Colorado River Basin, Pool et al. (2010) found that altered watersheds with high dam densities had higher non-native fish functional diversity, while watersheds with upstream land protection, lower dam densities, and variability in spring and summer precipitation supported an increased number of native fish species. They considered natural flow variability and overland flow from storm events to be vital for sustaining native species diversity.

Nonnative invasive species have been ranked as the second or third most important threat to the biodiversity of native fishes (Miller et al. 1989, Hughes et al. 2005, Reed and Czech 2005). Over twice as many nonnative fish species as native fish species reside in Arizona waters (Rinne 1995). Lomnicky et al. (2007) estimated that nonnative aquatic vertebrates occurred in 83 $\pm$ 10% of Arizona streams, and westwide, in 83 $\pm$ 6% of large rivers. Nonnatives alter native fish assemblages through competition (Dudley and Matter 2000) and predation (Li and Moyle 1981, Meffee 1984, Dunham et al. 2004). Nonnative predators may entirely eliminate a native fish assemblage in a particular catchment—even in an otherwise unmodified watershed—if the native fish are stressed or experiencing low recruitment, as during a drought (Probst et al. 2008). Nonnative invasive aquatic macroinvertebrates can be problematic as well. Stoddard et al. (2005a) estimated that nonnative crayfish occurred in 7 $\pm$ 3% and Asian clam occurred in 6 $\pm$ 3% of the stream length in xeric regions of the western U.S. Although their occurrence probabilities were low, when present, the crayfish and clam were associated west-wide with a doubling or tripling of the risk of having poor vertebrate and macroinvertebrate biological integrity scores (Stoddard et al. 2005a).

Thus, while the retention or mimicking of natural hydrologic regimes is essential for maintaining native fish assemblages (Poff et al. 1997), a reduction in competition from nonnative species is just as important (Eby et al. 2003, Mueller 2005, Propst et al. 2008). A natural flow regime allows connectivity and genetic diversity, but it also allows nonnative fish easy access to native refugia (Propst et al. 2008). Recovery activities for native aquatic species includes managing water releases from dams to benefit native species life cycles, acquisition of bottomlands and easements, breaching of levees, stocking hatchery-raised threatened and endangered species, managing nonnative species introductions, and conducting targeted nonnative species control (Mueller 2005).

The only (semi-)aquatic species examined for this REA was the Lowland Leopard Frog (*Lithobates yavapaiensis*); the species was extirpated in California because of habitat loss and degradation and it has declined in the Arizona portion of its range. No fish species were selected as conservation elements for the Sonoran Desert REA. Fish are highly managed (meaning many threatened species are reared in captivity and introduced into appropriate habitats), and threatened species' locational data are considered sensitive. The endangered fish species in the Colorado River are managed by the Bureau of Reclamation, Fish and Wildlife Service, and State fish and wildlife agencies in the Lower Colorado River Multispecies Conservation Plan (LCRMSCP 2004). Desert pupfish are not ecoregionally distributed and they are managed at the local scale.

Instead, without aquatic species, the riparian zone became an REA focus for examining several conservation elements and related change agents, since it is also a critical desert ecosystem and the interface between Sonoran Desert terrestrial and water resources. Markedly altered flow regimes may eliminate native riparian vegetation (Rood and Mahoney 1990, Lytle and Merritt 2004), change riparian community composition (Busch and Smith 1995, Merritt and Wohl 2006, Stromberg et al. 2007, Merritt & Poff 2010, Mortenson and Weisberg 2010), species richness (Nilsson et al. 1991), and productivity (Stromberg and Patten 1990, Molles et al. 1998). Although historically riparian habitats composed about 1% of the land area of the western states, ground water pumping and a broad range of human disturbances have resulted in the loss of >90% of the region's wetlands and native riparian woodlands (Krueper 1996, Cline and Zarate 2010) and 80% of Colorado River delta wetlands (Hinojosa-Huerta et al. 2005). As much as 80% of all vertebrates use the remaining riparian habitats for cover and foraging, and over 50% of southwestern bird species use riparian woodland and shrubland for nesting (Knopf et al. 1988, Krueper 1996). Lucy's warbler and Bell's vireo are two riparian bird species conservation elements discussed in Appendix C. Xeroriparian habitats are just as important in arid ecosystems; in the lower Colorado River Basin, dry washes occupy <5% of the area, but support 90% of its bird species (Dimmitt 2000a, Levick et al. 2008). For more on birds and xeroriparian habitats, see the discussion of Le Conte's thrasher in Appendix C.

Photo: Xeroriparian habitat with velvet mesquite (*Prosopis velutina*), Ironwood Forest National Monument, M.A. Dimmitt, Arizona-Sonora Desert Museum, Tucson, Arizona.

Just as was done for terrestrial landscape intactness (in Chapter 3, Section 3.2.3), a companion fuzzy logic model for aquatic intactness was developed and organized by 5th level HUC (Figure 4-6). It is used later in the report to assess status for aquatic conservation elements (Section 4.2.1). The model includes 10 primary inputs with three major contributors to high aquatic intactness—low hydrologic alteration, high land and water quality, and low road impacts, represented as intermediate results in purple boxes below (Figure 4-6).

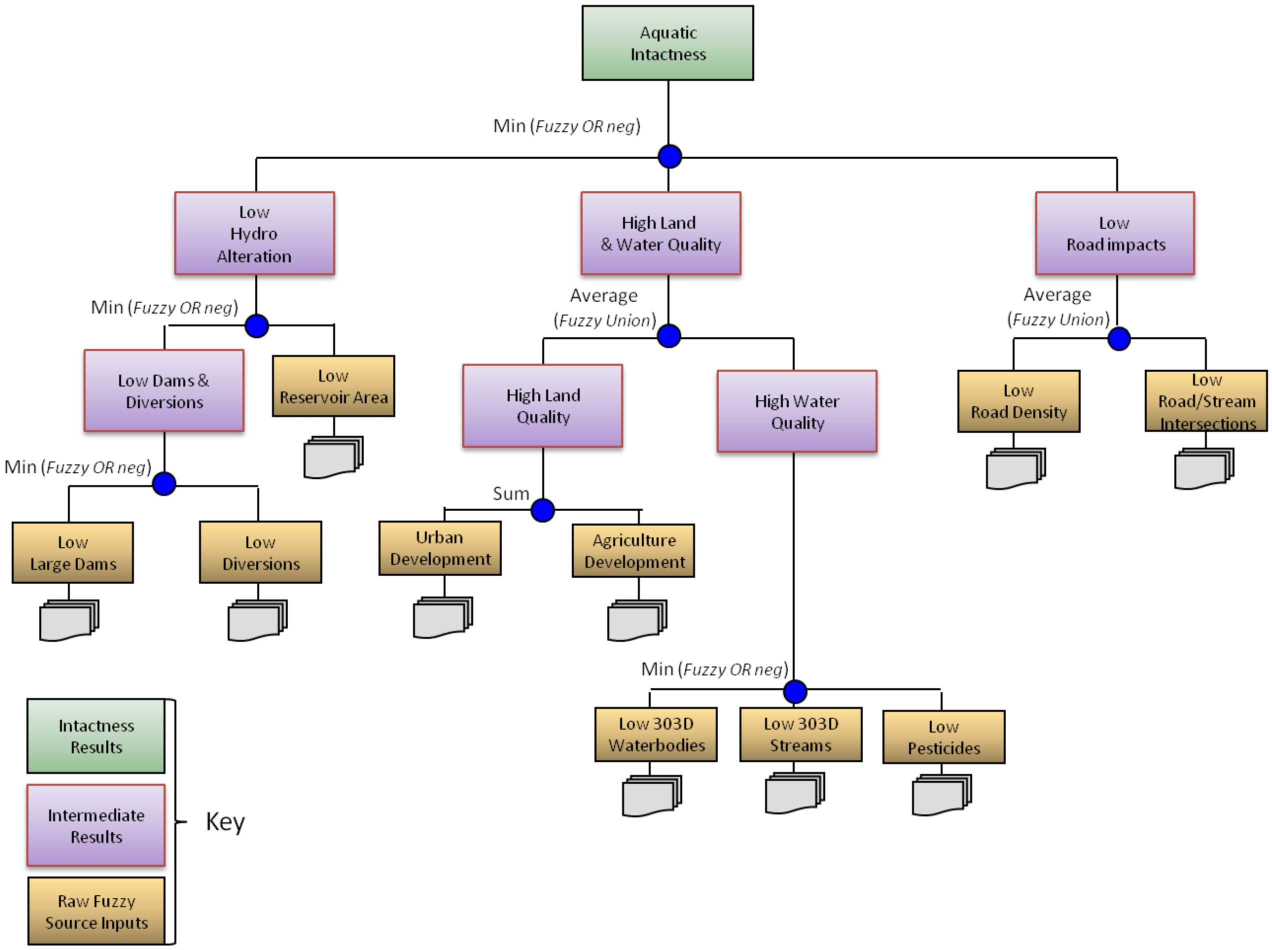


Figure 4-6. Fuzzy logic model for aquatic intactness in the Sonoran Desert ecoregion.

The intermediate results maps for the three major contributors represent aquatic degradation drivers and show widespread aquatic impacts throughout the ecoregion (Figure 4-7). Darker color is higher on a relative scale. For example, in Figure 4-7A and C there are few areas with either low hydrologic alteration or low road impacts. The map in Figure 4-7B shows areas in the Salton Sea basin and the Phoenix-Tucson corridor with high land use and low water quality as expected. Final aquatic intactness results are provided in Section 4.2.1. Appendix A contains specific results for each stated aquatic management question listed at the beginning of this section.

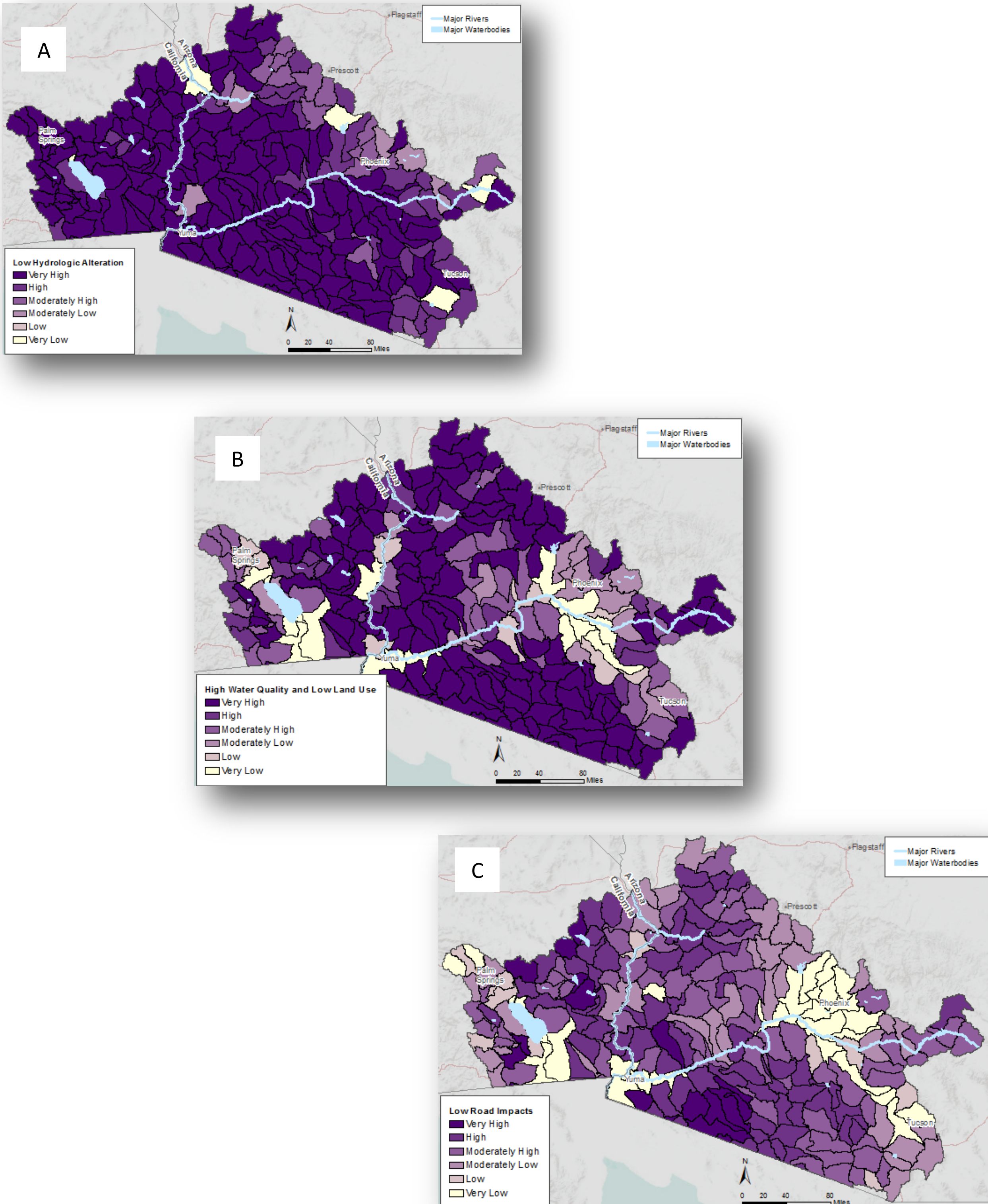


Figure 4-7. Intermediate results for aquatic intactness model including (A) Low Hydrologic Alteration, (B) High Land and Water Quality, and (C) Low Road Impacts. Darker color is high on a relative scale to map topic; i.e., dark purple area along southern border in map 4-6C means low road impacts (very low road density).

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Photo: Mesquite bosques at the margin of a dune field, Chuckwalla Valley. M.A. Dimmitt, Arizona-Sonora Desert Museum Digital Library.

4.2 Distribution and Status of Conservation Elements

Species Management Questions

1. What is the current distribution of available occupied habitat and CE status?
2. Where are potential areas to restore connectivity?
3. What is the location of terrestrial biodiversity sites?
4. Where are HMAs located?

Conservation elements were organized into three categories—wildlife species, ecological systems, and designated sites, and analyses were conducted on 11 wildlife species (3 mammals, 5 birds, 2 reptiles, and 1 amphibian, Table 4-2). Three ecological systems were assessed, including the two major coarse filter vegetation communities plus riparian vegetation (Table 4-3). Sites of ecological and management concern included designated sites, high biodiversity sites, and herd management areas (HMAs). In addition, Natural Heritage occurrence data were examined that were provided by NatureServe. Natural heritage data summaries included number of species, number of U.S. Fish and Wildlife Service threatened and endangered species, and number of globally critically imperiled, imperiled, and vulnerable species (G1 –G3, Master et al. 2000) organized by 5th level HUCs. The first three management questions listed are answered in the text (Section 4.2) for wildlife species, vegetation communities, and designated protected areas. All other management questions results and conservation elements not featured in the body of the text may be found in Appendices A, B, or C.

Table 4-2. List of species conservation elements (CEs) evaluated for the Sonoran Desert ecoregion.

Species CEs	
Bell's Vireo (Vireo bellii and Vireo bellii pusillus)	Lowland Leopard Frog (*Lithobates yavapaiensis*)
Desert Bighorn Sheep (Ovis canadensis nelsoni)	Lucy's Warbler (Oreothlypis luciae)
Mojave Desert tortoise (Gopherus agassizii)	Mountain Lion (Puma concolor)
Sonoran Desert tortoise (Gopherus morafkai)	Mule Deer (Odocoileus hemionus)
Golden Eagle (Aquila chrysaetos)	SW Willow Flycatcher (Empidonax traillii extimus)
Le Conte's Thrasher (Toxostoma lecontei)	

Table 4-3. List of ecological systems with highlighted dominant species and other site-related conservation elements (CEs) examined in the Sonoran Desert ecoregion.

Ecological Systems CEs
Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Creosotebush)
Sonoran Paloverde Mixed Cacti Desert Scrub (Saguaro Cacti)
Riparian Vegetation
Sites CEs
Designated Sites
Biodiversity Sites – Terrestrial and Aquatic
HMAs

4.2.1 Evaluating Wildlife Species Current Distribution and Status

Current distribution mapping for the species conservation elements were derived from state GAP, Southwest ReGAP, or compilations of state agency spatial data. Acquisition of state wildlife agency data was emphasized because it tended to be more conservative, although occasionally it was impossible to reconcile boundary issues between the different states. Original species distribution mapping of potential habitat was not possible due to a lack of detailed occurrence records necessary to conduct MaxEnt modeling. An existing MaxEnt model for Mojave desert tortoise (*G. agassizii*, Nussear et al. [2009]) was available for use in this REA. For the other Sonoran Desert species, species distribution models and maps were based on state-level data that tended to be more restrictive than the more generalized SW ReGAP data.

The total area examined in the ecoregion was 34.9 million acres (14 million hectares). Current distributions for the terrestrial species ranged from about 139,000 acres to almost 26,846,000 acres (Table 4-4).

Table 4-4. Total current distribution area (in 1000s of acres) for terrestrial species conservation elements for the Sonoran Desert ecoregion.

Species CEs	Total Distribution Area	Percent of Ecoregion
Bell's Vireo (*Vireo bellii and Vireo bellii* pusillus)	2,821	8.1%
Desert Bighorn Sheep (*Ovis canadensis nelsoni*)	7,863	22.5%
Mojave Desert tortoise (*G. agassizii*)	3,181	9.1%
Sonoran Desert tortoise (*G. morafkai*)	6,951	19.9%
Golden Eagle (*Aquila chrysaetos*)	17,257	49.4%
Le Conte's Thrasher (*Toxostoma lecontei*)	9,772	28%
Lowland Leopard Frog (*Lithobates yavapaiensis*)	678	1%
Lucy's Warbler (*Oreothlypis luciae*)	13,753	39.4%
Mountain Lion (*Puma concolor*)	13,893	39.8%
Mule Deer (*Odocoileus hemionus*)	26,846	76.9%
SW Willow Flycatcher (*Empidonax traillii extimus*)	139	0.4%

Species status was evaluated in two ways—1) a review of background information (discussed in individual species profiles in Appendix C) and 2) an examination of the overlay of current distribution with terrestrial and aquatic landscape intactness (at 4 km x 4 km resolution for terrestrial species and organized by 5th level HUC for the lowland leopard frog).

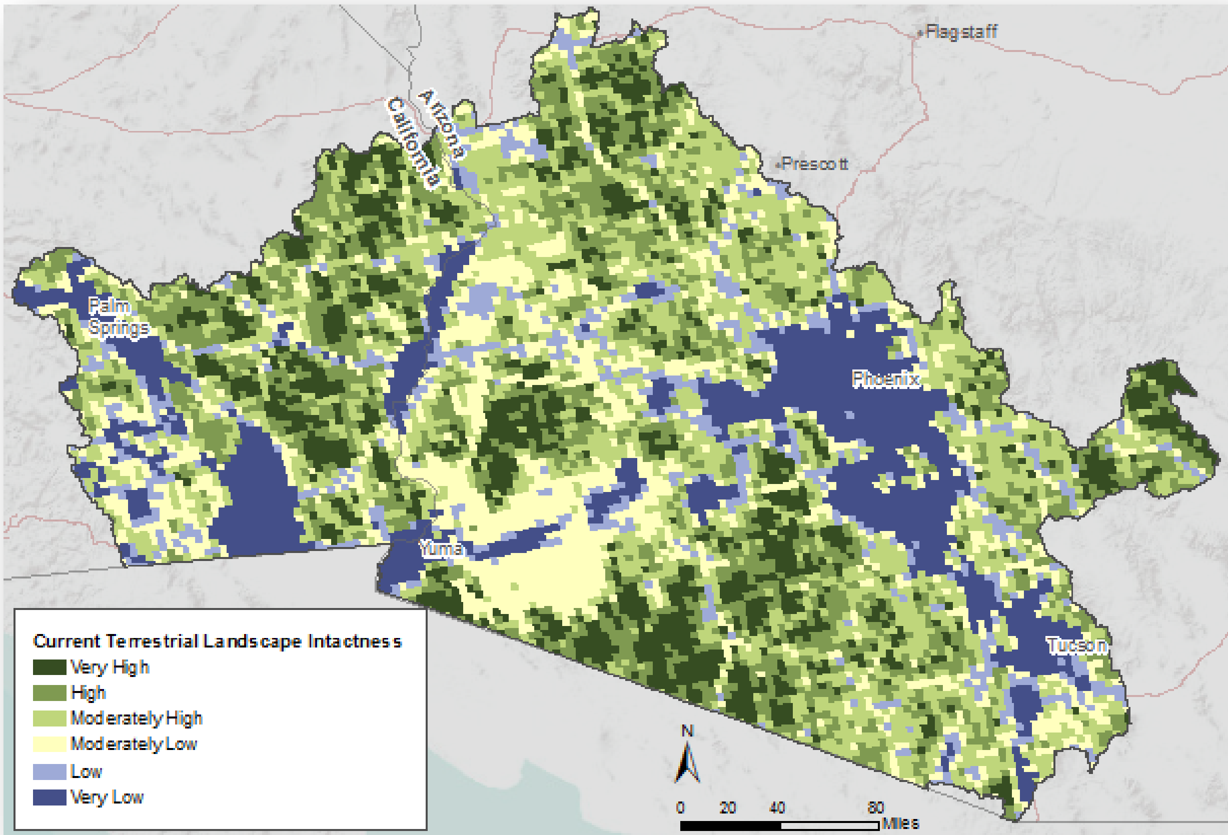
Terrestrial landscape intactness was mapped following the methods described in Chapter 3, Section 3.2.3 and 3.2.4. Intactness is an indicator of habitat quality based on available spatial data reported at a fairly coarse 4 km X 4 km scale; expectations of accuracy should match the scale of the reporting unit. Working at the ecoregion scale and at finer local scales will require calibration of intactness with finer scale map and field data. As a result, in this report, use of the term habitat quality is a relative term meaning potential quality. The intactness model is generalized, based on landscape characteristics, and typically not tied to individual species' requirements. However, for this model, numerous species-level attributes and indicators (Appendix D) were evaluated, paying particular attention to known change agents that provide the most important information related to changes in species status over time. Unfortunately, the scientific literature does not provide many quantifiable indicators, and when it does, spatial data are typically lacking. For example, golden eagle status is closely tied to prey density (especially jackrabbits). Prey density would be a strong indicator for this species, but prey density data are not available to create a spatial model. Even if data for this indicator could be generated, it would still be challenging to use because of its inherent dynamism—many prey species such as jackrabbits display boom and bust population cycles every 7 to 10 years (Gross et al. 1974).

This model of intactness is fundamental to assessing status for all conservation elements in the REA. Some of the more common status indicators for species pertain to one or more types of human development (including urban, agriculture, mining, recreation and roads); in other words, minimal human development generally indicates intact habitat conditions for a species and high levels of development indicate degraded conditions. For this reason, status was evaluated for each species against the overall intactness model as it provides the best regional perspective for vegetation condition and habitat quality, development profile, and natural habitat fragmentation patterns. Not all species demonstrate the same level of tolerance to the various model inputs, but an overall intactness model provides a standard baseline from which to explore specific species or regions where tolerances to various components may vary. Current terrestrial landscape intactness at 4 km x 4km resolution (Figure 4-8) and aquatic intactness organized by 5th level HUC (Figure 4-9) for the Sonoran Desert ecoregion show the full range of values from Very Low to Very High. In general, results for the terrestrial intactness model showed the greatest percent area (26%) in the Moderately High category followed by High with 21%. Very High and Very Low intactness showed similar amounts, 13.5% and 14.7% respectively. Aquatic intactness showed a similar pattern for the Moderately High and High categories, but it had a higher percentage of area in the Very Low class (19% vs. 14.7% for terrestrial intactness).

In cases where more quantifiable thresholds have been reported and can be tested, the logic model is easily modified. For example, Figure 4-10 shows two terrestrial intactness results for mountain lion. Map 4-10A shows the overall intactness model results overlaid by mountain lion distribution to provide a status profile and Map 4-10B shows the same mountain lion distribution over a customized version of the intactness model that includes a road density tolerance threshold of 0.60 km/km^2 reported by Van Dyke et al. (1986). One can easily see the difference a reported threshold can have on the results. The histograms show a significant decline of suitable potential mountain lion habitat when this threshold is enforced in the model. Map 4-10B clearly shows islands of high quality mountain lion habitat based on noted attributes and indicators for this species (Appendix D). A handful of these blocks are very large while others are small and somewhat isolated from one another. Mountain lions could occur over a good portion of the ecoregion according to the distribution data (nearly 40%), but in areas of low or very low intactness, mountain lions would be expected to come into regular contact with human activities often with negative consequences. Prey density (especially mule deer) is another important indicator of mountain lion habitat. While spatially explicit information for primary prey species density is not available, one can simply compare the status results using the reported road density threshold with current distribution of mule deer and bighorn sheep and observe the overlap.

The three mammal species conservation elements in the Sonoran Desert share a similar status profile (Figure 4-11). Desert bighorn sheep has more of its distribution in more intact habitats than mule deer and mountain lion. Of the three mammal species, the adaptable mule deer showed more of its current distribution in least intact habitats. Note that species distribution is indicated in blue on the distribution maps for each of the 11 species and intactness is represented in the histograms. Live maps may be viewed on the data portal for panning, zooming, or combining this information with other data layers (weblink in Section 2.2.3).

For the reptiles, the two desert tortoise species showed similar status profiles based on the terrestrial landscape intactness results (Figure 4-12). Most of the distribution for both species is located within the three higher intactness classes with *G. agassizii* more skewed to potentially higher quality habitat than *G. morafkai*. 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. The lowland leopard frog status results, based on the aquatic intactness model organized by 5th level HUCs, shows approximately 60% of its current distribution in the lower intactness categories, including 27% in the Very Low category. Some portion of this result may be due to the coarse scale of the 5th level HUC, but the results support reported declines of the frog in the ecoregion (Rorabaugh 2006).



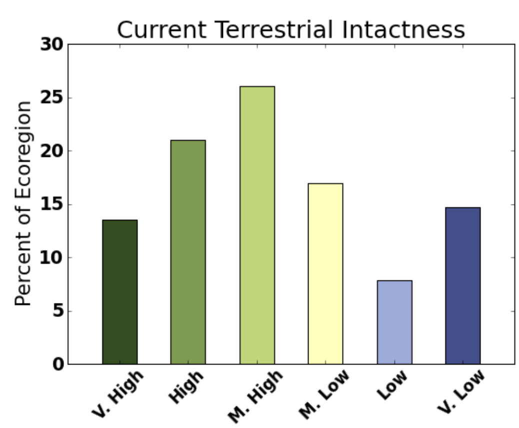
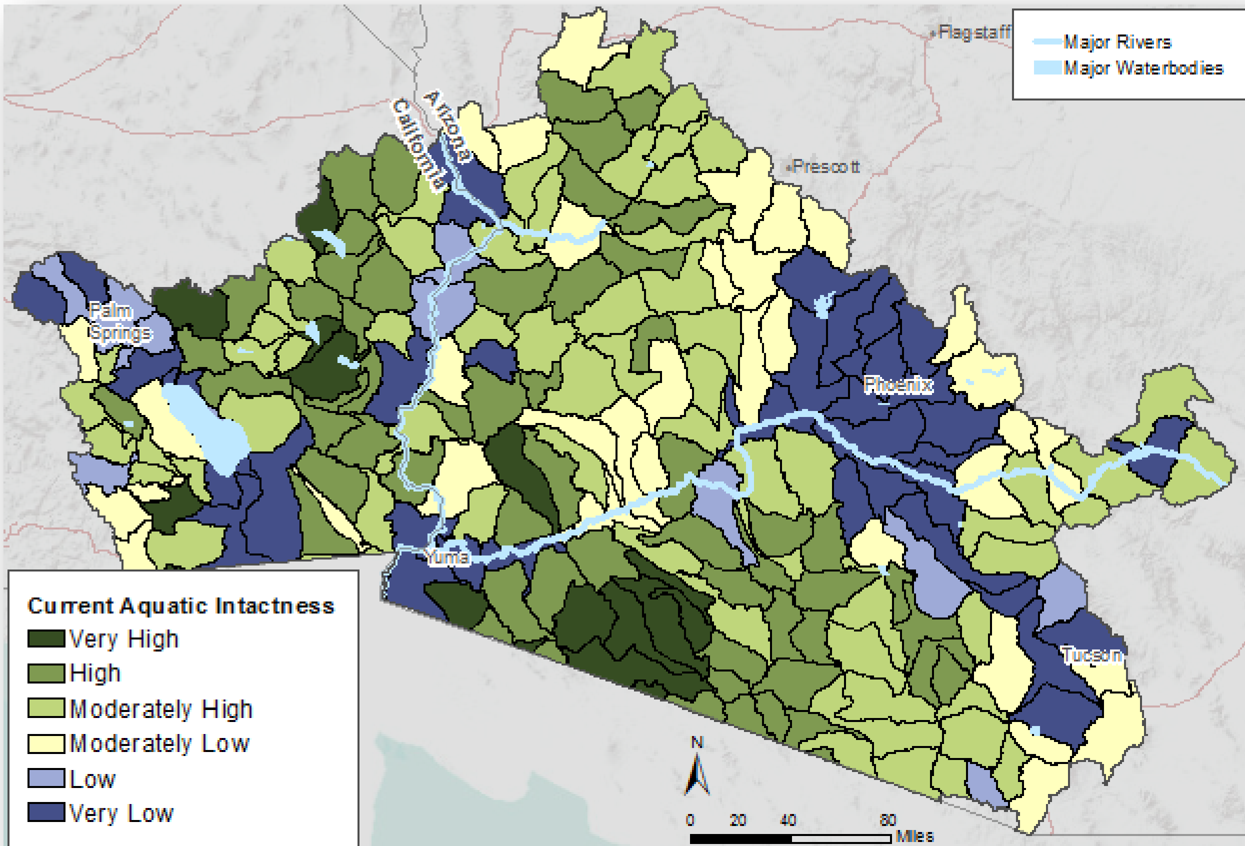


Figure 4-8. Current terrestrial landscape intactness organized by 4 km x 4 km grid cells for the Sonoran Desert ecoregion with associated histogram indicating areal percent of the ecoregion in various intactness classes.



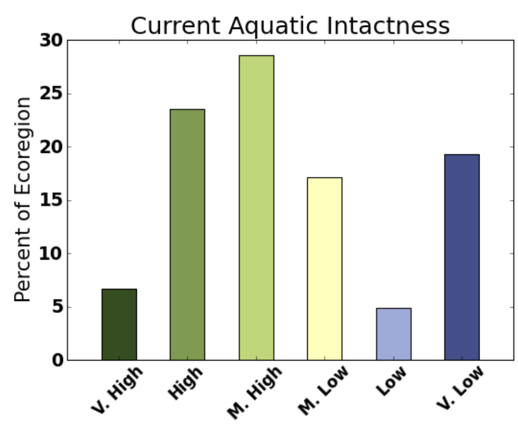


Figure 4-9. Current aquatic intactness organized by 5th level HUCs for the Sonoran Desert ecoregion with associated histogram indicating areal percent of the ecoregion in various intactness classes.

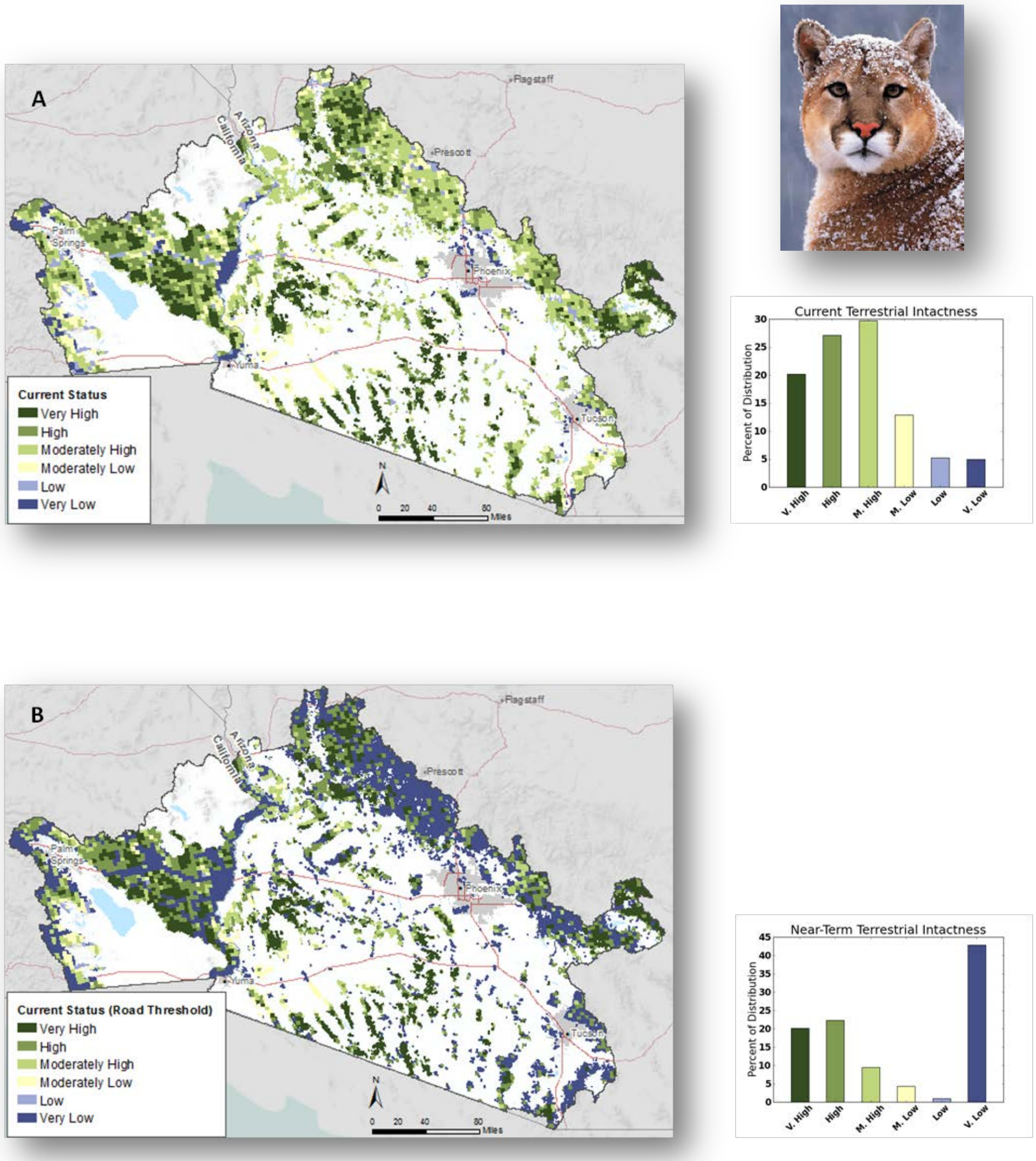


Figure 4-10. Map shows (A) mountain lion status created by overlaying current distribution against the general terrestrial intactness model and (B) mountain lion status according to customized intactness model with a road density tolerance of 0.6 km/km^2 (Van Dyke et al. (1986). Results are organized by 4 km x 4 km grid cells for the Sonoran Desert ecoregion with associated histograms indicating areal percent of the ecoregion in various intactness classes.

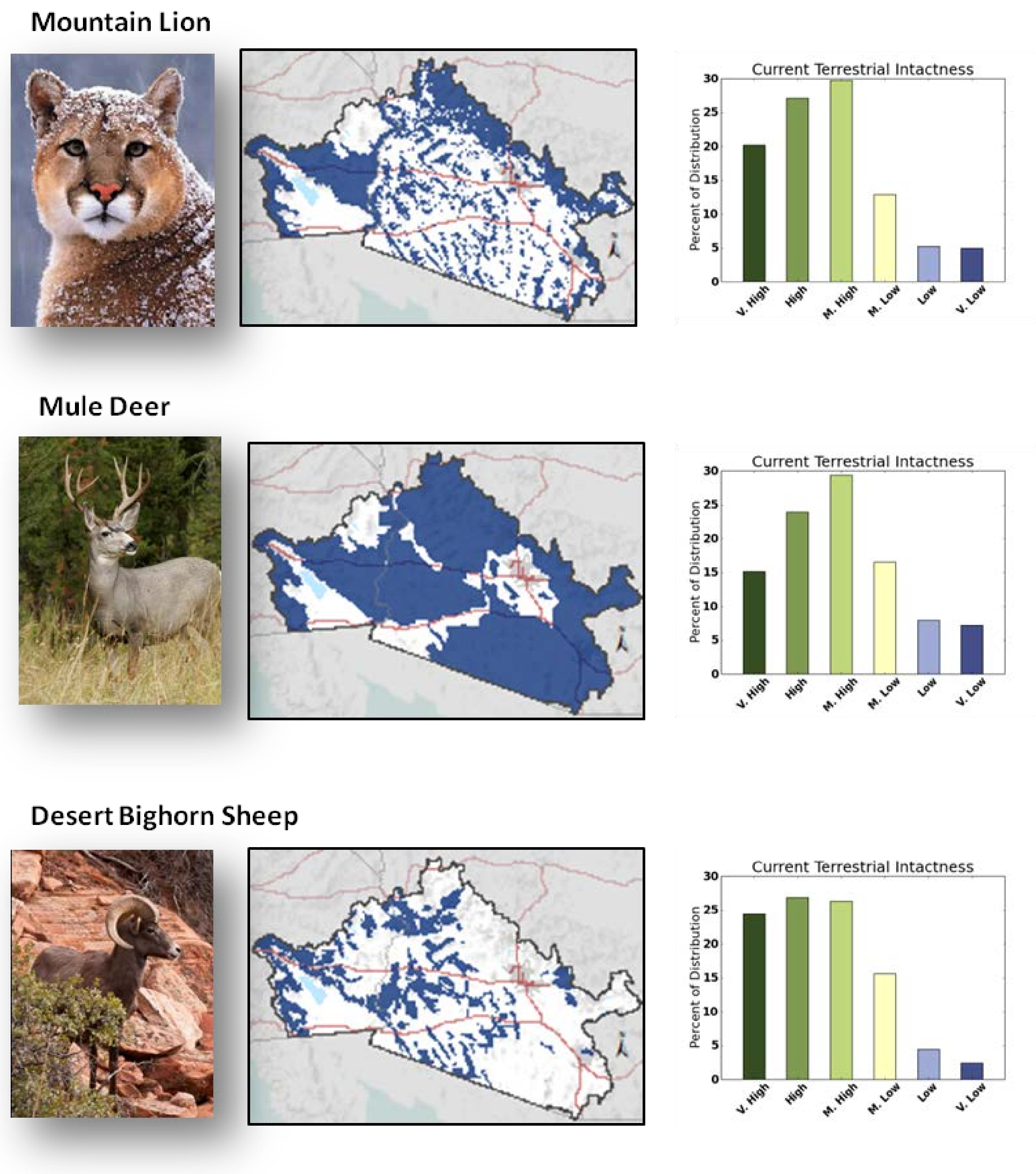
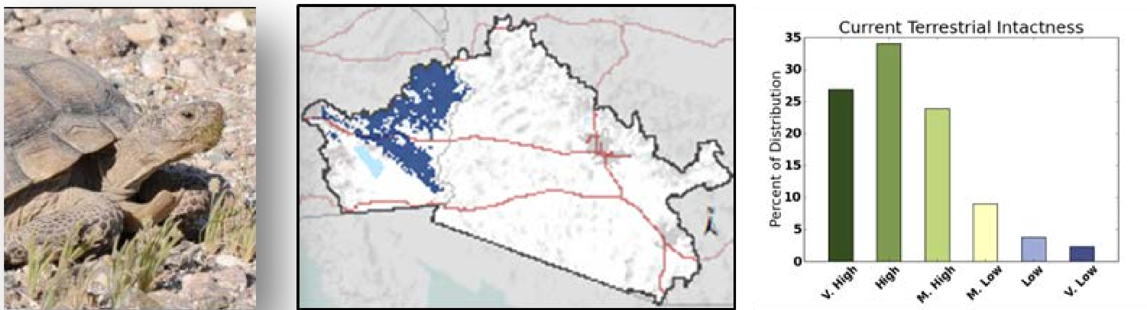
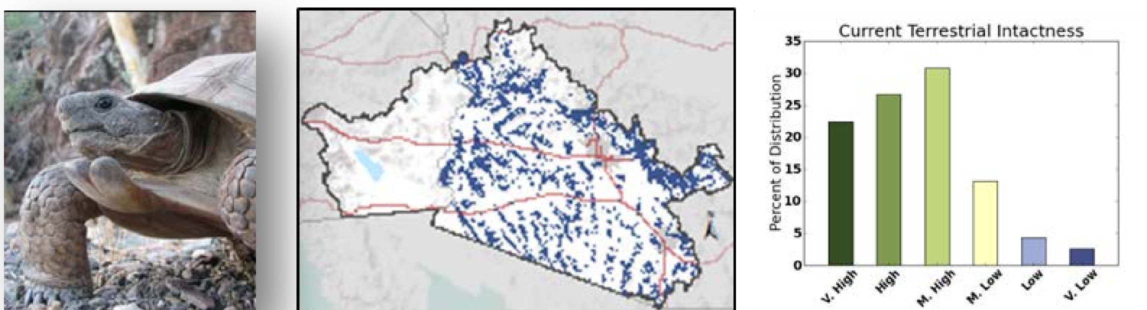


Figure 4-11. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for mountain lion, mule deer, and desert bighorn sheep in the Sonoran Desert ecoregion.

Desert Tortoise (agassizii)



Desert Tortoise (morafkai)



Lowland Leopard Frog

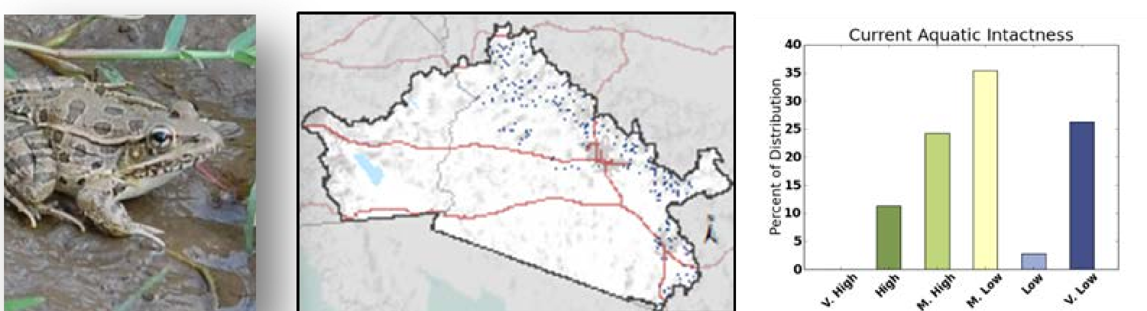
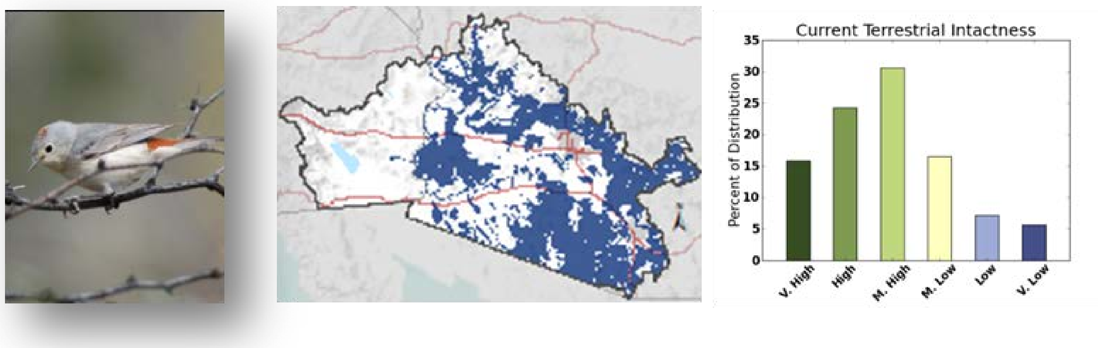


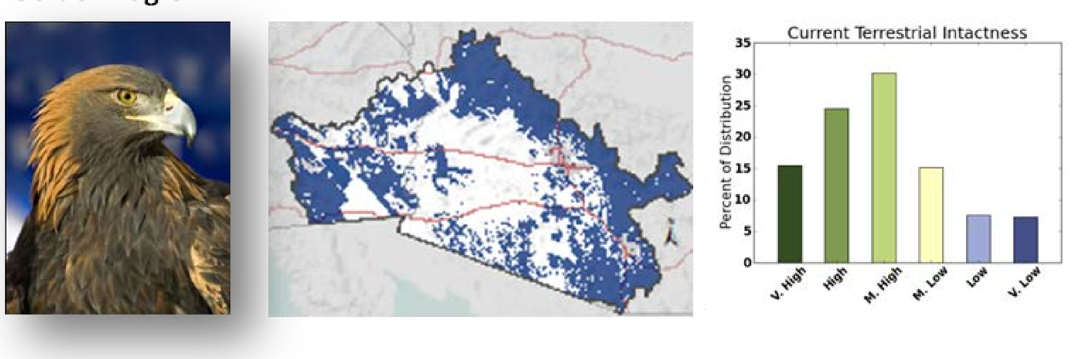
Figure 4-12. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Mojave desert tortoise (G. *agassizii*), Sonoran desert tortoise (G. *morafkai*), and lowland leopard frog (*Lithobates yavapaiensis*) in the Sonoran Desert ecoregion.

For three bird species (Lucy’s Warbler, Golden Eagle, and LeConte’s Thrasher), approximately 70% of their current distribution is in Moderately High to Very High terrestrial landscape intactness classes (Figure 4-13). However, the distributions of all three species are over-represented, Le Conte’s thrasher in particular. In eight years of canvassing for the Arizona Breeding Bird Atlas, the thrasher was recorded mainly in limited areas in southwestern Arizona. Roughly 30% of the habitat for these species is in Moderately Low to Very Low terrestrial landscape intactness classes. In these areas, especially the Very Low (5-8%) class, the animals would be expected to be under significant stress.

Lucy’s Warbler



Golden Eagle



LeConte’s Thrasher

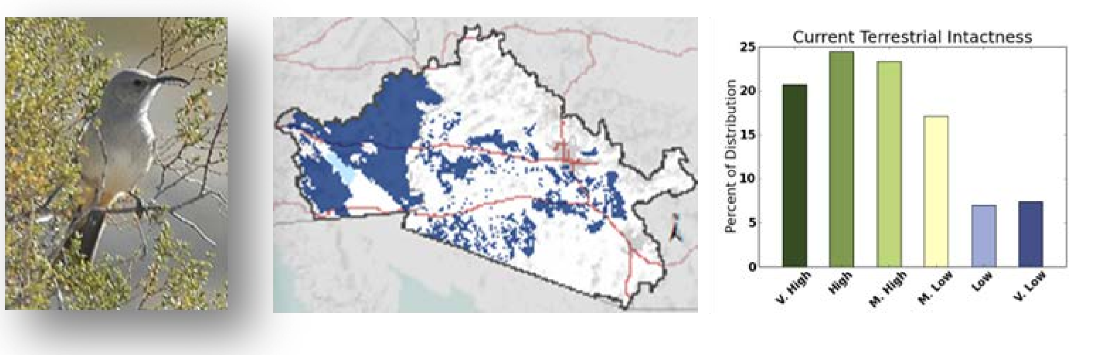


Figure 4-13. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Lucy’s warbler, golden eagle, and Le Conte’s thrasher in the Sonoran Desert ecoregion.

For the remaining bird species (Bell's vireo and southwestern willow flycatcher), the intactness profiles are not as positive (Figure 4-14). This is especially true for southwestern willow flycatcher, which has over 70% of its current distribution classified as Moderately Low to Very Low with regard to terrestrial landscape intactness. Although both these species will use tamarisk for nesting, their troubles are not entirely due to the disappearance of native riparian vegetation. Both suffer from nest parasitism by brown-headed cowbird (*Molothrus ater*); where cowbirds have been controlled in least Bell's vireo recovery areas in the Sonoran Desert of California, the vireo has shown a modest recovery. For more details on birds and other wildlife species conservation elements, see Appendix C.

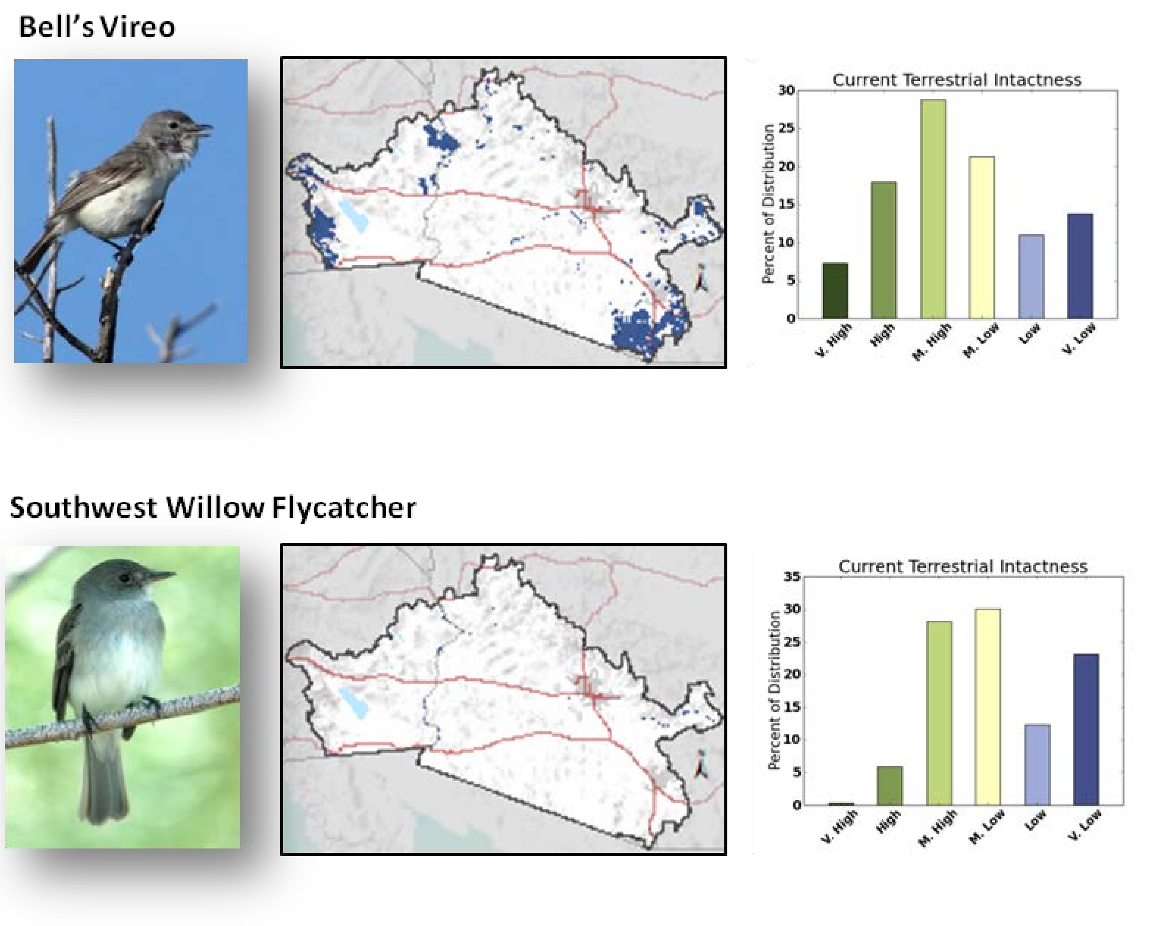


Figure 4-14. Current distribution (in blue on maps) and conservation element status (histogram) based on current terrestrial intactness model for Bell's vireo and southwestern willow flycatcher in the Sonoran Desert ecoregion.

4.2.2 Wildlife Species Connectivity

This section addresses the management question, Where are potential areas to restore connectivity? Least-cost path analysis for the Natural Landscape Blocks for California (Spencer et al. 2010) combined with general corridor mapping in Arizona (AZDOT 2006) provided a map of key linkage zones for the ecoregion (Figure 4-15). In California, Spencer et al. (2010) identified natural landscape blocks of > 5000 acres and created a cost surface by combining landcover cost and protection status cost. In general, water and highest intensity developed classes from LANDFIRE EVT received the highest costs; agriculture and lower intensity developed classes received moderately high costs; invasive species received moderate costs; and natural vegetation received lowest costs. Costs were also derived from protected areas, such that more highly protected areas (e.g., wilderness) received lower costs, and less protected areas received higher costs. A 25-meter buffer around major highways (converted to 30m raster) and a 30m raster of all roads (BLM ground transportation database) were used to assign road costs (among the highest overall costs). Potential linkages were hand drawn between neighboring natural landscape blocks by connecting each one using a system of drawn sticks (centroid to centroid). ArcGIS Cost Distance and Corridor tools determined the final California Essential Connectivity Areas.

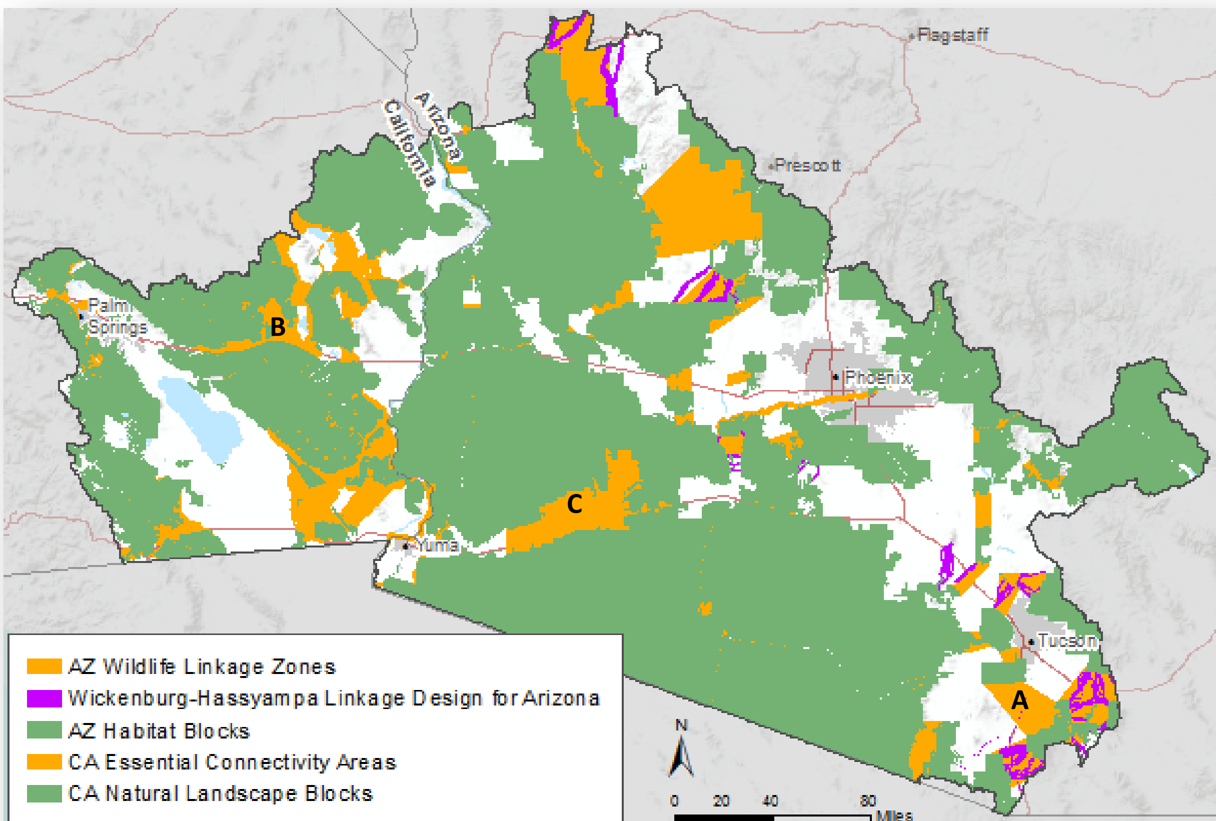


Figure 4-15. Landscape connectivity results based on generic (non-species specific) least-cost path analysis for the Sonoran Desert ecoregion. Connectivity mapping in California based on Spencer et al. (2010) and in Arizona based on Arizona Wildlife Linkages Workgroup (http://www.azdot.gov/inside_adot/OES/AZ_WildLife_Linkages/assessment.asp).

For more details on wildlife connectivity mapping in Arizona, see the Arizona Wildlife Linkages Assessment Document created by the Arizona Wildlife Linkages Workgroup (http://www.azdot.gov/inside_adot/OES/AZ_WildLife_Linkages/assessment.asp). Mapping in both states is ongoing and likely to be revised. Each of the identified corridors contains different types and levels of challenges. Management for some corridors (orange areas) must overcome the complexity of growing urban sprawl as seen in the region between Phoenix and Tucson and south of Tucson (zone A). Others must mitigate major highways (zone B) or deal effectively with invasive species (zone C, Figure 4-15). Both states have mitigated highway barriers with fencing and underpasses (e.g., for desert tortoise) and Arizona has addressed highway mitigation for desert bighorn sheep as well after doing field research to determine common bighorn highway crossing points (photos below).

Photos: Examples of Desert bighorn overpasses on US Hwy 93 just north of the Sonoran Desert ecoregion boundary, Scott Sprague, Arizona Fish and Game Department.

Case Study No. 1

Mojave Desert Tortoise (*Gopherus agassizii*)
Sonoran Desert Tortoise (*Gopherus morafkai*)

The desert tortoise was selected as a core conservation element for the Sonoran Desert REA because it is an iconic species of the region that reflects inter-regional variability in climate, landform, and vegetation. The tortoise is a good indicator of desert condition because it is widely distributed across the ecoregion and, at the same time, sensitive and vulnerable to multiple disturbance factors. The desert tortoise inhabits desert environments in the Mojave and Sonoran deserts in southern California, southern Nevada, Arizona, southwestern Utah, and northwestern Mexico. Once recognized as a single species (*Gopherus agassizii*) with two recognized populations, it has recently been split into two species (Averill-Murray 2011). The Mojave desert tortoise occurs north and west of the Colorado River and retains the Latin name *Gopherus agassizii*. It was listed as threatened in 1990 and, 22 years after listing, the species is still declining, particularly in the western portion of its range in California (Brussard et al. 1994, Tracy et al. 2004, USFWS 2008, 2011). The Sonoran population is now called *Gopherus morafkai*, distinguished from *G. agassizii* by its physical features, different habitat, life history traits, and DNA evidence (Murphy et al. 2011). The Sonoran desert tortoise occurs east and south of the Colorado River, from Arizona into Mexico. REA results produced maps for current status and future condition for the two desert tortoise species.

Current Distributions

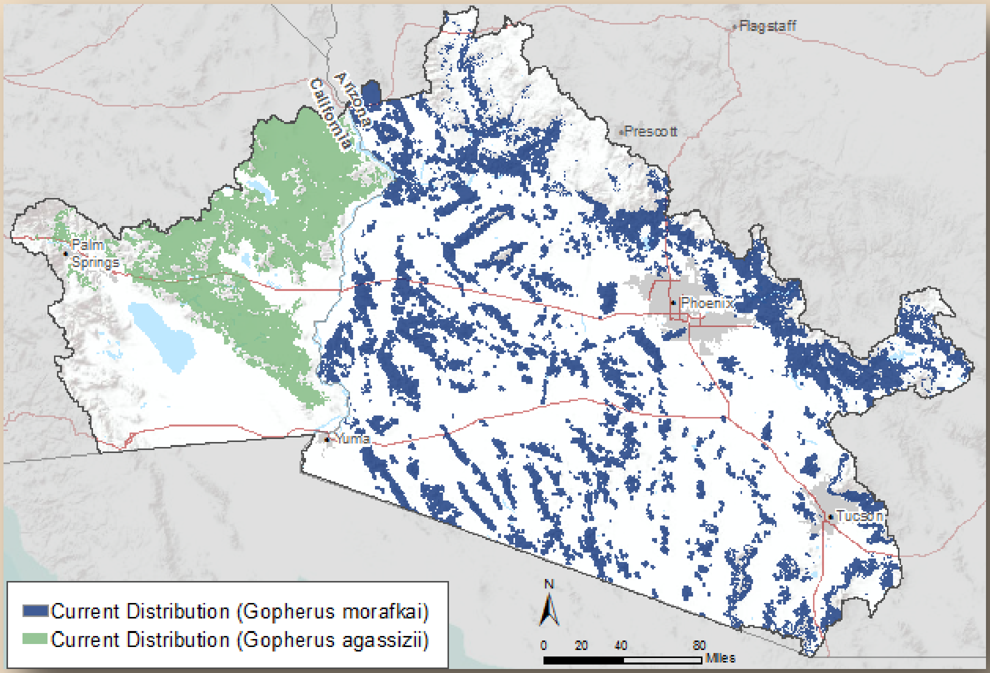


Figure 1. Potential distribution of the Mojave desert tortoise (*G. agassizii*) in green (based on a model developed by Nussear et al. (2009) and the Sonoran desert tortoise (*G. morafkai*) in blue. Map answers the management question: What is the most current distribution of available occupied habitat for desert tortoise?

The distribution of the Mojave desert tortoise is based on a predicted habitat distribution from an existing MaxEnt model developed by Nussear et al. (2009, Figure 1, green) for a wider region including the Mojave Desert of Nevada and Utah. The U.S. Geological Survey is developing another MaxEnt model for predicted habitat for the Arizona distribution of the Sonoran tortoise. In the meantime, for this REA, data was acquired from Arizona GAP (Arizona Game and Fish Department) for the distribution of the Sonoran desert tortoise (Figure 1, in blue).

Mojave Desert Tortoise (*Gopherus agassizii*)

Photo: Mojave desert tortoise. K. Nussear, U.S. Geological Survey

The Mojave desert tortoise occurs mainly in creosote bush (*Larrea tridentata*) flats, but it is also found in salt desert scrub and on sloping terrain on alluvial fans or foothills. It forages mostly on annual plants produced by winter rains. The yearly life cycle of the Mojave desert tortoise is heavily influenced by the annual precipitation pattern in the western Sonoran (and Mojave) Desert—precipitation that mainly falls in the winter and early spring with little or no summer precipitation (Van Devender 2002, Dickinson et al. 2002). As a result, most Mojave tortoise activity takes place in the spring when winter annuals and spring grasses are readily available (Nagy and Medica 1986, Brussard et al. 1994). Mojave tortoise hatchlings may overwinter in their nest and may not eat fresh forage until the following winter or spring. In years of low winter rainfall, Mojave tortoises may feed on introduced annual grasses in the absence or scarcity of winter annuals (Esque 1994), and while it is known that a diet of invasive grasses will keep tortoises alive, it is unknown if over time such a diet will keep them fit (Esque et al. 2002).

The species faces the prospect of annual summer drought; in the hot summer months and through the winter, the tortoises spend many months of inactivity in burrows in estivation or hibernation without eating or drinking. Mojave tortoises actively dig their own burrows in the friable soils of the western Sonoran Desert's basins and alluvial fans; they have the opportunity to alter the depth and extent of burrows to provide optimal thermal refuge and proper nest temperatures. Mojave desert tortoises typically burrow under shrubs in coarse sandy or loamy soils; they will also burrow under rocks, layers of caliche (as in the photo below), or even cement slabs in disturbed areas (Andersen et al. 2000, Lovich and Daniels 2000). Tortoises use multiple burrow sites that may vary in aspect throughout the year; burrows are often located under shrubs for shade, thermal cover, and protection from predation (eggs and juveniles, Lovich and Daniels 2000).

Because the species is at the northern limit of the overall range of desert tortoise species and because of their dietary restraints and restricted access to water, the Mojave desert tortoise may be more vulnerable to mortality from drought, loss of condition, and other stressors than the Sonoran desert tortoise (Peterson 1996, Oftedal 2002). The harsher conditions of the western Sonoran Desert ecoregion are reflected in the demographic characteristics of Mojave tortoises: individuals mature earlier reproductively and have a shorter life span than the Sonoran tortoises (Curtin et al. 2009). Curtin et al. (2009) admit that relatively fast growth and early reproduction in a harsh environment may be counterintuitive, but that such a life history strategy may have a selection advantage in populations with high juvenile mortality and shorter overall life span.

Case Study No. 1

Photo: Mojave tortoise in its burrow. S. Schwarzbach, U.S. Geological Survey

Although similar threats and disturbances affect both tortoise species, there are differences related to their varying life histories and habitats (Curtin et al. 2009). For example, as a lowland tortoise, Mojave tortoise inhabits more developable flatlands and basins in fast-developing areas of California's Sonoran Desert; as a result, it is more directly threatened by displacement from urban, agricultural, and energy development than the Sonoran tortoise that frequents the rocky slopes of the Arizona Upland (also see development section below). The fragmentation of habitat through rural housing and energy development affect tortoise populations not just through direct alteration of habitat but also through providing infrastructure and amenities that benefit predators of juvenile tortoises (Doak et al. 1994, Boarman 2003). Residential development, roads, and landfills favor tortoise predators such as ravens, coyotes, and feral and domestic dogs. For example, during a 25-year period in the late 20th century, some Mojave and California Sonoran raven (*Corvus corax*) populations in recently developed areas increased by 450-1000% (Boarman 2003). Piles of tortoise shells (incriminating evidence) have been found under raven nests (Boarman 2003). In contrast, Boarman and Coe (2002) found that raven densities were low in the roadless portions of Joshua Tree National Park.

Desert tortoises in the Mojave Desert suffer more than Sonoran desert tortoises from the upper respiratory tract disease (URTD) mycoplasmosis. Losses from this disease were one of the reasons for listing the Mojave species as threatened under the Endangered Species Act in 1990 (Van Devender 2002, USFWS 2008). For the Mojave tortoise, the frequency and intensity of URTD may be influenced by the effects of other disturbances. Habitat degradation, drought stress, food shortages, and crowding may all affect the onset and severity of URTD infections (Tracy et al. 2004)

Declines in Mojave desert tortoise continue even though tortoise management areas have been established and some of the major disturbances in those areas have been excluded. Prospects for recovery of Mojave desert tortoise are bleak if threats to both adult and juvenile segments of the population are not reduced. Doak et al. (1994) found that the rate of desert tortoise population growth was most sensitive to the survival of large adult females, and they proposed that improving survival of adult females could reverse population declines. Tracy et al. (2004) observed that the threats to desert tortoise are interactive and synergistic, and that recovery management required attention to factors affecting other age classes as well, such as the increase in predation on juvenile tortoises.

Case Study No. 1

Sonoran Desert Tortoise (*Gopherus morafkai*)

Sonoran desert tortoises live on the rocky slopes and bajadas of Arizona east of the Colorado River in the Arizona Uplands and northwestern Mexico. There is a wide range in tortoise densities across the Sonoran Desert depending on habitat conditions and food availability; Sonoran tortoise populations may range from 15–100 adults/mi^2 (Averill-Murray et al. 2002). Home range sizes also vary, but a typical female tortoise home range in Arizona is 10 ha; males' territories may be larger, overlapping the range of several females (Van Devender 2002, Averill-Murray et al. 2002). The species does occur on occasion and in low densities in the valleys (USFWS 2010), but the frequency of dispersal of young or adults between mountain ranges is unknown. It appears that the Sonoran desert tortoise, with its patchy distribution, may have fewer opportunities for maintenance of genetic diversity and dispersal than the Mojave tortoise, which has greater continuity among populations across the broad basins of the Colorado Desert (disregarding fragmentation and human disturbance factors, Van Devender 2002, Hagerty et al. 2011).

Photo: Sonoran desert tortoise (*G. morafkai*), Arizona Game and Fish Department

Sonoran desert tortoises construct burrows under shrubs and rocks or in caliche caves; the tortoise may expand existing crevices under rocks, but the rocky soil does not permit the extent of burrowing that occurs in the more friable soils of the Colorado Desert. Desert washes are important to this species as they provide exposed banks with variable aspects, exposed caliche caves for locating burrows, and xeroriparian vegetation for thermal cover (Riedle et al. 2008). Unlike the Mojave tortoise that estivates in its burrow during the summer drought, the Sonoran tortoise is active in the summer during the monsoon season when fresh forage is available. Eggs usually hatch at the end of the summer rainy season, meaning that hatchlings have more access than Mojave tortoise hatchlings to fresh forage in most years (Averill-Murray et al. 2002). Besides summer annual forbs, the Sonoran tortoise feeds on warm season grasses such as big galleta (*Pleuraphis rigida*), bush muhly (*Muhlenbergia porteri*), and threeawns (*Aristida* spp.). These grasses become sparser to the west where the summer monsoon rains dwindle; as a result, Sonoran tortoises living on the drier mountain ranges closer to the Colorado River subsist on alternate food sources more similar to those available to Mojave tortoises (Van Devender 2002).

The eggs and young of both species of tortoise are subject to heavy predation by a range of mammal and bird species as well as other reptiles (e.g., Gila monsters). With their soft shells, the young are rather defenseless, and they also must spend a greater proportion of their time foraging, exposing them to predation (Morafka 1994). Raven predation, however, may not be as high for tortoises in Arizona as it is in California; the increases in raven populations subsidized by development have not (yet) occurred to the same extent. Bird predation on tortoises in general may be less in much of tortoise habitat in Arizona because of the greater cover provided by denser upland vegetation (USFWS 2010).

The greatest human-induced threats to Sonoran desert tortoise are urban and exurban development, associated road building and highway upgrading, and the increasing demands of a larger population on outdoor recreation. Throughout the 1990s the urban fringe in Phoenix advanced outward at the pace of ½ mile per year (Rex 2005). Population projections for the Phoenix areas for the next 5 decades envision a 1–1.5 million increase per decade (assuming sufficient water availability, Rex 2005). Although urban development in lowland areas may not directly convert tortoise habitat on slopes and bajadas, it puts human influence and activities in closer proximity to tortoise habitat, increasing overall access, recreation use, harassment, and pet predation. Even if valley dispersal among populations is not common, it may be important to genetic diversity; barriers from development between mountain ranges create closed populations that, if degraded or damaged, will not have the ability to recover through recruitment from other populations (USFWS 2010). In 2010 the US Fish and Wildlife Service found that listing the Sonoran population of the desert tortoise was warranted, but that listing was precluded by higher priority actions (USFWS 2010). As a result, the Sonoran population of the desert tortoise was added to the candidate species list, where its status will be reconsidered annually.

Change Agents Affecting Both Species

Photo: Desert tortoise contemplates a road crossing.
W. Boarman, U.S. Geological Survey

Tortoises are directly threatened by humans in myriad ways including conversion of tortoise habitat by development, fragmentation and degradation of habitat by road networks and ORVs, vandalism, and direct mortality from collisions with vehicles on roads and ORV trails. Habitat fragmentation and barriers to movement created by interstate highways and canals can severely limit desert tortoise populations as well (Edwards et al. 2004). Off-road vehicles (ORVs) destroy and degrade habitat, crush burrows, and kill tortoises. Although both habitat damage and direct mortality may occur, habitat damage is the most strongly established effect of ORV use (Bury and Luckenbach 2002). Vandalism and intentional killing was a factor in listing the Mojave tortoise; at long-term monitoring plots in California, 14% of carcasses found between 1976 and 1982 contained evidence of gunshot wounds (Berry 1986).

Grazing practices affect tortoise populations through direct competition for the tortoise's herbaceous food plants and the general decline in abundance and species diversity in annual and perennial forbs that occurs over time in grazed areas. Grazing pressures that create a decline in diversity of winter annuals and fresh spring forage affect Mojave tortoises, while the general decline in C_4 (warm season) grasses in the Arizona Upland has adverse nutritional consequences for Sonoran tortoise, particularly when the forbs and grasses are replaced by invasive annuals. Although evidence suggests that Mojave tortoises might be more directly affected by grazing animals through soil compaction and trampling of their earthen burrows, a field survey of Sonoran tortoises in the Black Mountains of Arizona recorded almost 200 trampled burrows (Woodman et al. 1998). Both grazing-induced changes in species composition and trampling promote the invasion of nonnative plant species (USFWS 2010).

Photo: Young saguaro overtopped by buffelgrass in Saguaro National Park, National Park Service.

Development and road building also facilitate the spread of invasive annual plant species that introduce more frequent fire to desertscrub communities, which are not fire-adapted. Red brome (*Bromus rubens* subsp. *madritensis*) and buffelgrass (*Cenchrus ciliaris*, syn. *Pennisetum ciliare,* photo left), for example, directly reduce plant diversity, forage quality, and habitat structure (shrub thermal cover) for desert tortoise and produce fine fuels that carry intense and extensive fire (Brooks and Esque 2002, Esque et al. 2003, Esque et al. 2004). Dense stands of Sahara mustard (*Brassica tournefortii*) may also carry fire (especially when mixed with red brome, Brooks and Minnich 2006) and the dense growth of the mustard creates physical barriers to tortoise movements (see further discussion of fire and invasive species in Section 4.3, Change Agent Distribution and Intensity). The fire season for Mediterranean annuals (like red brome) peaks in the hot fore-summer season in May; the perennial grass (i.e., buffelgrass) fire season is longer, from October to the following July (Esque et al. 2002).

From 1990–2008, approximately 164,800 acres (66,690 ha) of desert tortoise habitat in Arizona burned on BLM lands (USBLM in USFWS 2010). The U.S. Fish and Wildlife Service (2010) estimates that 1.5% of tortoise habitat has been affected by wildfire in recent years over all ownerships in Arizona. Direct effects of fire in desert habitats include animal mortality and loss of vegetation cover. Although tortoises may escape fire in underground burrows, direct mortality from intense and slow-moving grass-fueled fire has been documented in the Sonoran Desert (Esque et al. 2003). Esque et al. (2003) estimated that 11% of adult desert tortoises present in the area of a fire at Saguaro National Park near Tucson, Arizona had died. Indirect effects of fire on tortoises may include increased predation and loss of thermal cover from the standing biomass of shrubs, desert trees, and cacti that supplement their network of burrows and rock shelters, although such effects may be species- or region-specific (Lovich et al. 2011a). However, loss of thermal refugia could lead to direct mortality if tortoise body temperatures exceed 40° C (104° F, Esque et al. 2002).

Current Species Status and Near-Term Development Scenario (2025)

Current status was evaluated for each wildlife species conservation element included in the REA by overlaying the species' current distribution against the overall current terrestrial intactness model—a regional model combining data for vegetation-habitat distribution, development, and natural habitat fragmentation patterns. (For maps of regional current landscape intactness, see Section 4.2.1.) The product is a map of ranked classes of status within both tortoise species' distributions (Figure 2). The distribution of the Mojave desert tortoise (*G. agassizii*) is from a potential habitat model by Nussear et al. (2009) and the distribution of Sonoran desert tortoise (*G. morafkai*) originated from the Arizona Game and Fish Department.

Case Study No. 1

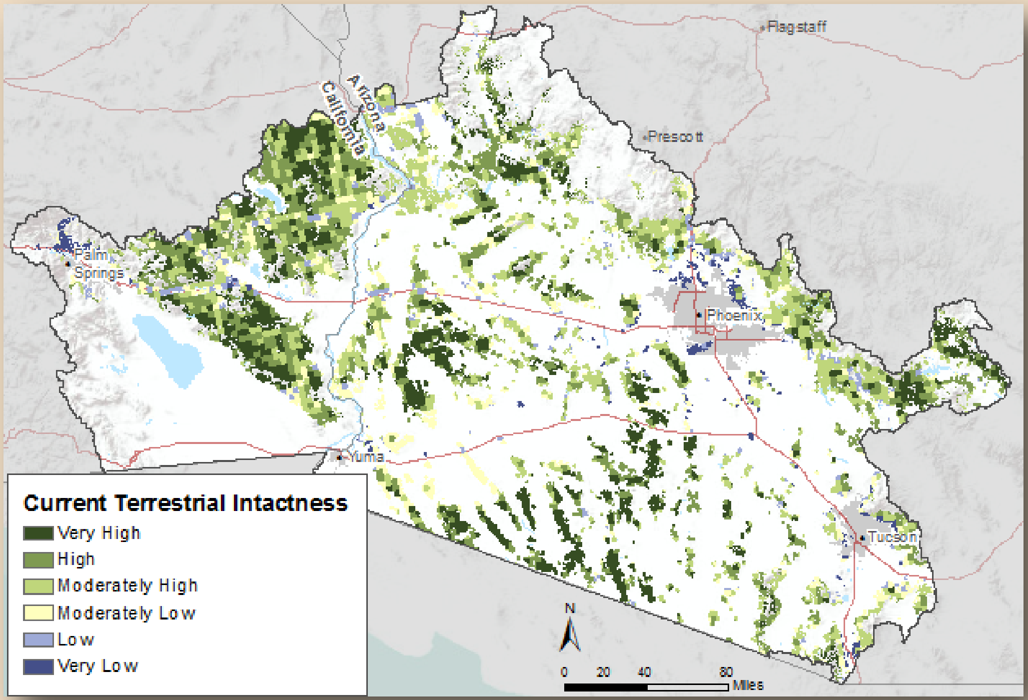


Figure 2. Current status for both Mojave desert tortoise (west of Colorado River) and Sonoran desert tortoise (east of Colorado River). See Figure 4 below for summary histograms.

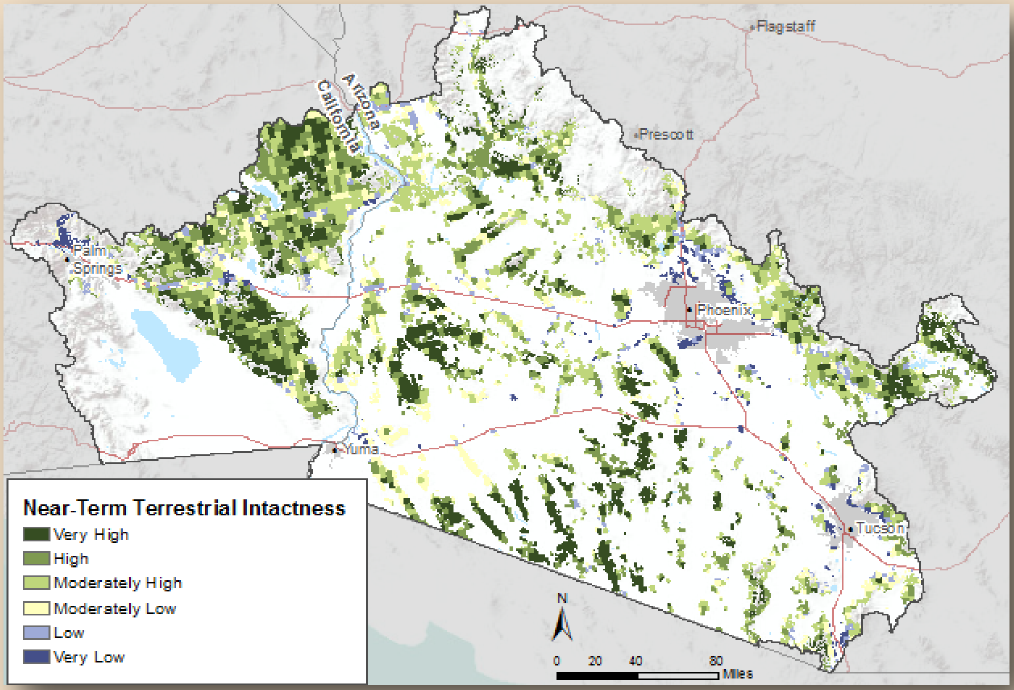
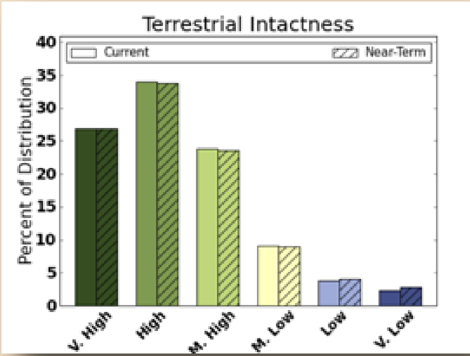


Figure 3. Map shows near-term future status (2025) for Mojave desert tortoise (west of Colorado River) and Sonoran desert tortoise (east of Colorado River). Differences between maps in Figures 2 and 3 are small and difficult to detect; see Figure 4 below for summary histograms.

Similar results were produced for both tortoise species for *near-term future status* (2025, Figure 3) by overlaying current distribution with a mapped model of near-term future landscape intactness to answer the management question, *What terrestrial species are vulnerable to change agents in the near-term horizon, 2025*? Although the intactness model was sound, available predictive data to populate the model was sparse, consisting mainly of renewable energy potential, urban expansion data, and a predictive model for expansion of invasive species. Predictive data was lacking relative to attributes like future roads, utility corridors, recreation, and agriculture. As a result, the regional map for the species' near-term future status (Figure 3) does not show dramatic differences from the current status map. However, summary histograms for Mojave desert tortoise (Figure 4, left) and Sonoran desert tortoise (Figure 4, right) do show small decreases in high intactness classes and modest increases in Low and Very Low intactness for both species in the near-term future (2025).



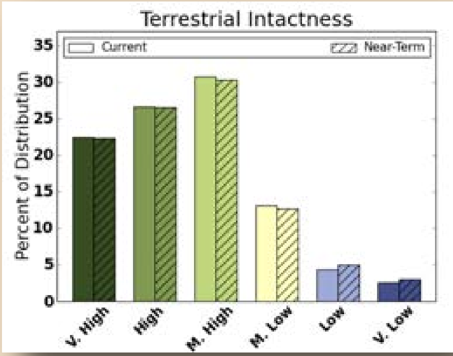


Figure 4. Left: Histogram comparing current (solid color bars) and near-term future (hatched bars) status of Mojave desert tortoise based on comparison of current distribution with current and near-term future terrestrial landscape intactness. Right: Similar results for Sonoran desert tortoise. Both sets of histograms show modest decreases in Very High and High intactness areas countered by slight increases in the Low and Very Low classes.

Future Energy Development Scenarios

REA products included the impacts of near-term future energy development (a component of the near-term terrestrial intactness model, see logic models Section 5.1 and 5.2) on each tortoise species (Figure 5A). Near-term energy development refers to 2011 priority projects that are in the approval process or have already been approved. The Sonoran tortoise, living on rocky slopes, is not likely to have its habitat directly converted for solar energy production, although large scale valley energy development with associated roads and infrastructure will contribute to the further isolation of Sonoran tortoise populations in Arizona. The Mojave tortoise's distribution in the basins of the Colorado 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 5B) is not tied to a specific time period, but it is based on those proposed areas still subject to planning and approval. Data for the mid-term energy projection included features from California BLM on verified and preliminary renewable energy rights-of-way, modified solar energy zones (SEZs), and Arizona restoration design energy project data (RDEP). A third category, maximum potential energy development (map not shown) covers a longer time frame and includes more speculative data for wind and solar potential. When the two tortoise species' distributions were overlaid against the maximum potential (renewable) energy development data, Mojave tortoise was shown to be at higher risk of impact than Sonoran, as we would expect (see histograms, Figure 6).

Case Study No. 1

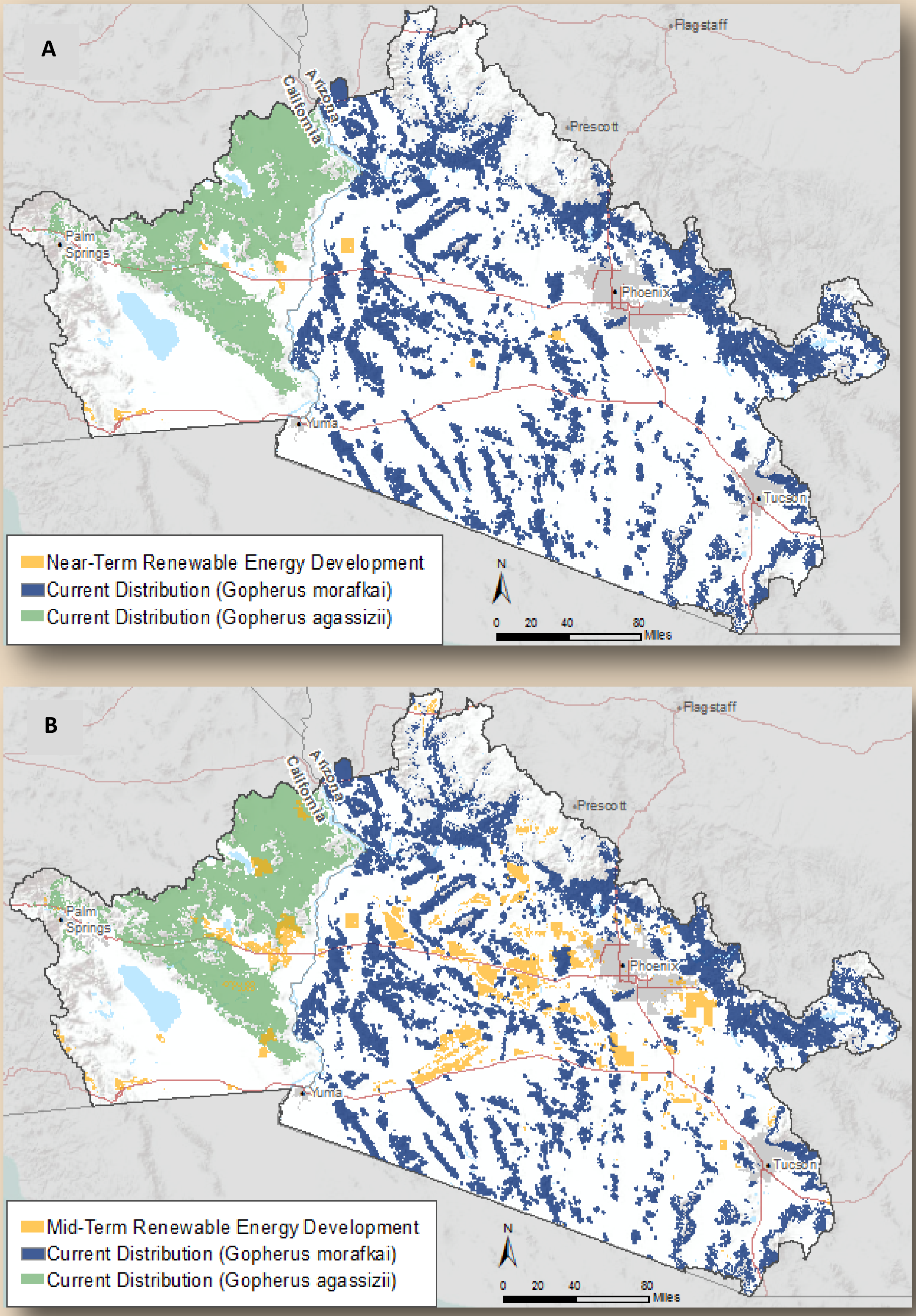


Figure 5. Maps show current distribution for the two species of desert tortoise with data for (A) near-term (2025, 2011 priority projects) and (B) mid-term (see text for definition for proposed development areas) renewable energy development in yellow.

Case Study No. 1

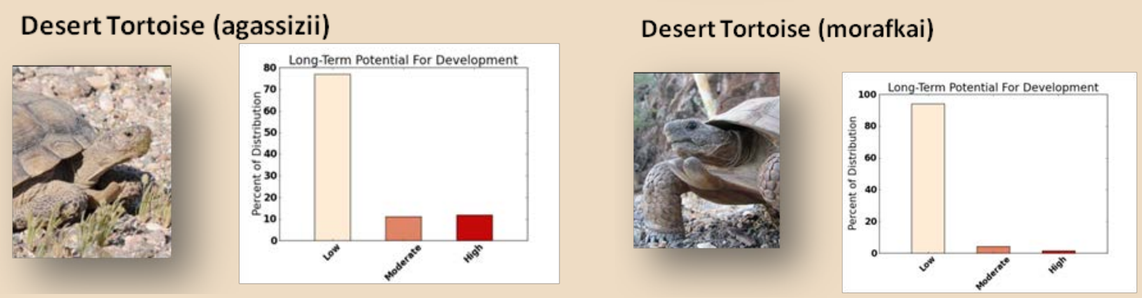


Figure 6. Risks of impacts from maximum potential (long-term) energy development on the two tortoise species, with Mojave tortoise (G. agassizii) experiencing higher risk of impact (left histogram).

The pace of approval and construction of renewable energy projects may be exceeding the state of our knowledge of the effects on various wildlife species (Bare et al. 2009). When considering the effects of major industrial renewable energy projects on desert tortoise, there is some evidence that desert tortoises may be able to adapt to some wind farm development (Lovich and Daniels 2000, Lovich et al. 2011b). Although wind energy facilities fragment the landscape with towers, road network, and associated infrastructure, there is very little road traffic within the sites, and human entry is limited for security reasons. Lovich et al. (2011b) found that the tortoises living in a wind farm near Palm Springs, California did not differ in most demographic characteristics from tortoises living in more natural situations. Thus, while the mortality of birds may be high among arrays of wind turbines (see discussion on golden eagle, Appendix C), desert tortoises may be able to coexist with wind energy, particularly with some pre-planning with tortoises in mind.

Solar energy is a different story. Solar arrays cover thousands of acres, and the land is scraped clean of vegetation. The area of the modified solar energy zones (SEZs) within the REA boundary (data used in the mid-term renewable energy development map, Figure 5B) is about 160,000 acres (DOE/BLM 2012). The largest SEZ area is 148,000 acres in eastern Riverside County, California; 9 projects have been proposed and 2 approved on 57,000 acres of this SEZ as of late 2011. Lovich and Ennen (2011) review the possible effects of industrial solar on desert wildlife and propose research necessary to inform the process and to mitigate the negative effects of solar energy development on wildlife.

Climate Change Scenario (2060)

REA results for climate show the Mojave tortoise under highest risk from climate change (Figure 7). Higher temperatures (estimated to be 2–3°C by 2050) and prolonged droughts may change the suitable elevation range for the species, possibly shrinking its distribution within its present range or prompting a northward or upward elevational shift (Barrows 2011). The low-elevation areas of the Colorado Desert, presently off limits to both species because of high temperatures, extended drought, and low forage value, may expand. The regional view of climate change results for seasonal temperature and precipitation changes suggest a more complex result. Both summer and winter precipitation decline in the 2015–2030 time period, but, for 2045–2060, while winter precipitation shows declines similar to the earlier time period (compared to historic levels), summer precipitation shows smaller declines compared to historic levels. The climate modeling results for vegetation change (based on broad vegetation classes minus human influence, Section 5.4.1.1) show C_4 (warm season) grasses expanding to the west in mid-century, indicating a change in the dominance of winter precipitation in the western Sonoran desert that could affect the Mojave tortoise. On the other hand, higher variability in the bimodal precipitation pattern in Arizona could have a pronounced negative effect on the Sonoran tortoise. A trend toward wetter springs will encourage the expansion of C_3 invasive grasses (cool season grasses such as red brome). If the timing and distribution of the summer monsoon is not radically changed, increasing temperatures will favor native C_4 grasses.

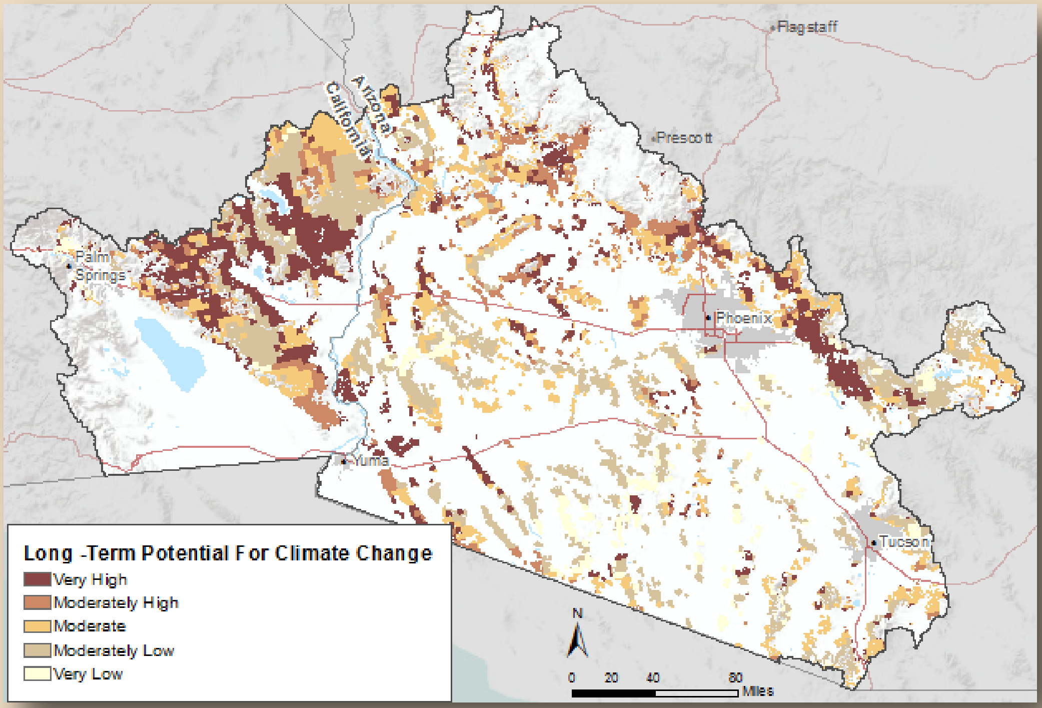


Figure 7. Map results answer the management question, *What terrestrial species are vulnerable to change agents in the long-term horizon, 2060, due to climate change*? The range of the Mojave desert tortoise (west of the Colorado River) is most highly affected by climate change. Mojave tortoises are at the northern limit of the overall range of the various desert tortoise species and populations, and the species is already in trouble; at first glance, one might assume that the Mojave tortoise may be more vulnerable to mortality or extirpation from climate change. However, there may be ameliorating circumstances such as the westward increase in C_4 grasses indicated by the climate modeling results (Section 5.4). Such a change in seasonal precipitation patterns could benefit tortoises in the western Sonoran Desert.

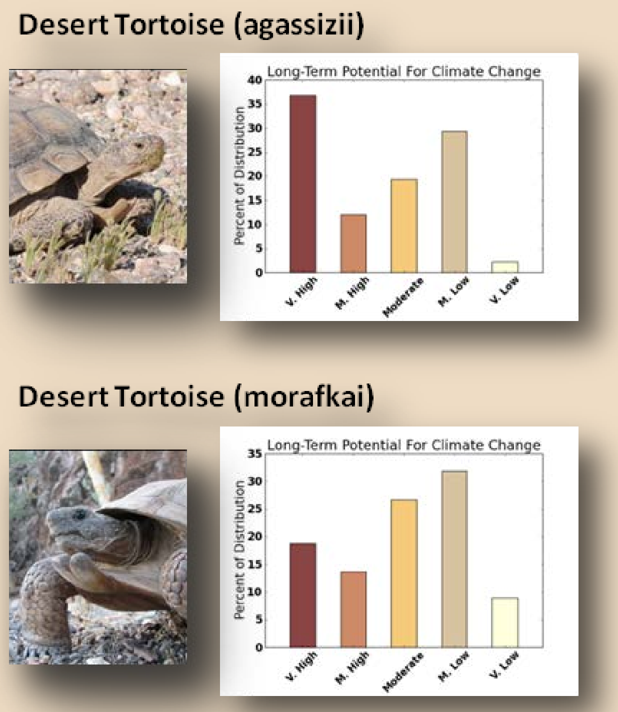


Figure 8. Histogram results for both species of desert tortoise indicating potential climate change impact from Very High (brick color left) to Very Low on the right.

The histogram results (Figure 8) indicate that potential impact on the Mojave desert tortoise is very high with almost half of its current distribution under Very High or Moderately High climate change potential. Sonoran desert tortoise fairs considerably better with roughly 30% of its current distribution within these same categories. Because the desert tortoise exhibits temperature-dependent sex determination of hatchlings, there is concern that increased temperatures from climate change could lead to skewed sex ratios that could affect future populations (Spotila et al. 1994, Baxter et al. 2008). Lewis-Winokur and Winokur (1995) found that the pivotal temperature for desert tortoise sex determination in hatchlings was 31° C. In their experiment, at 31° C, the male to female sex ratio was 5:7; at temperatures below that, the tortoises were all males. Lewis-Winokur and Winokur did not test temperatures above 31° C, but Spotila et al. (1994) did and found that above 32.8° C the hatchlings were all female. It is unknown whether the transitional range of temperature (31–32.8° C; 88–91° F) that produces both sexes (Hulin et al. 2009) is wide enough to allow tortoise adaptation to the increased temperatures that accompany climate change. On the other hand, it has been argued that skewed sex ratios are not found exclusively in stressed turtle populations (Lovich and Gibbons 1990) and that tortoises have survived other periods of temperature extremes in their long evolutionary history. Patterns of hibernation and estivation and the use and placement of burrows also play an important role in tortoise response to temperature extremes and prolonged drought.

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4.2.3 Vegetation Communities: Current Distribution and Status

> Vegetation Communities Management Questions
>
> 1. Where are existing vegetation communities, and what is their status?
> 2. What change agents have affected existing vegetation communities?

Two coarse filter vegetation communities plus riparian vegetation were evaluated for the Sonoran Desert ecoregion. For the specific vegetation communities, two different sources of data were compiled (LANDFIRE EVT v1.1 and NatureServe Landcover v2.7) to depict current distribution (Figure 4-16).

Besides the differences in classes mapped, the area covered for each vegetation community type according to the two classifications differed to varying degrees (Table 4-5**)**. While a visual inspection of the two shows each vegetation community in approximately the same general locations, the actual pixel-to-pixel agreement was only fair, with percent overlaps from 40 to slightly over 50 percent. Even though there are notable differences between the two classification systems, it is more appropriate to acknowledge the differences and choose the one most meaningful for a particular purpose than to attempt to hybridize the two into a single product.

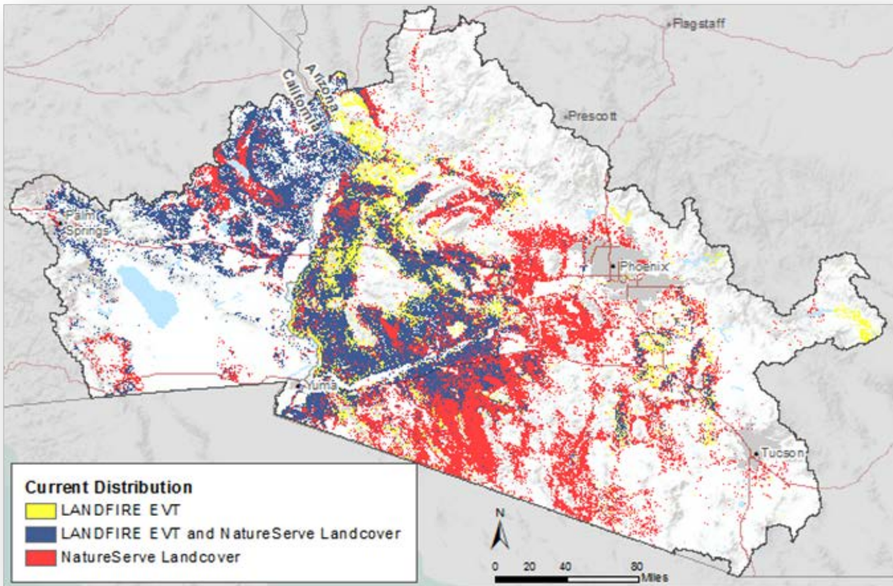
Evaluating current status for each vegetation community is challenging in several ways. Vegetation communities are dynamic over time and space, demonstrating a degree of fluidity especially along ecotonal boundaries driven by the pattern and timing of climate and natural and human disturbance. Specific plant communities are not fixed on the landscape as individual site histories dictate what community is expressed at a particular time. A fairly long history of human disturbance of the natural landscape from water management, invasive species, and grazing has had a profound impact on the native vegetation communities.

To address questions of historic change, LANDFIRE Biophysical Settings (BpS) data, modeled presettlement vegetation, was used as the reference condition. Biophysical settings provide a spatially explicit estimate of what vegetation communities would likely occur in a specific location based on physical conditions (e.g., soils, elevation, aspect, moisture, and natural fire regime). Because it is a model, any strict alignment with current distribution (i.e. LANDFIRE EVT) should not be expected. For example, the BpS and EVT maps for the creosotebush-white bursage and palo verde-mixed cacti vegetation communities show considerable overlap but also some differences (Figure 4-17). It is reasonable to assume that some of these differences represent conversion of this community type to other land uses. Overlaying current urban and agriculture land uses, roads, invasive vegetation, and uncharacteristic native vegetation against LANDFIRE BpS data highlights possible areas of change from historic reference condition for both matrix communities (Figure 4-18).

Table 4-5. Area (in thousands of acres) comparison for vegetation communities between NatureServe Landcover v2.7 and LANDFIRE EVT v1.1.

Vegetation Community	NatureServe Only	LANDFIRE Only	Both	Percent Overlap
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	5,361	1,417	4,823	41.6
Sonoran Paloverde-Mixed Cacti Desert Scrub	1,797	5,332	7,373	50.8
Riparian Vegetation	1,600			

Sonora-Mojave Creosotebush-White Bursage Desert Scrub



Sonoran Paloverde-Mixed Cacti Desert Scrub

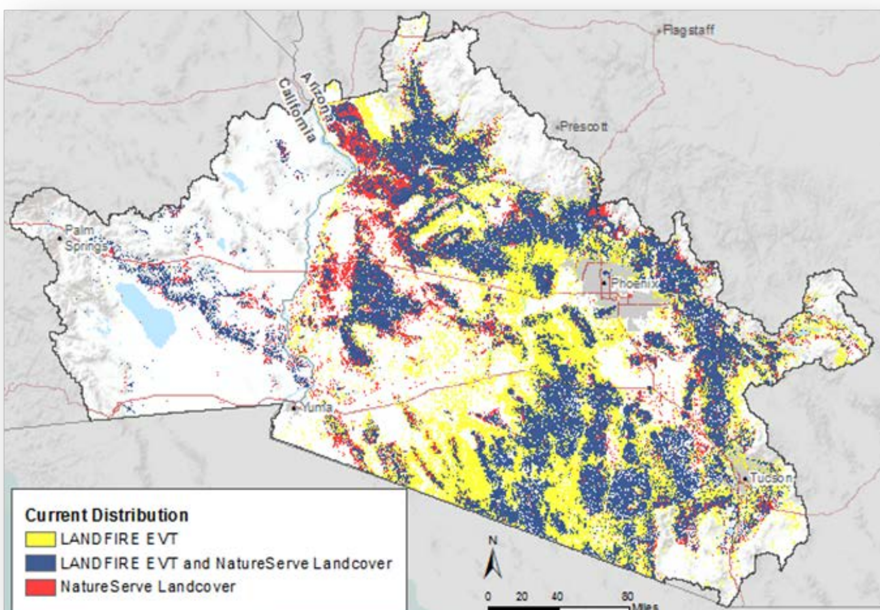


Figure 4-16. Map comparison between NatureServe Landcover v2.7 (in red) and LANDFIRE EVT v1.1 (in yellow) for the two matrix vegetation communities in the Sonoran Desert ecoregion. Areas common to both datasets are in blue.

A total of over 8.7 million acres (~37%) of the two natural vegetation communities mapped using LANDFIRE BpS were significantly changed in the ecoregion (Table 4-6). Changes due to invasive species conversion dominated the results, affecting over 5.2 million acres (Table 4-6). Conversion from urbanization and roads affected over 1.7 million acres and intensive agriculture (excluding grazing) converted over 1.1 million acres. The greatest total area changed (> 4.7 million acres or 30% of total BpS area) was in the Sonoran Paloverde-Mixed Cacti Desert Scrub class; however, the highest percent change was observed in Sonoran-Mojave Creosotebush-White Bursage Desert Scrub with 51% (>4 million acres) of its LANDFIRE BpS distribution converted by urbanization and roads, agriculture, and invasives.

More recent disturbances (approximately the last decade) such as fire, mechanical treatment, and other disturbances were analyzed in a similar fashion (Figure 4-19). A total area of about 395,000 acres (>1% of the combined area) was recently disturbed in the last decade (Table 4-7), mostly by fire (over 297,000 acres). Neither of the vegetation communities is well-adapted to fire resulting in a high probability that many of these burned areas will be later dominated by invasive grasses. Current distribution, historic change, and recent disturbance maps for each vegetation community are provided in Appendix B.

In addition to evaluating historic and recent disturbance to the matrix vegetation communities, which provides some insight into loss and recent disturbances, the status of the existing setting in which these communities currently occur was also evaluated. To do this, the current LANDFIRE EVT v 1.1 and NatureServe Landcover v 2.7 distributions for each community were overlaid against the current terrestrial landscape intactness model results. The assumption was that each natural vegetation community is affected in various ways based on the overall intactness of its immediate neighborhood.

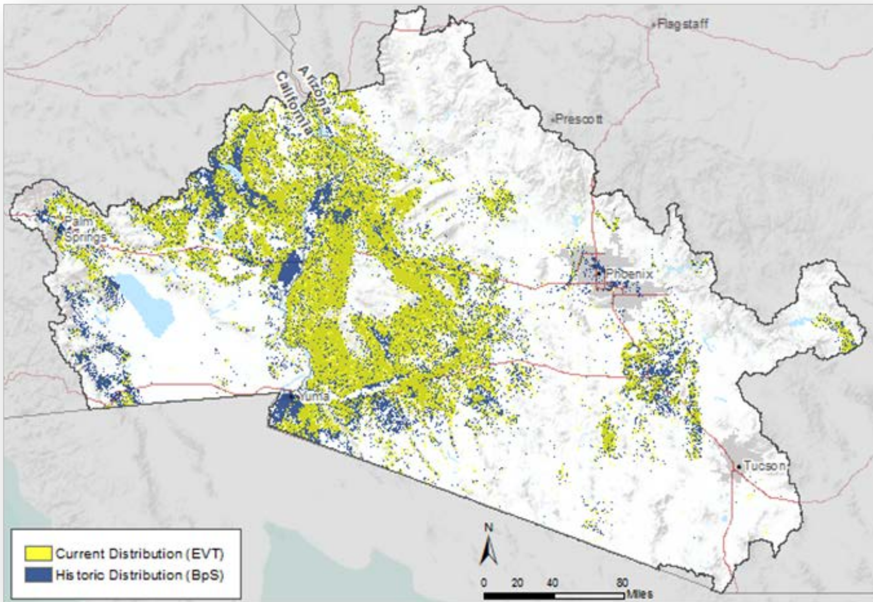
Status profiles for Sonoran-Mojave Creosotebush-White Bursage Desert Scrub for each classification were very similar and showed around 50% of the area in Moderately High or Moderately Low categories (Figure 4-20). The NatureServe version, which had more of this community mapped around Phoenix, had more of its area in the Low and Very Low categories. In either case, only around 10–14% of the area was contained in areas of Very High terrestrial landscape intactness, mostly in the northwest or south-central portion of the ecoregion. Results for Sonoran Paloverde-Mixed Cacti Desert Scrub in each classification system showed similar status profiles and better results than those for the Creosotebush-White Bursage community (Figure 4-21). Nearly 20% of this community had Very High intactness. LANDFIRE shows this community as absent in southeastern California, while it is known to be actually present there where it is a linear feature along large desert washes. These and other classification errors can be resolved at the local field office level.

4.2.3.1 Riparian Vegetation

Riparian ecological systems have undergone significant physical and biological changes throughout the ecoregion because of direct conversion to other uses; changes in natural flow regimes and suppression of fluvial processes (Stromberg 2001, Stromberg et al. 2007a); livestock grazing (Armour et al. 1994); and invasive species invasion (e.g., tamarisk, Stromberg et al. 2007b). As much as 90% of pre-settlement riparian ecosystems have been lost (LUHNA 2011).

Livestock grazing has damaged approximately 80% of stream and riparian ecosystems in the western US (Belsky et al. 1999). Grazing alters streamside morphology, increases sedimentation, degrades riparian vegetation through trampling and consumption and causes nutrient loading to the system. Invasive plants such as tamarisk often successfully out-compete native species, because tamarisk has high fecundity and it has been shown to be more tolerant to drought and flow alterations than natives (Stromberg et al. 2007a, Merritt and Poff 2010). For more details on riparian systems see the Tamarisk Case Study Insert that follows Section 4.3.

Sonora-Mojave Creosotebush-White Bursage Desert Scrub



Sonoran Paloverde-Mixed Cacti Desert Scrub

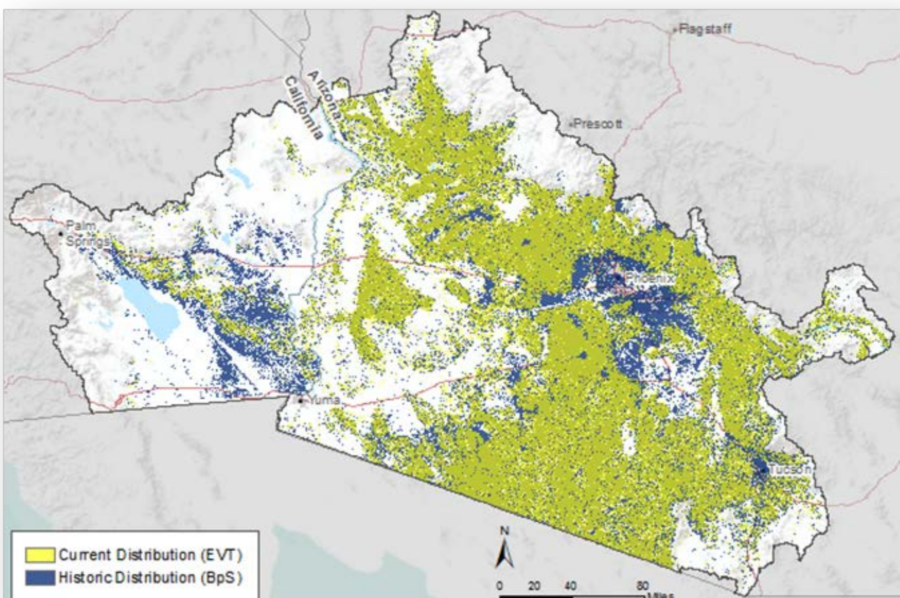
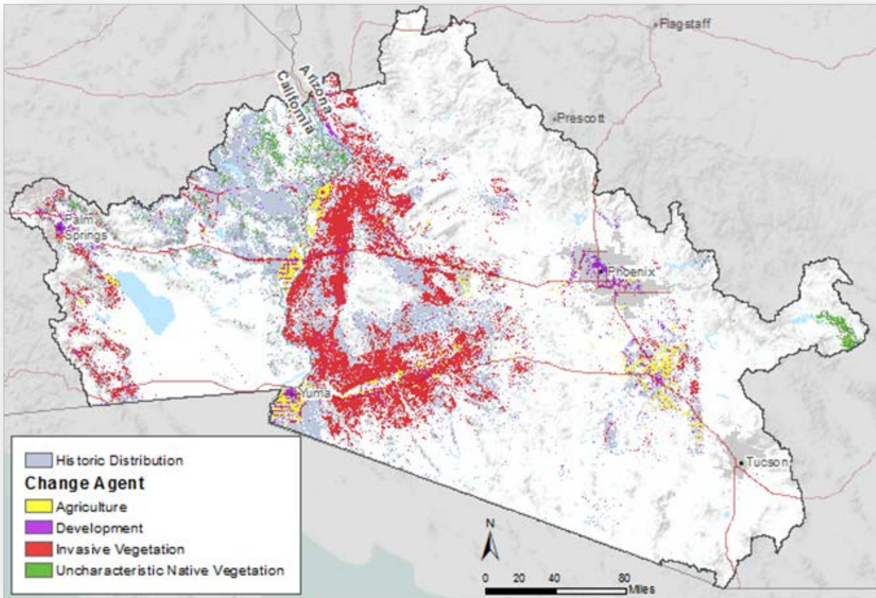


Figure 4-17. Comparison between LANDFIRE current distribution (EVT) and historic distribution (BpS) for Sonoran-Mojave creosotebush-white bursage desert scrub and Sonoran paloverde-mixed cacti desert scrub. Some of the differences between current distribution and modeled historic distribution may represent conversion of these community types to other land uses.

Sonora-Mojave Creosotebush-White Bursage Desert Scrub



Sonoran Paloverde-Mixed Cacti Desert Scrub

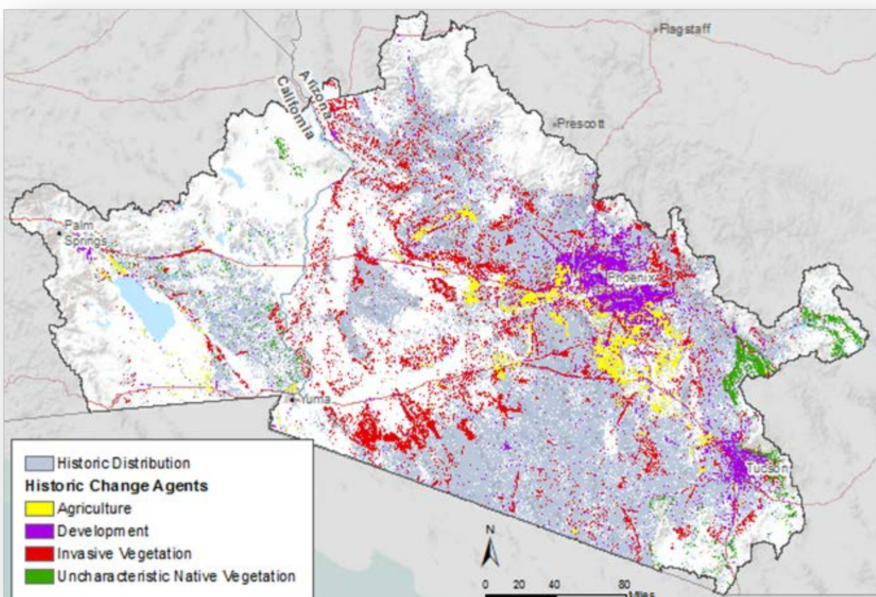
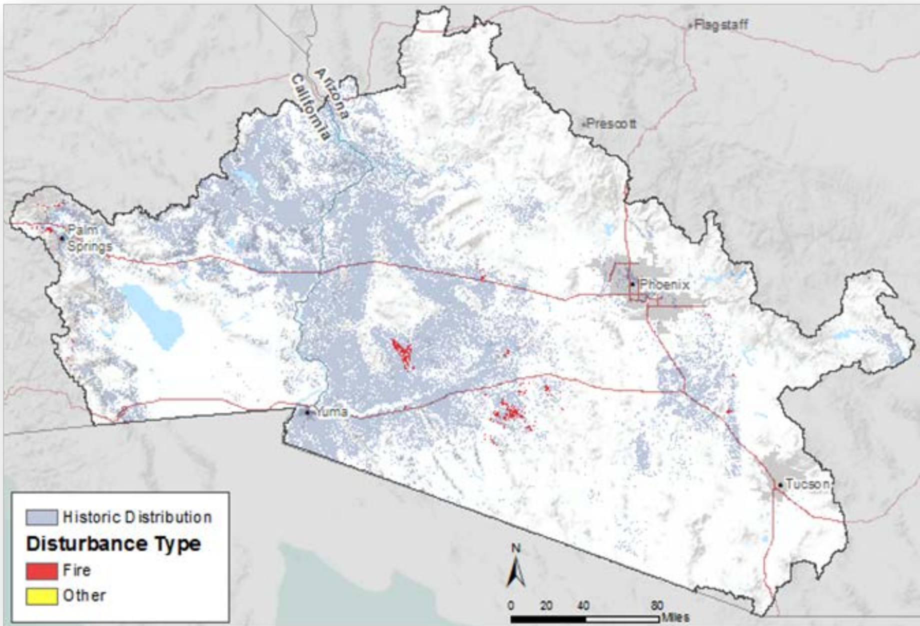


Figure 4-18. Conversion of major vegetation communities within the Sonoran Desert ecoregion. Overlaying current urban and agriculture land uses, roads, invasive vegetation, and uncharacteristic native vegetation against LANDFIRE BpS data (representing reference condition, in gray) highlights possible areas of conversion to different land cover from historic modeled reference condition for both matrix communities

Sonora-Mojave Creosotebush-White Bursage Desert Scrub



Sonoran Paloverde-Mixed Cacti Desert Scrub

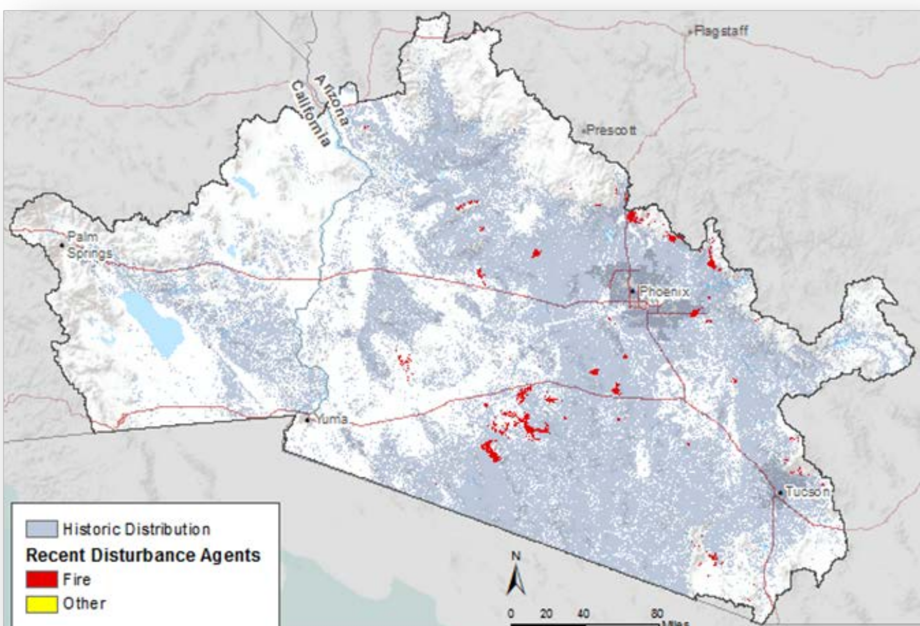


Figure 4-19. Recent disturbance (within the last decade) of major vegetation communities in the Sonoran desert ecoregion. A total area of about 298,000 acres (>1% of the combined area) was recently disturbed in the last decade in the ecoregion (Table 4-6), mostly by fire.

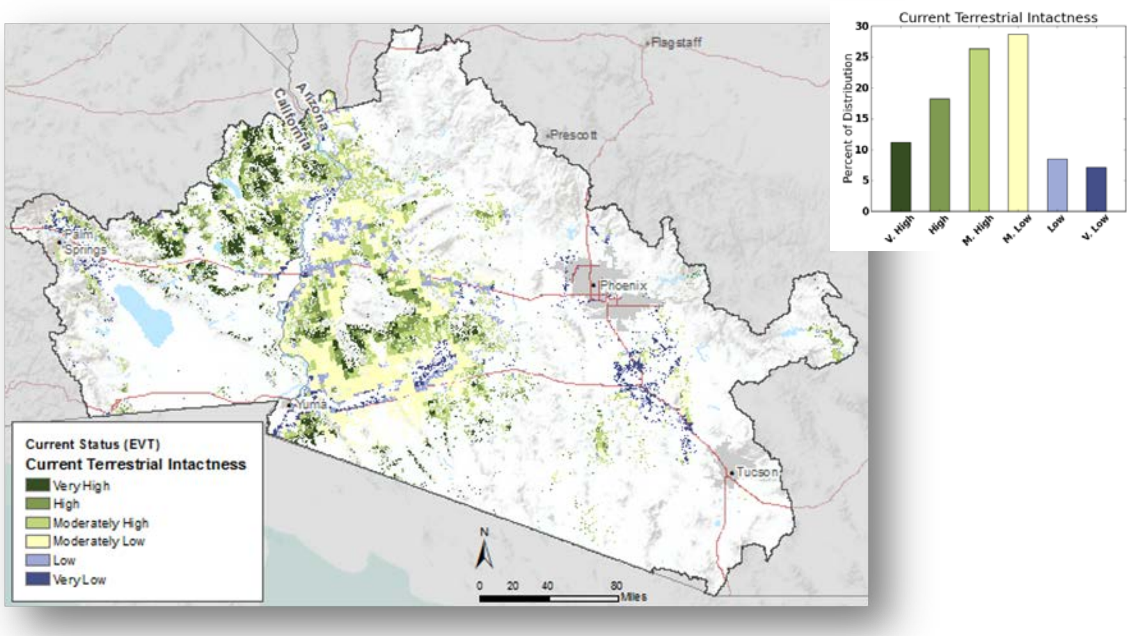
Table 4-6. Summary of area (in 1000s of acres) of historic change for each matrix vegetation community, comparing existing vegetation to LANDFIRE BpS data (representing reference condition). Acres represent conversion to different land cover from modeled presettlement vegetation.

Vegetation Community	Total BpS Area	Urban & Roads	Agriculture	Invasives	Unchar Native Veg	Total Changed	Percent
Sonoran-Mojave Creosotebush-White Bursage Desert Scrub	7,858	429	433	2,909	274	4,045	51.5%
Sonoran Paloverde-Mixed Cacti Desert Scrub	15,730	1,255	672	2,345	429	4,701	30%
Totals	**23,588**	**1,684**	**1,105**	**5,254**	**703**	**8,746**	

Table 4-7. Summary of area (1000s of acres) for each matrix vegetation community based on LANDFIRE BpS data that has been recently disturbed within the last decade in the Sonoran Desert ecoregion.

Vegetation Community	Total BpS Area	Fire	Mechanical	Other	Total Disturbed	Percent
Sonoran-Mojave Creosotebush-White Bursage Desert Scrub	7,858	85	0	80	165	1.1%
Sonoran Paloverde-Mixed Cacti Desert Scrub	15,730	212	0	18	230	1.4%
Totals	**23,588**	**297**	**0**	**98**	**395**	

Sonora-Mojave Creosotebush-White Bursage Desert Scrub - LANDFIRE



Sonora-Mojave Creosotebush-White Bursage Desert Scrub - NatureServe

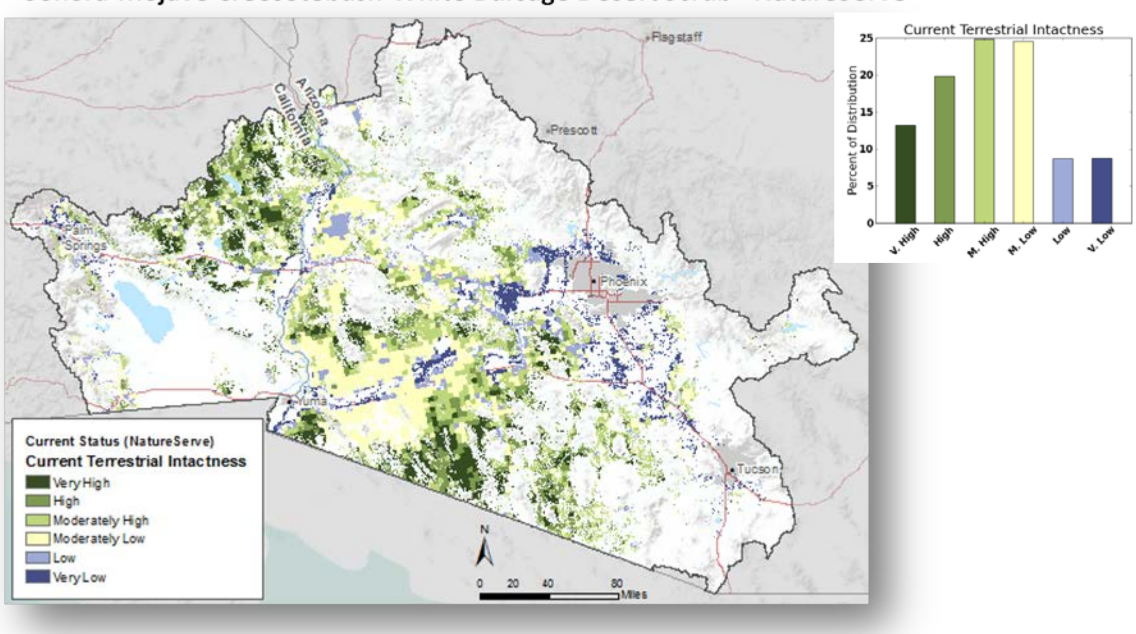
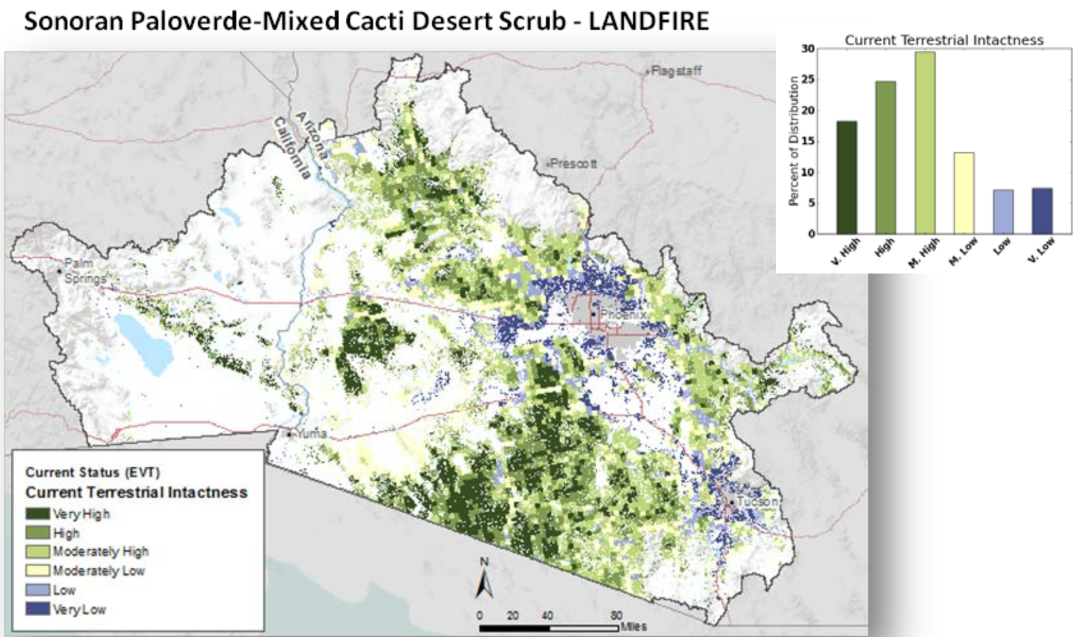


Figure 4-20. Current status for Sonoran-Mojave Creosotebush-White Bursage Desert Scrub for the Sonoran Desert ecoregion mapped by overlaying LANDFIRE existing vegetation (top) and NatureServe Landcover data (bottom) against current terrestrial intactness model results. The NatureServe version (bottom) with more of this community mapped in the Phoenix area had more of its distribution in the Low and Very Low categories.



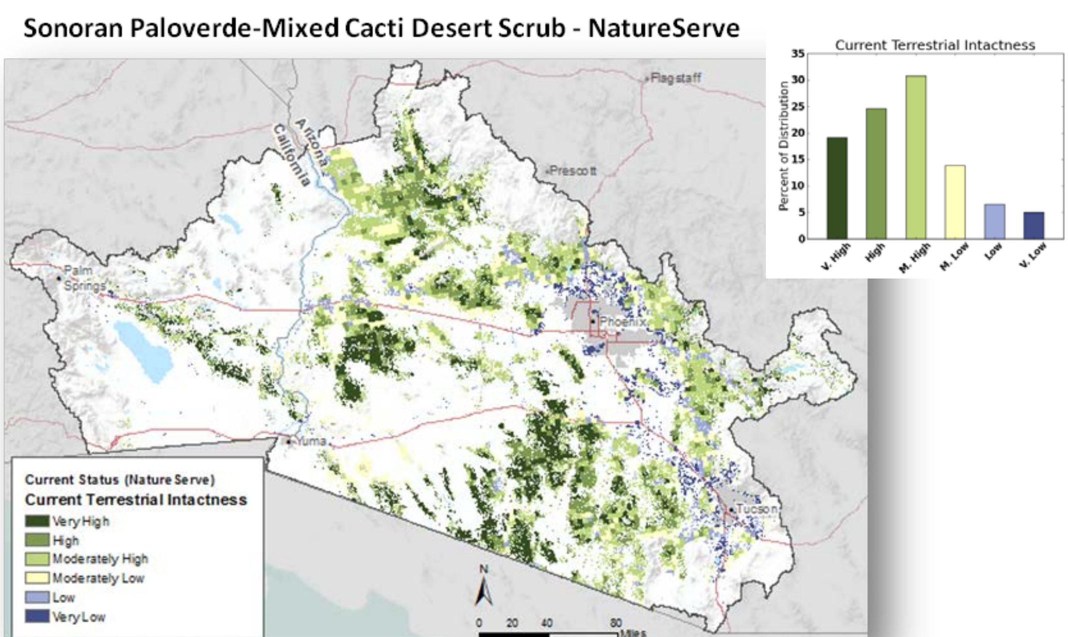
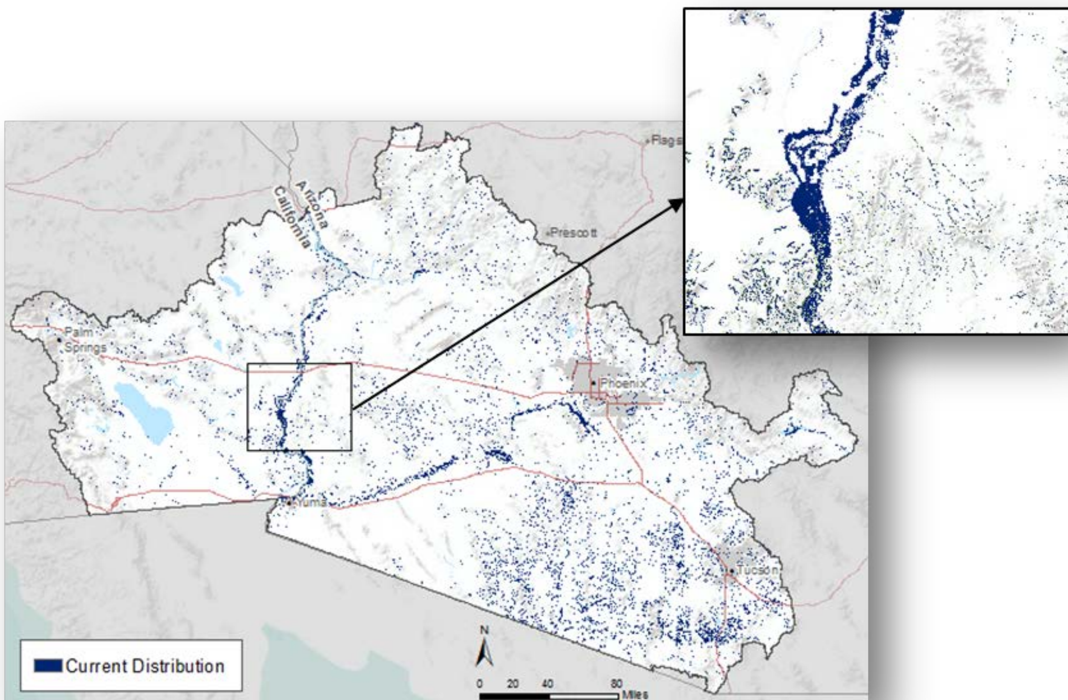


Figure 4-21. Current status for Sonoran Paloverde-Mixed Cacti Desert Scrub for the Sonoran Desert ecoregion mapped by overlaying LANDFIRE existing vegetation (top) and NatureServe Landcover data (bottom) against current terrestrial intactness model results.

Mapping riparian systems is difficult to do using satellite remote sensing. The narrow linear nature of the community makes it difficult to delineate with high levels of accuracy. For the REA assessment, NatureServe Landcover v2.7 was used to assess current distribution. Status was evaluated using the terrestrial landscape intactness results at 4km resolution. Use of the HUC as a reporting unit was considered and rejected for linear features such as riparian areas because of its lower resolution. According to the NatureServe Landcover data, 1.6 million acres of riparian vegetation currently exist in the ecoregion. Status results based on the terrestrial landscape intactness model shows that the dominant category is Moderately High with a significant number of acres at both extremes (Figure 4-22). Although a 4 km grid is an appropriate reporting unit for a region-wide assessment, it is less discriminating in characterizing linear communities. Future assessments should examine different analyses methods and reporting unit for linear features.



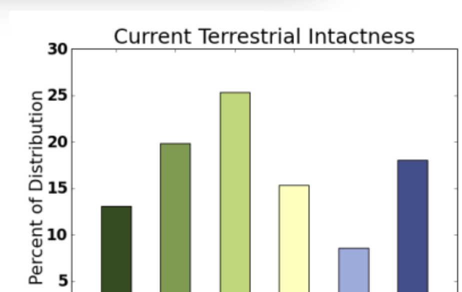


Figure 4-22. Map shows zoomed in portion of the riparian vegetation distribution (in blue) based on NatureServe Landcover v2.7 (inset) for the Sonoran Desert ecoregion. General status histogram accompanies map with percent of distribution in various classes calculated by overlaying NatureServe Landcover data against current terrestrial intactness model results.

4.2.4 Evaluating Designated Sites: Current Distribution and Status

Approximately 28% of the Sonoran Desert ecoregion (~9.2 million acres) is currently under federal, state, local government or private conservation land designation, including conservation easements (Figure 4-23). These data are limited to designated protected lands and do not include other conservation lands under current land management plans by the various agencies. In some instances, these land designations are nested, in which case the more protected designation is displayed over the top of another (e.g. wilderness area above a national park). Approximately 832 miles of wild and scenic rivers and national trails are also included in the map.

The status of these lands was evaluated by overlaying the designated land polygons over the top of terrestrial landscape intactness and summarizing the results (Figure 4-24). Wilderness Areas made up the largest proportion of the protected areas followed by Areas of Critical Environmental Concern. Other categories occupying over 500,000 acres include Other Protected Lands, State Parks, and National Monuments. Combined sites totaling between 100,000–500,000 acres include National Wildlife Refuges, National Parks, and Roadless Areas. Designations with less than 100,000 acres include Wilderness Study Areas, National Conservation Areas, and State Wildlife Management Areas. A table of total area (acres) for each status category for all designated lands in the Sonoran Desert ecoregion is located in Appendix A.

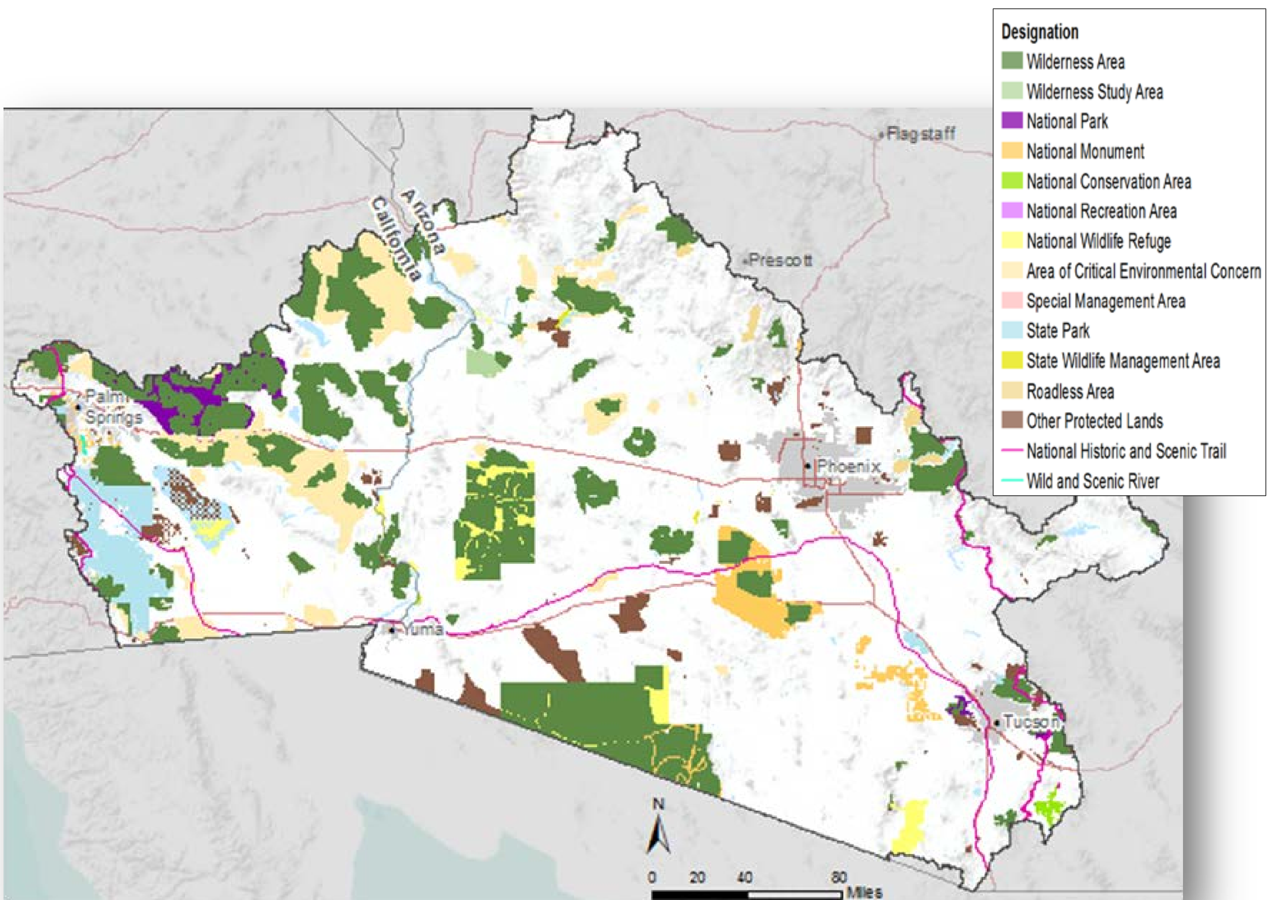
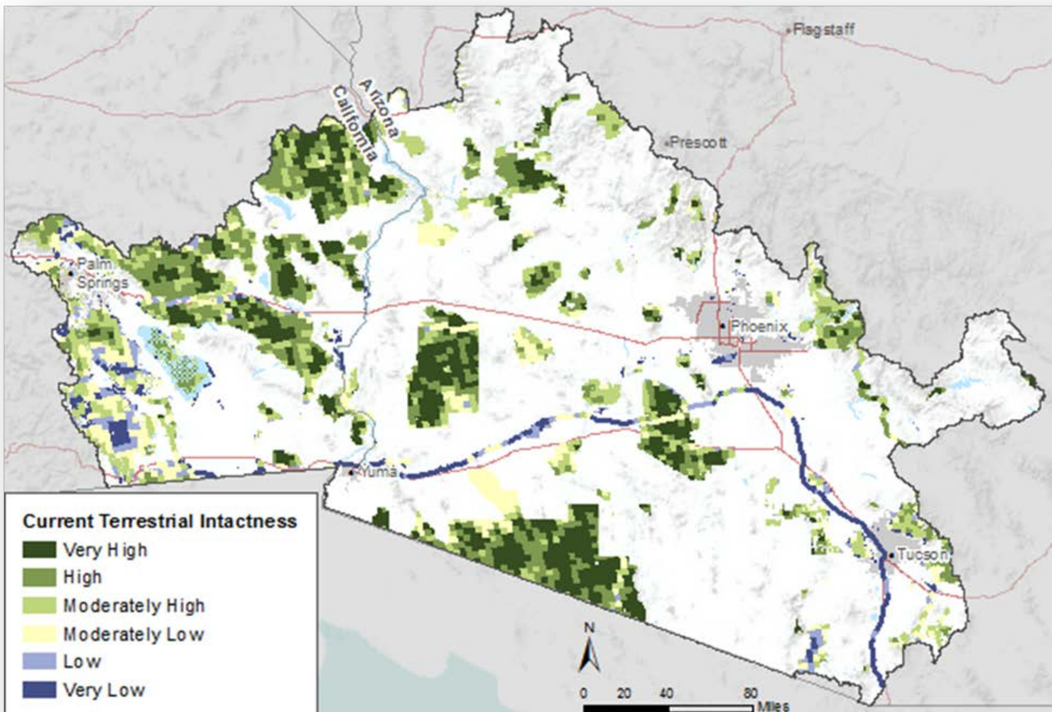


Figure 4-23. Map of designated protected lands in the Sonoran Desert ecoregion.

In general, terrestrial landscape intactness for special designated lands was heavily skewed (>75% of the area) towards more intact landscapes as one would expect; however, not all designation classes scored the same (histograms Figure 4-25). Wilderness Areas, National Wildlife Refuges, and National Monuments showed the best intactness profiles. National Parks and Areas of Critical Environmental Concern also did well. Roadless Areas, National Conservation Areas, and Wild and Scenic Rivers had similar profiles and peaked at Moderately High intactness. Wilderness Study Areas were dominated by Moderately Low intactness, which was surprising. The remaining designation types (National Historic and Scenic Trails, State Parks, State Wildlife Management Areas, and Other Protected Lands) possessed the lowest intactness profiles.



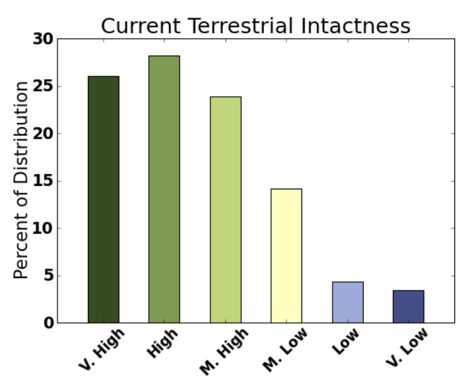


Figure 4-24. Status of designated protected lands in the Sonoran Desert ecoregion created by overlaying designated lands with current terrestrial landscape intactness.

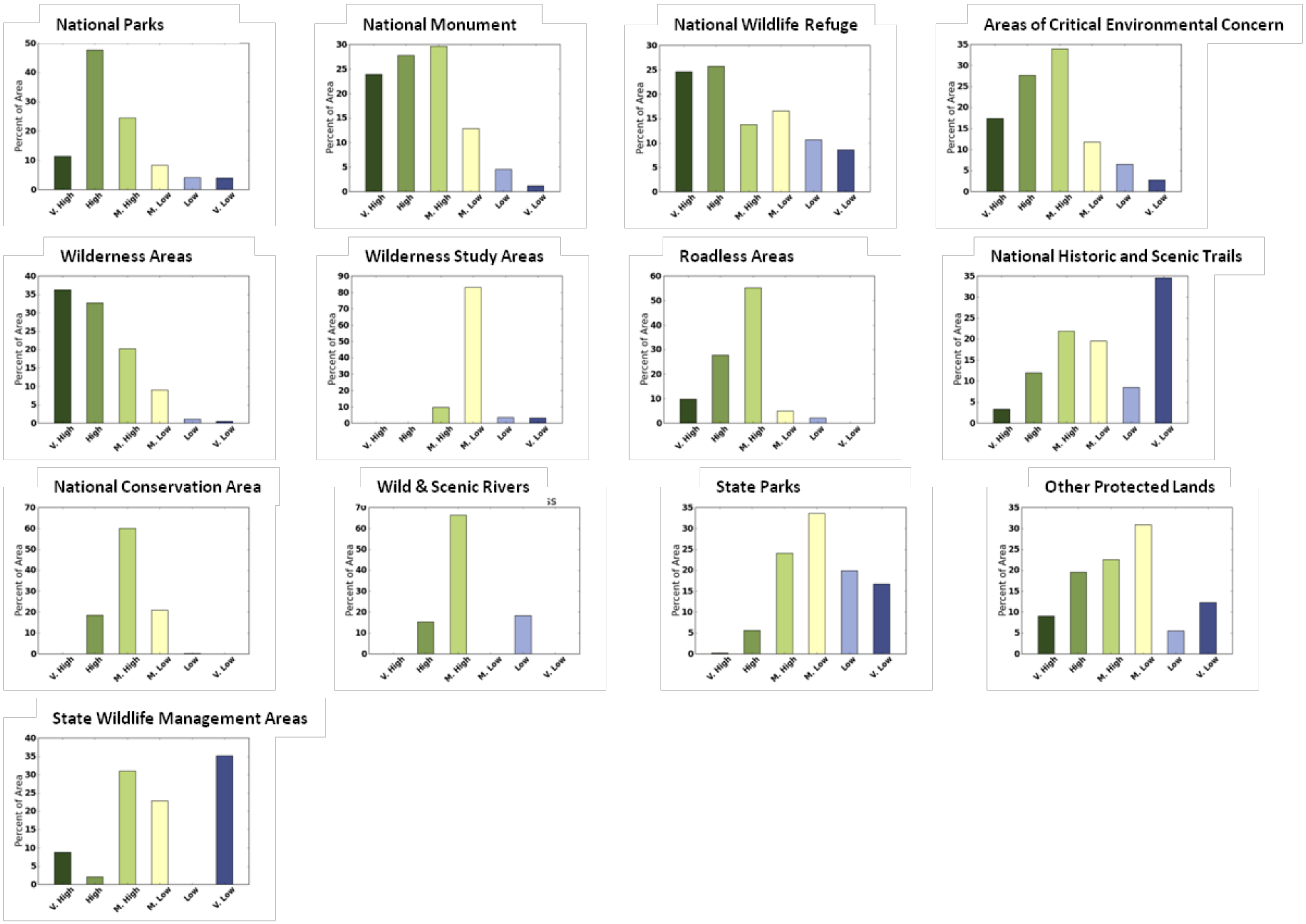


Figure 4-25. Terrestrial landscape intactness profiles for each designated land class. Note that y-axis (acres) varies for each histogram.

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4.3 Change Agent Distribution and Intensity

The status of conservation elements must be assessed with reference to both natural and anthropogenic disturbance factors. Although the current distribution and status of REA conservation elements were presented together in Section 4.2 to economize on presentation space, the status or condition of various conservation elements should not be discussed without examining the risks that these resources experience from a collection of regional disturbances or change agents. The primary change agents affecting the region were introduced in Section 2.4.3 (Table 2-4). This section of the report presents those change agents that are associated with current conditions—invasive vegetation, fire, and a current development footprint. Change agents associated with future conditions are presented in Chapter V Potential Future Conditions in the Sonoran Desert.

4.3.1 Invasive Vegetation

Invasive Species
Management Question

MQ F1 Where are the areas dominated by tamarisk, red brome, buffelgrass, and Sahara mustard?

Invasive vegetation species are significant change agents in the Sonoran Desert ecoregion. These species alter ecosystem processes, such as fire regimes; they have the potential to expand their distribution in spite of human and natural disturbances and to adapt and shift their range in response to climate change. As these species expand in distribution and dominance on the landscape, native species and communities become increasingly marginalized, which over the long term may seriously degrade the status and function of these systems. Major invasive vegetation species in the Sonoran Desert ecoregion include red brome (*Bromus rubens*), tamarisk (e.g., *Tamarix chinensis, T. aphylla,* and *T. ramosissima*), Sahara mustard (*Brassica tournefortii*), and buffelgrass (*Cenchrus ciliaris*, syn. *Pennisetum ciliare*). Several of these species, especially the annuals, have strong potential to mediate a feedback cycle that can dramatically change the natural fire regime of ecologically significant vegetation communities, such as palo verde-mixed cacti desert scrub (Burquez-Montijo et al. 2002, Esque and Schwalbe 2002). Continued changes in fire cycle combined with projected changes from global climate change raise the possibility of widespread type conversion of desert shrublands to low-diversity nonnative communities with major effects on ecosystem function and the abundance of desert wildlife (Smith et al. 2000, Dukes and Mooney 2004).

Red brome is a nonnative, annual grass from the Mediterranean region that was introduced into the western United States in the mid-1800s (Salo 2005, Newman 2001) and that now occupies broad areas in the Arizona Upland of the Sonoran Desert (ASDM 2010, Turner and Brown 1982). Red brome typically occurs below 5,000 feet elevation on gentle to moderate slopes, often in shallow, sandy loam or clayey soils where it is tolerant of high salt and pH conditions (Wu and Jain 1978). Red brome is a prolific seed producer (Wu and Jain 1978); seeds are dispersed by wind, small mammals, and water (Drezner et al. 2001, Hulbert 1955). Red brome does not form a persistent soil seed bank. However, it germinates earlier and requires less rainfall than native annual species, and it may displace natives in wet years (Reid et al. 2008, Salo 2005, Newman 2001, Beatley 1966). On the other hand, red brome populations may be adversely affected by drought (Salo 2005). Red brome readily invades disturbed areas (Newman 2001), and it is enhanced by grazing and fire (Hulbert 1955). The species also invades undisturbed habitats (Reid et al. 2008, Burgess et al. 1991, Beatley 1966), including scrub communities and mesquite bosques in the Sonoran Desert (Simonin 2001). This ability to invade undisturbed habitat makes this species particularly problematic in the Southwest, where, by altering fire regimes, it threatens native plant communities and associated wildlife species.

Buffelgrass is a drought-tolerant, warm-season, perennial bunchgrass native to Africa, Asia, and the Middle East. It occurs primarily in disturbed sites, along roadsides, in desert washes, and on rocky hillsides (Búrquez-Montijo et al. 2002, Rutman and Dickson 2002, Burgess et al. 1991). The elevational range of this species is generally between about 66 and 2300 feet (20–701 m), although it has been found above 2950 feet (899 m) in Arizona. It spreads aggressively by seed, and it can also spread vegetatively by rhizomes (Arriaga et al. 2004, Williams and Baruch 2000). This species germinates with relatively low amounts of precipitation (Ward et al. 2006). Buffelgrass was introduced to the United States as livestock forage in the 1930s; it has also been used for erosion control and soil stabilization (SABCC 2010a). It is particularly problematic in the Sonoran Desert of southern Arizona and northern Mexico (SABCC 2010b), where it alters fire regimes, soil ecology, hydrology, and geomorphology, thereby threatening native plant communities and associated wildlife species. In Arizona, it has invaded upland desert scrub habitat and it is also considered a threat to native desert grassland, chaparral, and oak woodland (Van Devender and Dimmitt 2006). Buffelgrass is an invasive species that is currently spreading into new areas and it is considered a serious threat to key desert species including the saguaro cactus, foothill palo verde, and desert tortoise (Esque et al. 2006, Esque et al. 2004).

Sahara mustard is an annual herb native to arid and semi-arid regions of North Africa and the Middle East (Cal-IPC 2012). It occurs at low elevations in the Sonoran Desert ecoregion, often on sandy soils and stabilized dunes (J. Weigand, personal communication), where it is capable of forming dense stands; but it has also recently been found in large stands on rocky slopes (Brooks 2009). It has recently expanded its range after years of high winter rainfall (Barrows et al. 2009). This species poses several threats to native vegetation communities, including creation of continuous fuel loads in areas of discontinuous native fuels and rare fires (Brooks 2007). It also competes with native species for soil moisture and nutrients (Cal-IPC 2012).

Because of the recent expansion of Sahara mustard, which was not well captured in existing landcover classifications, and because of its potential effects on fire regime, a predictive model was developed for the species using MaxEnt (Elith et al. 2011) to identify areas of high potential for its occurrence (Figure 4-26). Occurrence data were compiled from a variety of sources, and predictive surfaces were derived from elevation, climate, distance from highways, surficial geology, and soil characteristics. Occurrence data were not uniformly collected and likely do not fully capture the range of locations on which Sahara mustard is found (Figure 3-8 in Section 3.2.5); occurrence records were particularly common along highways and notably underrepresented in sandy areas some distance from highways (J. Weigand and T. Esque, personal communication). For the occurrence locations that were available, this model performed reasonably well (Area Under Curve, AUC: 0.857). The most important factors included distance from highways, elevation, and winter precipitation. In general, large areas of higher probability occur in low elevation basins east of Yuma, north of Yuma to Parker, west of the Salton Sea, and along major highways throughout the Sonoran Desert.

Photo: Sahara mustard (*Brassica tournefortii*), Arizona-Sonora Desert Museum

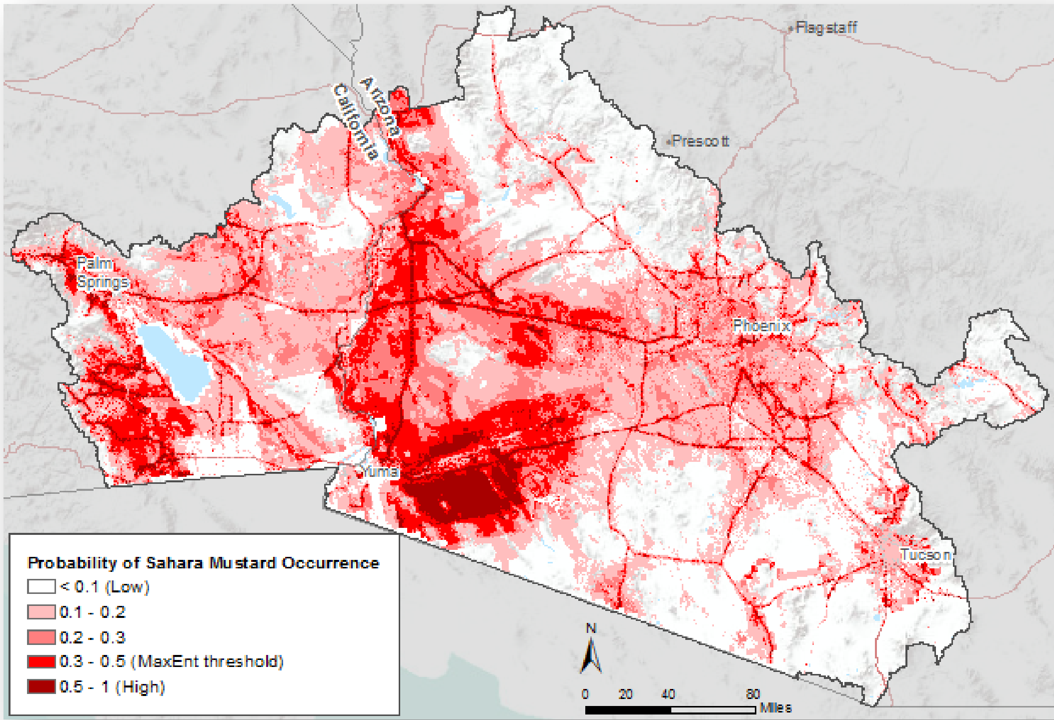

Figure 4-26. Predicted current distribution of Sahara mustard (*Brassica tournefortii*).

Another key invasive species is tamarisk (*Tamarix spp.*) with multiple species and hybrids present. Tamarisk became widely distributed in the 1800s, when it was planted as an ornamental plant; it is now found throughout nearly all western and southwestern states (Lovich 2000). Tamarisk is of particular concern because its dense and rapid growth allows it to out-compete native plant species. In addition, it is extremely drought resistant, has high fecundity, produces salts that inhibit the germination and growth of native species, and alters fire regimes (Busch and Smith 1995, Glenn et al. 1998). Tamarisk affects native wildlife by changing the composition of forage plants and the structure of native riparian systems, which is particularly important to some canopy-nesting birds. However, some native birds will use tamarisk for nesting, including the endangered southwestern willow flycatcher (van Riper et al. 2008, Brown and Trosset 1999, Sogge et al. 2005). For more discussion about riparian ecosystems and tamarisk see the Tamarisk Case Study Insert.

Accurately mapping the full distribution of major invasive vegetation species is quite difficult due to a general lack of systematically sampled occurrences, the difficulty in distinguishing low seasonal abundance within the satellite imagery often used to create land cover classifications, and the requirement of carefully calibrated satellite imagery time series to capture the particular phenology of the invasive species, such as early season green-up of invasive annual grasses. Invasives may be difficult to detect where they are co-dominants, present in the understory, or not actively growing during the season of imagery. The REA was hampered by a lack of regional invasives mapping or modeling. As a result, results from multiple mapping efforts were combined to estimate the extent of major invasive vegetation species in the Sonoran Desert (Figure 4-27). To create the map, invasive classes were extracted from LANDFIRE Existing Vegetation Type (v1.1), NatureServe Landcover (v2.7), and LANDFIRE Succession Classes, and they were combined with areas of invasive vegetation cover from the Integrated Landscape Assessment Project (ILAP 2012) Current Vegetation dataset and higher probabilities from our Sahara mustard occurrence model. Mapped areas of tamarisk and high-probability areas from a recent tamarisk probability map (Jarnevich et al. 2011) were also included. These data and models likely underestimate total distribution of invasive vegetation, because most methods used remotely-sensed imagery and required dominance of a site by these species to be detectable. Even where these species occur as minor components of the vegetation community, they may expand and dominate quickly due to disturbance, land use and climate change. Furthermore, these species may greatly expand or contract their range and dominance during years of higher or lower available moisture during their peak growing periods; thus the current mapped distribution represents only a snapshot in time of a highly dynamic process.

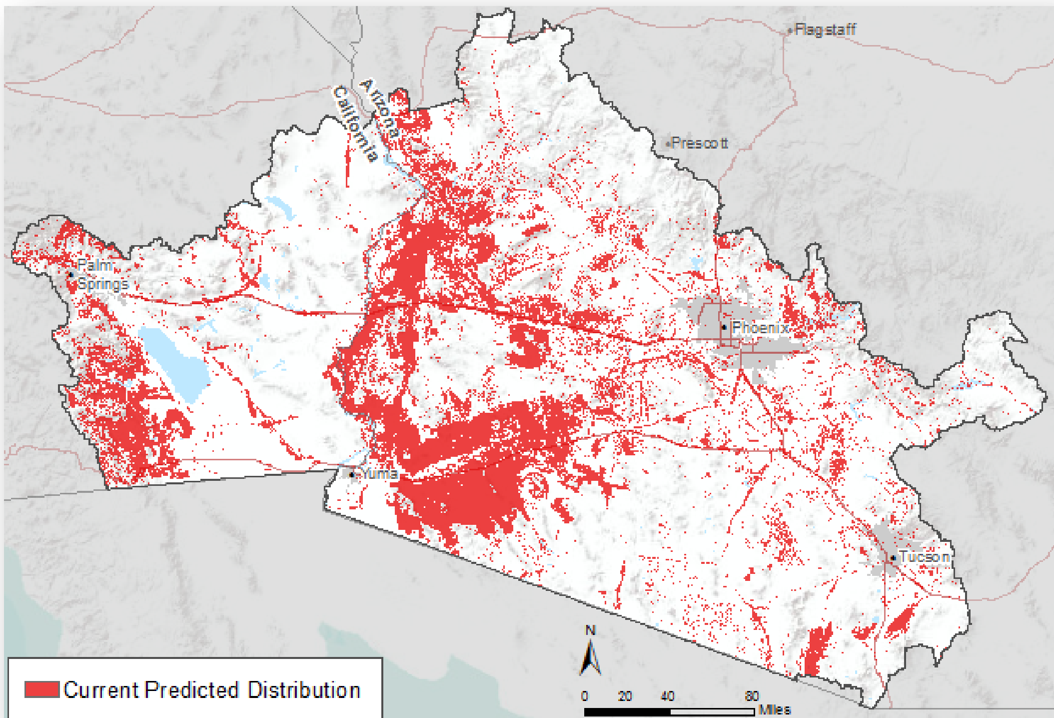

Figure 4-27. Map shows distribution of invasive riparian vegetation (tamarisk) and invasive upland vegetation (including red brome, buffelgrass, and Sahara mustard) across the Sonoran Desert ecoregion.

4.3.2 Changes in Fire Regime

Fire is a natural ecosystem process in many regions. In any given region, species are typically adapted to a particular fire regime, which can be characterized in terms of fire frequency, seasonality, severity, and size (Pausas and Keeley 2009). The degree to which fire may become an ecologically significant change agent is related to the extent to which the fire regime has been altered compared to reference conditions and the associated effects of the altered fire regime on the vegetation community. For example, certain vegetation communities adapted to frequent, low-intensity fire are threatened by the consequences of decades of effective fire suppression, which can increase the potential for large, high-severity fires (Schoennagel and Nelson 2010). In contrast, other communities adapted to very infrequent fire are now threatened by increases in fire frequency due to invasive plants and human ignitions.

Fire regimes have been altered in many Southwestern ecosystems compared to reference conditions that would have been present prior to Euro-American settlement. In recent decades, invasive species and human activities (e.g., grazing, urbanization, fire suppression), as well as other sources of human ignitions, have altered fire regimes in many fire-adapted ecosystems and introduced fire to other ecosystems that historically rarely experienced fire. Some widely-distributed invasive species, such as red brome, increase fire frequency, size, and duration of the fire season by increasing fine fuel loads and continuity, thus allowing fires to spread into areas that were once fuel-limited (Hunter 1991, Brooks and Pyke 2001). These alterations to fire regime can promote further species invasion and thus create a tight feedback loop of increasing fire frequency (Mack and D'Antonio 1998). In the western US, the source of invasions has been linked to various anthropogenic disturbances, including but not limited to grazing, transportation (roads and trains), logging, and residential development (Kemp and Brooks 1998). Just as exotic species are likely to spread from these areas, human-caused ignitions are also likely to increase in areas with higher levels of human presence (Syphard et al. 2007, 2008).

In many ecosystems where fire historically served an important ecological function, several decades of effective fire suppression, combined with alterations to fuel load and pattern by anthropogenic land use and management practices, have led to conversions in vegetation type (e.g., shrub encroachment in semi-desert grasslands) or structure (e.g., increased canopy density as well as surface and canopy fuel loads, McPherson 1995, Van Auken 2000, Keane et al. 2002). Unless fuel loads are reduced, or unless fire occurs under non-severe weather conditions, fires in many of these communities may now become abnormally large and severe, which can result in dramatic reduction in aboveground live biomass, leading to cascading ecological impacts (DellaSala et al. 2004, Lehmkuhl et al. 2007, Hurteau and North 2009).

Fire-Related Management Questions

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

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

MQ E3 Where are fire-adapted communities?

To answer the first fire-related management question, *Where are areas with that have been recently changed by wildfire?*, estimates of areas changed by recent (1999–2010) wildfires using fire perimeters (2000–2010) were supplemented with fire disturbance data that included measures of fire severity (LANDFIRE Disturbance datasets 1999–2008, Figure 4-28). LANDFIRE estimates of fire severity should be interpreted with caution; they may have poor accuracy for predicting actual fire severity in desert systems because of methods and definitions of fire severity developed primarily for forested systems. Furthermore, fire severity in desert ecosystems is not well understood or described in the literature. In general, any area that has experienced fire has been changed by it to a degree that generally increases with increasing severity. High severity fires tend to result in early successional vegetation states followed by a recovery period during which characteristic species recolonize the site. However, areas with uncharacteristically high severity (due in part to legacy effects of fire suppression and fuel buildup) or where fire was historically rare may transition to a different vegetation state altogether, such as dominance by invasive vegetation. It is not possible given existing data to evaluate the underlying change in vegetation resulting from fire. This is due in large part to the lack of accurate region-wide maps of pre- and post-fire vegetation. While the most recent version of LANDFIRE Existing Vegetation (v1.1) has been updated in areas of disturbance, the updates are not necessarily an accurate reclassification of the post-fire vegetation, but instead appear to be the result of applying a rule set based on pre-fire vegetation type and fire severity coupled with a systematic update of the entire product to correct areas of major inaccuracy. The majority of the higher-severity fires occurred at the fringes of the ecoregion; typically in communities like chaparral that would have experienced fires under reference conditions. However, several lower-severity fires occurred in central areas of the ecoregion, including the King Valley Fire in 2005 which burned areas of the Kofa National Wildlife Refuge. Even when fires are of lower severity, they may still result in high mortality of species that are not fire-adapted and increase susceptibility of burned areas to invasion by nonnative species such as Sahara mustard (USFWS 2006, T. Esque personal communication).

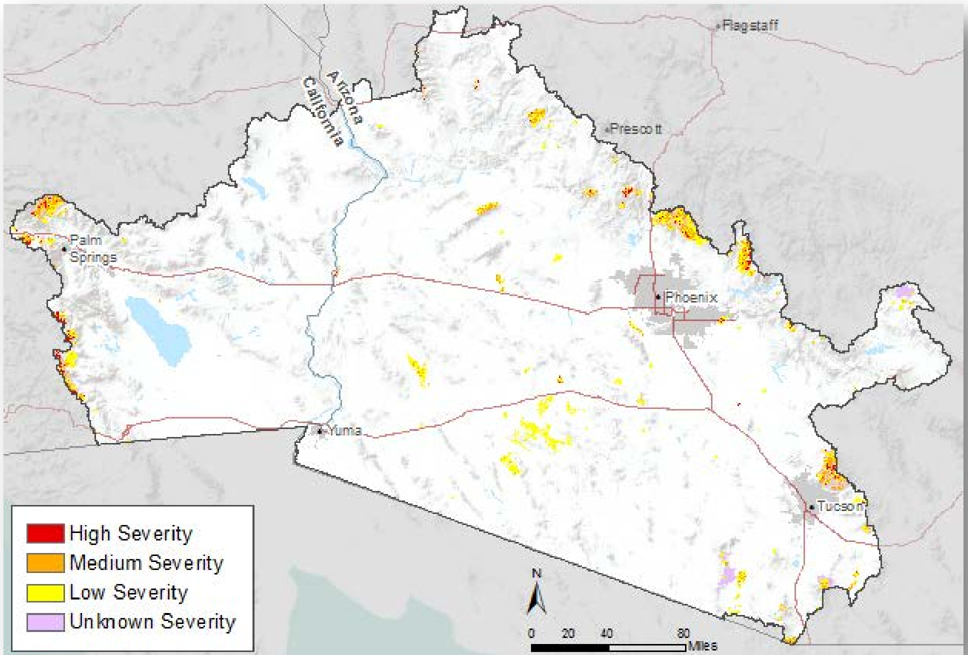

Figure 4-28**.** Fire perimeters annotated by severity (where available) for fires in the Sonoran Desert ecoregion, answering the management question MQ E1, *Where are the areas that have been changed by wildfire between 1999 and 2009*?

To answer the fire-related question (*Where are the areas with potential to change from wildfire?* MQ E2) and to estimate the distribution of these areas, MaxEnt models were developed for potential fire occurrence (Figure 4-29). In reality, fire has the potential to cause a greater or lesser magnitude of change due to fine scale fuel conditions, local fire behavior, fire weather, and pre-fire vegetation sensitivity to fire disturbance along with many other factors. It is not possible given existing data to evaluate these factors at the ecoregion scale. Instead, the focus was on predicting where fires are likely to occur on the premise that this would provide meaningful context for more detailed, local assessments of potential impacts due to fire. Thirty years of fire occurrence data were subdivided into human and naturally caused fires (21,310 human caused fires; 1,324 naturally-caused fires) and developed into separate MaxEnt models for each due to the very disparate relationship between fire cause and underlying geographic and environmental variables. Both models performed reasonably well (human-caused fire model Area Under Curve or AUC: 0.704 and natural model AUC: 0.814). The most influential factors in the human model include: distance to highways, distance to urban areas, distance to major rivers, and winter precipitation). The most influential factors in the natural model include: summer temperature, elevation, winter precipitation, and distance to major rivers. Even though the density of strong, fire-season lightning events (1990-2009) was included in the natural model, it was not a particularly important factor.

In general, the potential of naturally-caused fire occurrence increases toward the edges of the ecoregion and on a few mountain ranges, such as the Harcuvar Mountains in the north central portion of the ecoregion. Some of these areas were historically adapted to fires (chaparral); however, legacy effects of fire suppression and alteration of vegetation composition and structure may result in uncharacteristic fire behavior. Human-caused fire potential increases around Phoenix, Parker, Yuma, and Palm Springs. Some of these same areas also showed higher likelihood of invasive vegetation occurrence (Figure 4-27), indicating that increased fire occurrence due to human ignitions coupled with continuous fine fuels may result in significant impacts to the native vegetation communities and may further expand the distribution of the invasives.

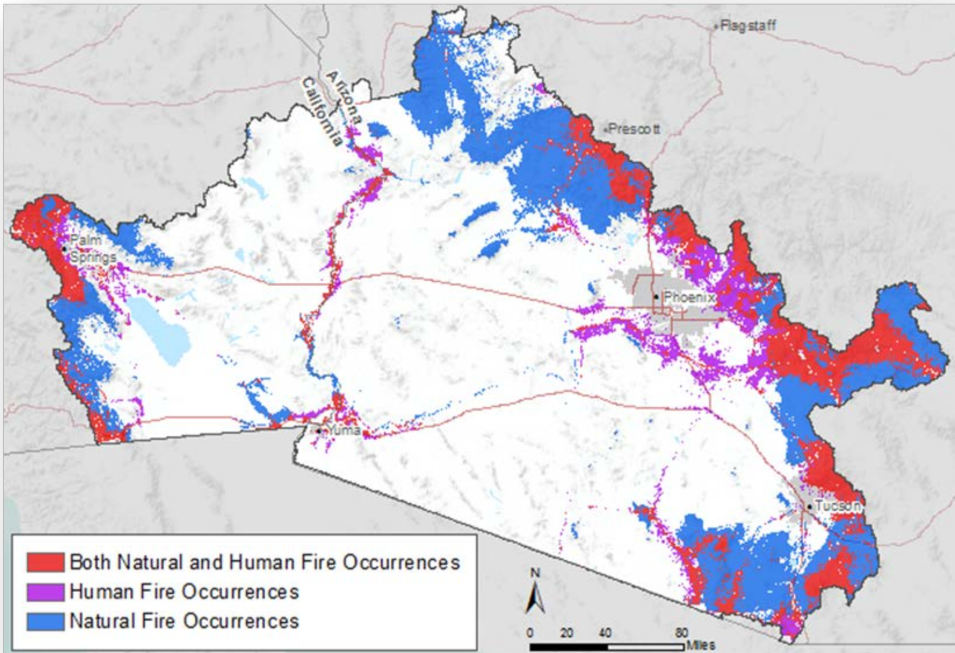

Figure 4-29. Potential fire occurrence from human and natural sources for the Sonoran Desert ecoregion, answering the management question, *Where are the areas with potential to change from wildfire?*

Fire-adapted communities were identified using the LANDFIRE Fire Regime Groups dataset (Figure 4-30, management question MQ E3). Again, these areas primarily occur at the fringes of the ecoregion, indicating that vegetation communities throughout much of the ecoregion are adapted to very rare fire occurrence. Fire occurrence in areas historically adapted to frequent fires may still produce uncharacteristic behavior, severity, or alteration of the vegetation communities due to legacy effects of fire suppression, which may lead to buildup of fuels. The degree to which fire regimes have been altered in these areas cannot be fully determined. While estimates of fire regime departure exist (e.g., LANDFIRE Fire Regime Condition Class), these estimates are based on differences in vegetation composition and structure compared to reference condition proportions of various succession classes. Such comparisons are particularly challenging in arid ecosystems, due to the difficulty in correctly detecting fine-scale differences in vegetation composition or structure using remote sensing techniques. Because these estimates of fire regime departure do not directly capture changes in fire frequency and departure, they may under-represent the degree of fire regime departure present in these communities. Existing estimates of current fire frequency and severity were not available to determine these measures during this REA.

Photo: Burn in Arizona, BLM

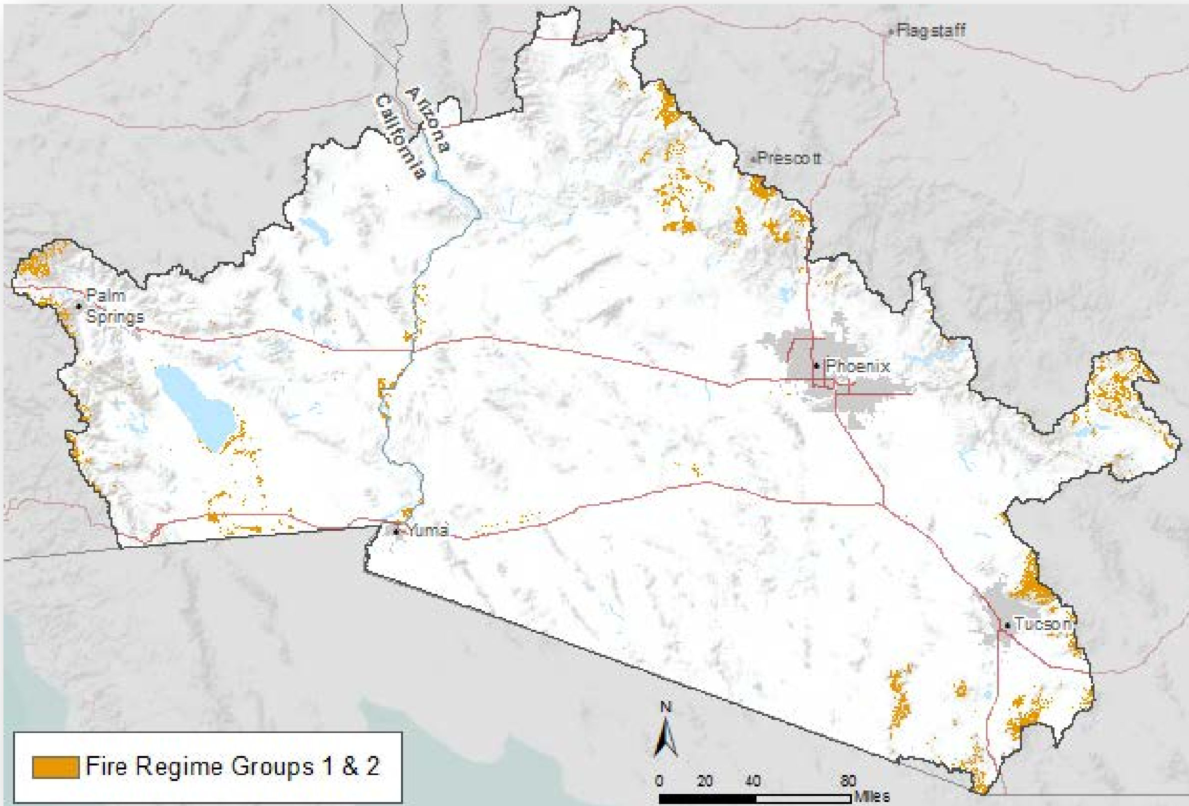

Figure 4-30**.** Map answers management question MQ E3, *Where are fire-adapted vegetation communities in the Sonoran Desert ecoregion*?

4.3.3 Current Development

Four major components of development were assessed for the ecoregion—energy, urbanization (including roads), agriculture, and recreational development. A dozen major inputs derived from multiple original datasets were compiled using a fuzzy logic model (Figure 4-31) to create a combined development footprint for the ecoregion (Figure 4-33). Reliable spatial data were available for all but recreation and existing wind energy locations (such as San Gorgonio in southeastern California). Recreation data proved to be very difficult to acquire and what was acquired was of uneven quality. The addition of these missing elements as they come available will improve the model. For the composite model, a subset of the compiled and analyzed recreation data was used to address more specific recreation management questions such as MQ H1, *Where are high-use recreation sites, developments, roads, infrastructure, or areas of intensive recreation use located (including boating)?* (See Appendix A for more details on recreation.) The recreation data used for the composite development model focused on land recreation only and included point, line, and polygon inputs (Figure 4-32D).

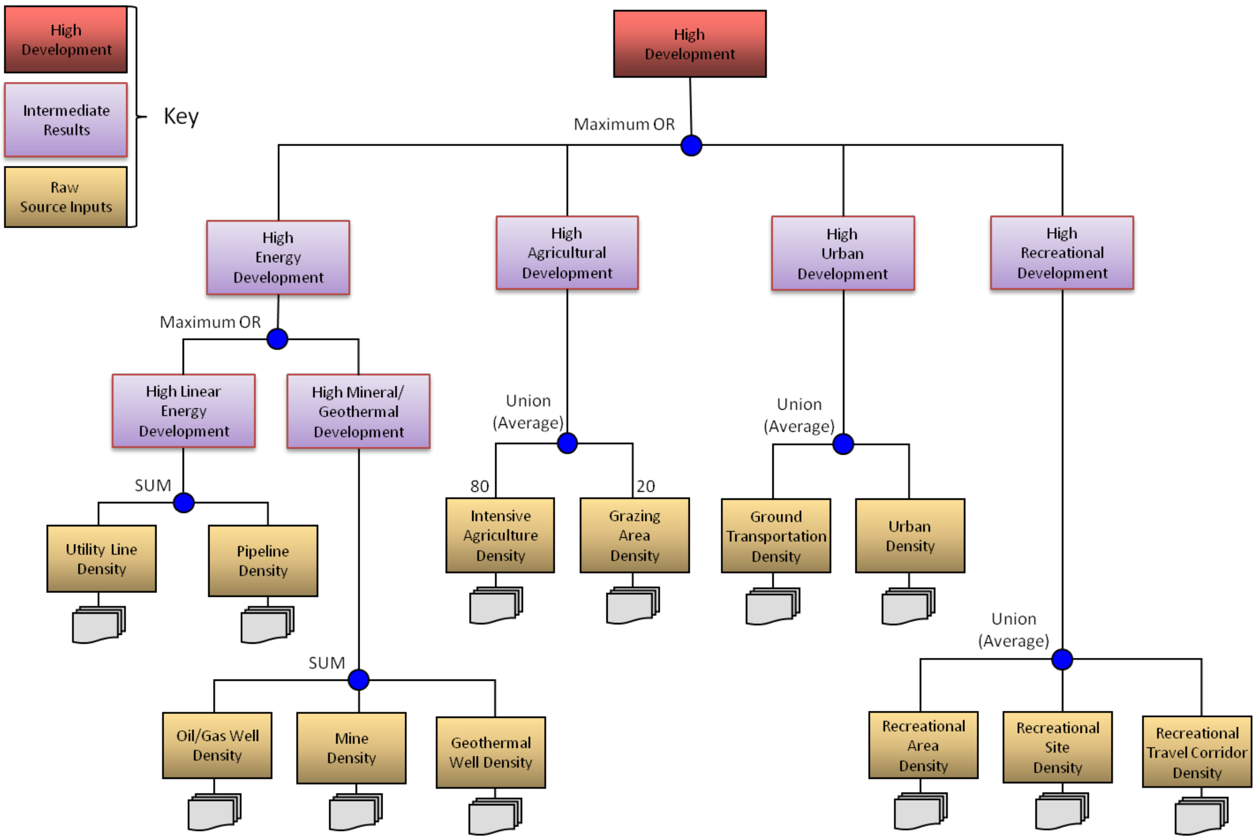

Figure 4-31. Current development fuzzy logic model for the Sonoran Desert ecoregion.

Current energy development, one of the intermediate model results (top four boxes in logic model above), was comprised of spatial data for both linear features (utility lines and pipelines) and point features (oil/gas wells, mines, and geothermal wells) that were aggregated using a *Maximum OR* logic operator (Figure 4-32A). The urban development component of the fuzzy logic model averaged urban landcover density and road density based on the transportation data files provided by BLM to create an intermediate urbanization result (Figure 4-32B). No weighting or special treatment of roads was conducted as the dataset was inconsistently attributed to allow for more detailed treatment of the road infrastructure, which ranged from OHV dirt paths to interstate highways

Agricultural development results were derived from agriculture landcover data and grazing allotment data using an *Average (or Union)* logic operator and weighting converted agricultural land vs. grazing lands by 80/20 (Figure 4-32C). Livestock grazing in the ecoregion has altered the natural landscape, important details on recent livestock density and overall range condition remains a serious data gap in the model. With more detailed and complete grazing data, the development model as well as the terrestrial and aquatic intactness models would be greatly enhanced. Recreation development data was also substandard and the model would do a better job of incorporating recreation impacts with more detailed and complete data for the wide array of recreational activities (both active and passive).

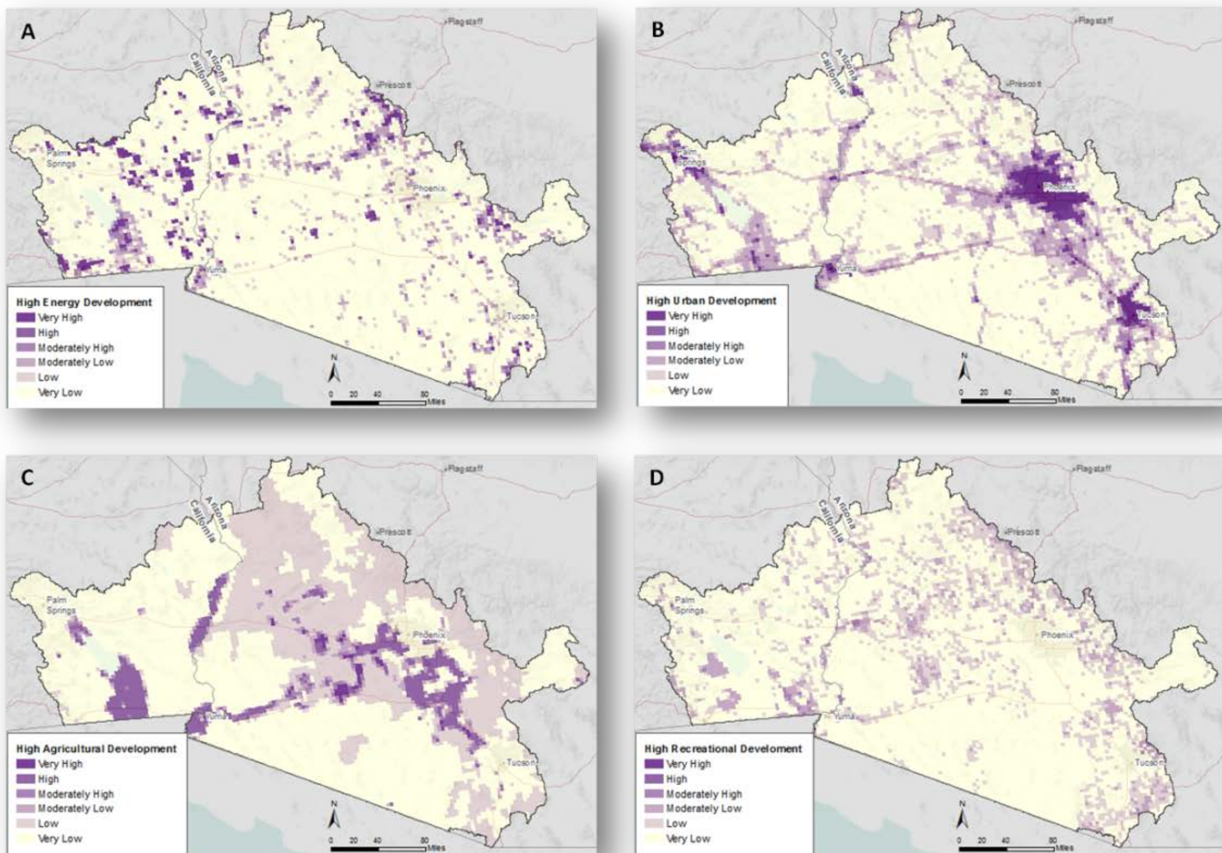

Figure 4-32. Intermediate results of the current development fuzzy logic model showing (A) current energy development, (B) urban development, (C) agriculture development, and (D) recreation development for the Sonoran Desert ecoregion.

The full development footprint for the Sonoran Desert shows a concentration of human activities in the northern and eastern portions of the ecoregion in the Phoenix-Tucson urban corridor and in the western portions of the ecoregion in the urban and agricultural areas of the Palm Springs area and the Imperial and Coachella valleys of California (Figure 4-33).

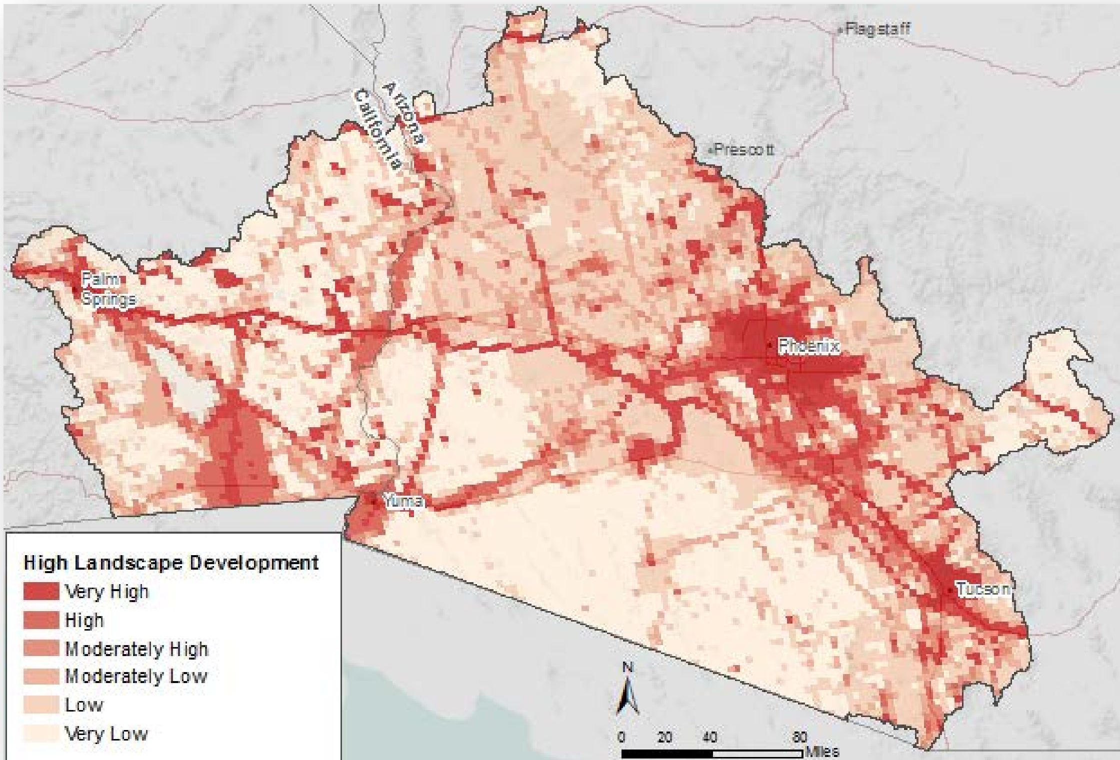

Figure 4-33. Composite of current development in the Sonoran Desert ecoregion.

Photo: Phoenix. Wikimedia Commons, gobeirne.

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Photo: Barrel cactus fire victim. National Park Service

Tamarisk (*Tamarix* spp.)

This is one of two case studies that demonstrate how the data collected during the REA process can be applied to management issues of concern. Case studies delve into greater detail to cover the underlying ecological and human influences affecting the selected conservation element or change agent and to articulate the nature of regional issues and associated management questions. Case studies also demonstrate how REA data and results can be applied to land use planning and resource management. Tamarisk was selected for a case study because it represents a key management issue in its own right, but it also relates to discussions of river regulation, flow regime changes, groundwater, and changes in native riparian species distribution and biodiversity.

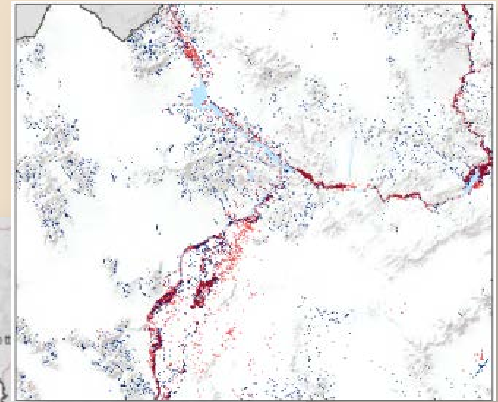
Photo: Columbia University Invasive Species Summary Project

The history of the expansion of tamarisk throughout the riparian areas of the southwestern U.S. parallels the development and allocation of water resources in arid and semi-arid ecosystems in the 20th and 21st centuries. Tamarisk (or saltcedar) is an invasive shrub that has been designated as a change agent in the Sonoran Desert REA because it affects native riparian ecosystems and aquatic sites of conservation concern. The name *tamarisk* refers to a number of related species in the genus *Tamarix* (e.g., *T. ramosissima, T. chinensis*, and *T. aphylla*) that are similar in appearance and that hybridize freely (Gaskin and Shafroth 2005). The species did not become widely distributed in the U.S. until the 1800s, but it is presently found throughout nearly all western and southwestern states (Lovich 2000). In a survey of 475 gaging stations across the western U.S., Friedman et al. (2005) found tamarisk to be the third most frequently-occurring riparian woody plant in the region. Tamarisk is widely distributed across the Sonoran Desert ecoregion (Figures 1 and 2). Any depiction of its distribution derived from remotely-sensed data is likely to be an underestimate as the species is not always distinguishable when mixed with native vegetation.

Tamarisk occurs in low-lying areas such as riparian habitats, washes, and playas. It tolerates a range of soil types, but it is most commonly found in alkaline and saline soils that are seasonally saturated (Brotherson and Field 1987). Although tamarisk can spread in the absence of disturbance (DiTomaso 1998, Cooper et al. 2003, Merritt and Poff 2010), human activities enhance the establishment of this species, through the damming of free-flowing rivers (with subsequent changes to flow regimes and seasonal flooding cycles), groundwater pumping, grazing, agriculture, irrigation, and urban development (Figure 3, conceptual model, Development and Disturbance). All of these activities have resulted in the conversion of many diverse southwestern riparian zones to nonnative monocultures. Tamarisk exerts competitive pressure on native riparian vegetation through a variety of pathways: it 1) tolerates a greater depth to groundwater than native species; 2) outcompetes native species in saline conditions; 3) reduces seedling recruitment of natives through its prodigious seed production, dense cover, and underlying litter layer; and 4) increases riparian zone fire frequency (Busch and Smith 1995, Lite and Stromberg 2005). Tamarisk concentrates salt in leaf litter, inhibiting other plant species' germination and growth (Figure 3, Soil Ecology, Glenn et al. 1998, Busch and Smith 1995, Vandersande et al. 2001). Dense stands of tamarisk also create overbank flooding that alters stream channel structure and sediment deposition (Figure 3, Geomorphology, Flooding Regime, and Hydrology Changes, Lovich 2000, Dudley et al. 2000, Cooper et al. 2003).

Case Study No. 2

Figure 1. Maps show distribution of tamarisk (in red) relative to the distribution of other riparian vegetation (NatureServe landcover dataset).



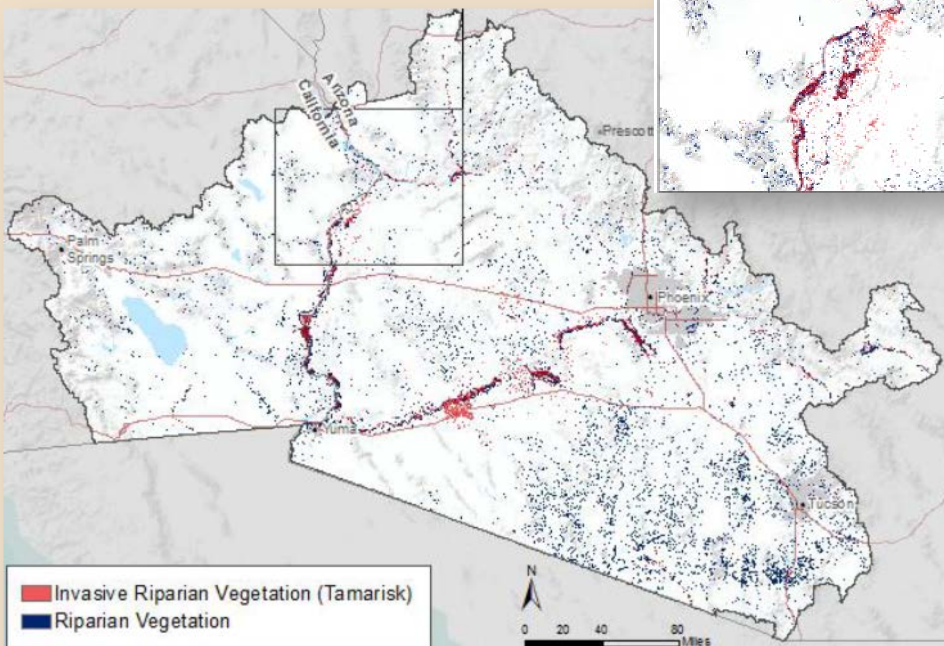


Figure 2. Current distribution of tamarisk (in blue) near the confluence of the Colorado and Gila Rivers as mapped for the Sonoran Desert REA.

Case Study No. 2

Flow Alteration. Although it is likely that native riparian species would have declined with the extensive flow alteration of western U.S. streams and rivers regardless of the presence of invasive species (Merritt and Poff 2010), flow regulation has facilitated the spread of tamarisk. The creation of dams and reservoirs has enhanced tamarisk establishment and survival by altering the frequency, timing, and velocity of flows, reducing the frequency of seasonal flooding, and providing stable substrates for colonization (Figure 4, Shafroth et al. 2002, Lite and Stromberg 2005, Stromberg et al. 2007b, Merritt and Poff 2010). Even slight modifications in flow regime affect cottonwood recruitment (Merritt and Poff 2010). While native riparian species like cottonwood and willow produce seeds during a narrow germination period that corresponds to a former spring flooding time frame, tamarisk produces hundreds of thousands of seeds over the entire growing season; in regions with summer rainfall, tamarisk seeds may germinate late in the season following monsoonal storm events (Shafroth et al. 1998, Stromberg et al. 2007b).

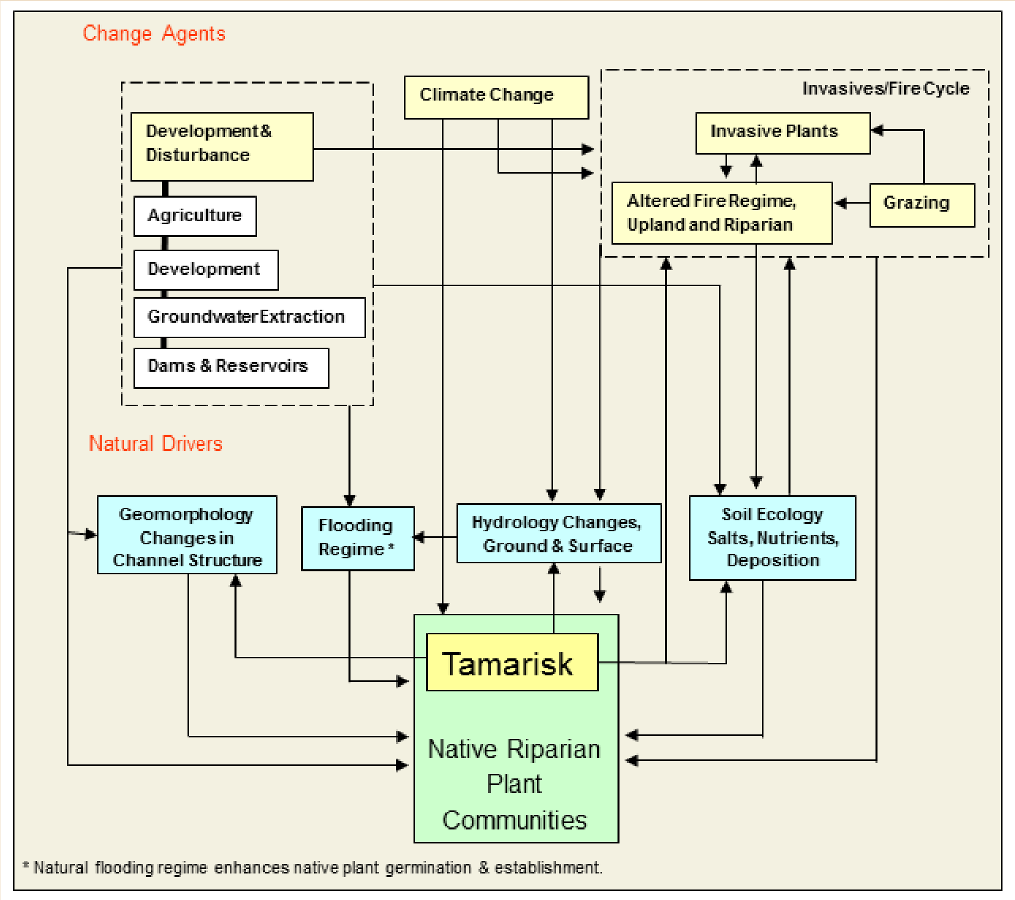


Figure 2. Conceptual model for tamarisk in the Sonoran Desert ecoregion.

Flow regulation isolates a river from its floodplain and eliminates regular flooding, which exposes riparian and former backwater areas to chronic drying and increased soil salinity from natural sources and irrigation return water (Busch et al. 1992, Merritt and Poff 2010). Busch and Smith (1995) compared sites on the highly regulated lower Colorado River and the Bill Williams River that retains a more regular flooding regime and available groundwater. Their ordination analysis showed that riparian vegetation communities were correlated with moisture availability and salinity gradients. The persistence of cottonwood (*Populus fremontii*) and willow (*Salix* spp.) on the Bill Williams River was attributed to the periodic flushing of accumulated salts and replenishment of shallow groundwater (Busch and Smith 1995). Tamarisk, with its higher salt tolerance and ability to tap deeper groundwater levels has a competitive advantage in regulated systems. In an earlier study, Busch et al. (1992) compared reaches along the Bill Williams River having intact native riparian vegetation to disturbed reaches along the Colorado River that were dominated by tamarisk; they found that where cottonwood and willow competed successfully with tamarisk, soil salinity levels were 1-3 g/l NaCl compared to 6-8 g/l NaCl where invasive tamarisk was dominant. Glenn et al. (1998) supported these field results with a greenhouse experiment, concluding that a native cottonwood-willow association is not competitive with tamarisk above about 4 g/l NaCl.

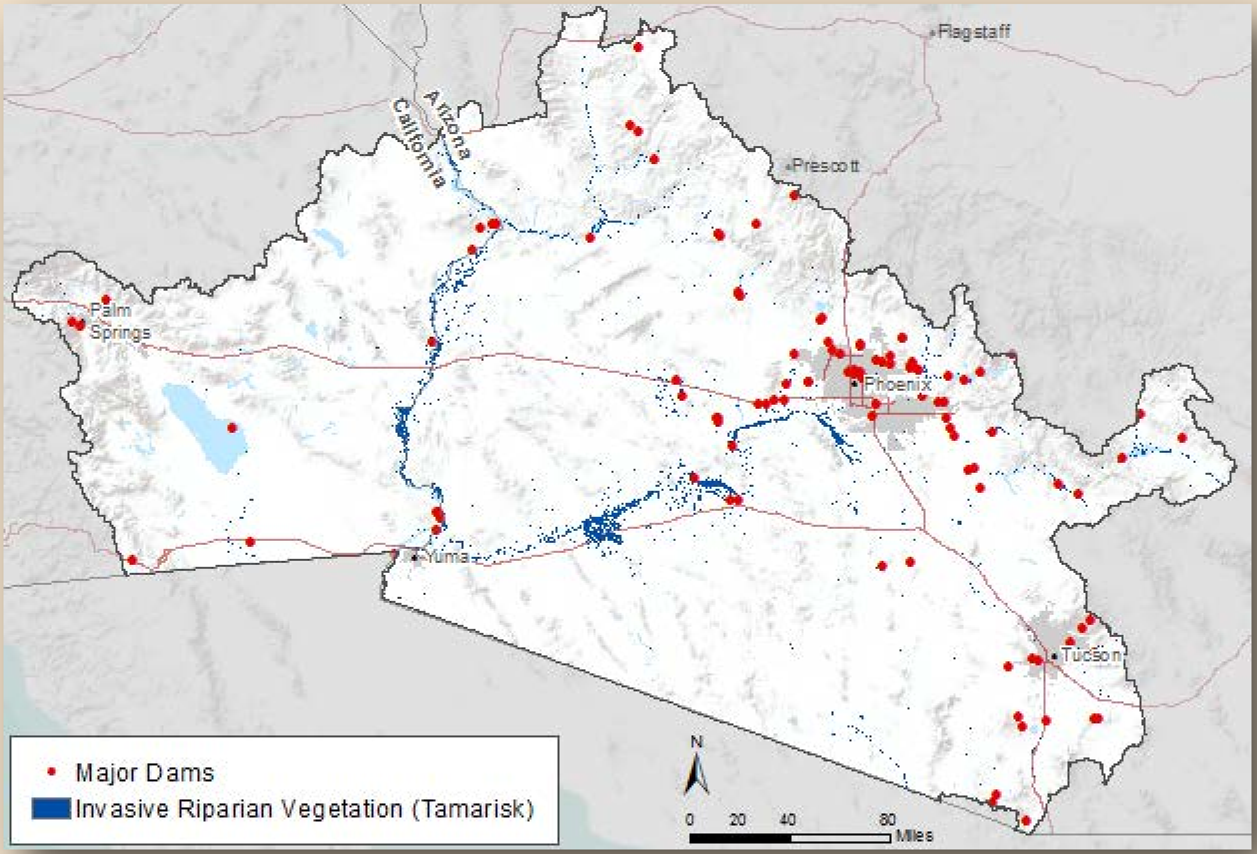


Figure 4. Distribution of tamarisk relative to the distribution of dams in the Sonoran Desert ecoregion.

Thus, although natural flow conditions do not deter the recruitment of tamarisk in the Sonoran Desert, managing to imitate natural flow conditions and flooding regimes to promote native species allows natives to compete more successfully with tamarisk (Cooper et al. 2003, Birken and Cooper 2006, Merritt and Poff 2010).

Depth to groundwater. Groundwater withdrawals for human use put native species at risk and promote the spread of invasives such as tamarisk. In semiarid and arid aquatic ecosystems, permeable floodplain substrates do not retain moisture, and shallow groundwater serves as a more reliable source of water than surface water for riparian plant communities. Depth to groundwater is a limiting factor that affects the distribution of native plant species within the riparian zone (Stromberg et al. 1996, Lite and Stromberg 2005, Nagler et al. 2009). Stromberg et al. (1996) found in a study of riparian vegetation on the San Pedro River in

Arizona, that optimal groundwater levels were <0.25 m for obligate wetland herbaceous species, < 1 m for cottonwood and willow seedlings, and < 3 m for mature cottonwood. Tamarisk tolerates a wide range of groundwater depths as a seedling and adult (up to a depth of 10 m) and thus it can out-compete other more sensitive native species (Stromberg et al. 1996, Stromberg et al. 2007a). Lite and Stromberg (2005) discussed the need to 1) refine the hydrologic thresholds that indicate a shift in composition between native and exotic riparian vegetation and 2) determine the groundwater levels at which drought-tolerant species tend to assert dominance. Over a two-year study period, Lite and Stromberg (2005) found that where surface flow persisted >75% of the time, with inter-annual groundwater fluctuation < 0.5 m, and average maximum depth to groundwater < 2.6 m, native cottonwood and willow remained dominant over tamarisk. At increasing groundwater depths between 2.5 and 3.5 m and groundwater fluctuations between 0.5 and 0.8 m annually, cottonwood persisted alongside tamarisk, but willow, which requires shallower groundwater levels, declined sharply.

Fire in Riparian Zones. Fire is increasing in frequency in riparian areas of the southwestern U.S. for a number of reasons in addition to typical or climate change-induced drought cycles: increased human ignitions, a lack of flood flows, a buildup of litter and woody debris, lowered water tables, and the increasing dominance of fire-adapted invasive species (Ellis 2001). Unlike native riparian vegetation that lacks fire adaptations to resist burn damage or to repopulate burned areas, tamarisk readily re-sprouts from the roots after fire, and it is better able to utilize remaining post-fire soil moisture (Busch and Smith 1993, Busch 1995). A buildup of leaves and litter under dense growth increases fire frequency in riparian areas dominated by tamarisk; fire risk is magnified in regulated systems that lack regular flood flows to flush out accumulated litter (Figure 2 Altered Fire Regime, Busch and Smith 1993, Busch and Smith 1995, Ellis et al. 1998, Ellis 2001). In a study of the lower Colorado River, Busch (1995) found that wildfire could be expected to burn over 20% of riparian vegetation along the lower Colorado River each decade. Though the majority of burned (and re-burned) area during the decade-long study period was already dominated by tamarisk, Busch (1995) noted that cottonwood was virtually absent from post-fire vegetation communities of any kind, indicating the absence of conditions conducive to cottonwood recruitment.

Effects on Wildlife Habitat. Tamarisk affects native wildlife by changing the composition of forage plants and the structure of native riparian systems. Tamarisk reduces the value of critical habitat for some wildlife species dependent on specific native riparian habitats, particularly those that require mature canopy trees (Chen 2001, Johnson et al. 1999, Hunter et al. 1988, Cohan et al. 1978), but it does provide some habitat value for other species (D'Antonio 2000, Dudley et al. 2000, van Riper et al. 2008). For example, the southwestern willow flycatcher, a listed endangered species, will use tamarisk for nesting (McCarthey 2005, Cardinal and Paxton 2005, Sogge et al. 2005; see also southwestern willow flycatcher section, Appendix C). Sogge et al. (2005) found that across the southwestern states approximately 25 percent of southwestern willow flycatcher breeding sites, supporting one-third of the roughly 1,300 known flycatcher territories, were in tamarisk-dominated sites. However, increased fire risk in tamarisk dominated riparian areas is also one of the greatest threats to willow flycatcher breeding sites (USFWS 2002). Brown and Trosset (1989) found that, besides willow flycatcher, five other species nested regularly in tamarisk along the Colorado River in the Grand Canyon; the species with >10 nest sites that they recorded in tamarisk for the Grand Canyon sites were Bell's vireo (*Vireo bellii*), yellow warbler (*Dendroica petechia*), yellowthroat (*Geothlypis trichas*), yellow-breasted chat (*Icteria virens*), and Bullock's oriole (*Icterus bullockii*). On the other hand, many other songbirds, woodpeckers, and cavity nesters are never found in tamarisk and prefer cottonwood groves in all seasons (Ellis 1995).

Tamarisk also affects instream habitats and aquatic species. Tamarisk removal at a spring in Ash Meadows National Wildlife Refuge in Nevada resulted in an increased density of Ash Meadows pupfish, because the shade produced by the dense tamarisk thickets had reduced the algae necessary to sustain the pupfish (Kennedy et al. 2005). In studies examining the response of aquatic macroinvertebrates to exotic riparian vegetation, Bailey et al. (2001) found a two-fold decrease in macroinvertebrate richness and a four-fold decrease in total abundance of macroinvertebrates on tamarisk leaf packs vs. native Fremont cottonwood leaf packs placed in an Arizona perennial stream; and Moline and Poff (2008) noted that native leaf packs remained in the stream longer than leaves from tamarisk, making the leaves available longer to macroinvertebrate leaf shredders.

Restoration of Native Riparian Species

Present riparian restoration efforts to reverse the spread of tamarisk cover a management spectrum from the restoration or imitation of fluvial processes that favor the natural establishment of native species to mechanical and chemical tamarisk clearing operations and irrigated native tree planting. Tamarisk removal may be a lower priority or even unnecessary on perennial free-flowing rivers where fluvial processes remain more intact and native species can compete with invasives (Stromberg et al. 2007b). Stabilizing groundwater levels by limiting groundwater withdrawals (Stromberg et al. 1996) and managing to reduce salinity levels to < 4 g/l NaCl (Busch et al. 1992, Glenn et al. 1998) protect existing native riparian plant communities. In areas of tamarisk dominance, clearing and planting efforts are not likely to be successful without a concurrent restoration of accessible shallow groundwater. If tamarisk clearing is pursued, a more gradual or patch replacement of tamarisk, such as might occur with scouring floods, may ensure that enough tamarisk woodland remains available during a transitional period for bird species that use tamarisk for nesting. Bateman and Paxton (2009) provide a thorough review of wildlife use of tamarisk and likely wildlife responses to tamarisk control.

Restoration of native riparian vegetation with a return to natural fluvial processes requires active management to allow (or mimic) regional hydrologic regimes with characteristic perennial stream flows, flood timing and intensity, and available shallow groundwater. Native species recruitment may occur in sections of rivers below dams if larger flood flows exceed the storage capacity of the dam or if flood flows are managed through spring water releases (Shafroth et al. 1998). Outcomes will vary with flood timing and intensity; high volume spring flooding may scour the stream channel, rearrange sediments, and provide a seedbed for native species early in the season. Summer water releases for irrigated agriculture in reaches below dams, on the other hand, may favor tamarisk dominance because tamarisk is able to take advantage of moist summer seedbeds (Shafroth et al. 1998, Stromberg et al. 2007a, b).

Rivers that retain more of their natural flow regime as well as available groundwater reserves provide a better opportunity for recovery of native vegetation following riparian fire. Although mature cottonwood tree mortality is very high following moderate to severe riparian burns, cottonwoods do respond with stem and root sprouts and root suckering following lighter fires (Smith et al. 2009). Native cottonwood seeds may sprout after a riparian fire if managed post-fire flooding is employed during the spring cottonwood seed dispersal period (Ellis 2001, Smith et al. 2009). Along the mainstem Colorado and Gila rivers, the hydrologic regime is so altered that there is little regeneration of natural vegetation and restoration is complicated by fire in tamarisk thickets (USBOR 2004). Finally, as a preventative measure, reducing fuel loads and litter in riparian zones through mechanical removal or through re-establishing flooding regimes could reduce the incidence of riparian fires in mature riparian canopies (Ellis 2001).

Tamarisk dominance on perennial free-flowing streams and rivers where native species should be competitive may indicate past or present heavy grazing pressure and suggest a need for a change in grazing management (Stromberg et al. 2007b). Livestock selectively forage on the shoots of native species and find tamarisk to be less desirable than native species. Hughes (2000) found on the Arizona Strip that when livestock were restricted to winter use and kept out of riparian areas in the spring and summer, native species were able to compete with tamarisk.

Tamarisk Beetle. During the late 2000s, the U.S. Department of Agriculture (USDA) allowed tamarisk control using defoliating *Tamarix* leaf beetles (*Diorhabda carinulata*) north of the 38th parallel to avoid conflict with southwestern willow flycatcher nesting territories to the south. When a later beetle release near St. George, Utah threatened to allow beetle invasions southward into Arizona, a lawsuit prompted the USDA to ban the release or interstate transport of the *Diorhabda* beetle in 2010 (Center for Biological Diversity 2009, Lamberton 2011). It is unknown what effect the remaining beetles will have on Sonoran Desert southwestern willow flycatcher habitat. Field studies north of the 38th parallel to monitor the beetle infestations and subsequent tamarisk mortality suggest that tamarisk is not weakened as much as had been hoped by beetle defoliation; shrubs re-sprout yearly and the amount of shrub mortality varies by location and post-defoliation conditions (Nagler et al. 2011).

Climate Change

Tamarisk has a higher drought tolerance than many native riparian species (Glenn and Nagler 2005). Climate change models predict that rising temperatures are unlikely to adversely affect tamarisk distribution, with the majority of habitat remaining suitable and only a small percentage of currently invaded lands becoming climatically unsuitable by 2100 (Bradley et al 2009). The effects of climate change, such as warming temperatures and increased fire frequency and intensity, are hypothesized to enhance tamarisk invasion and expansion, while limiting native riparian plant communities even more than currently (Figure 2, Altered Fire Regime, Climate Change, Merritt and Poff 2010, Seager et al. 2007). Climate change projections predict declining river flows (with maximum spring flows coming earlier in the season), more frequent droughts, and increasing human water consumption with its pressures on groundwater levels—all conditions that will make it more difficult for native species to compete with invasives in riparian areas (Smith et al. 2009).

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V. Potential Future Conditions of the Sonoran Desert

Potential future conditions for near-term (2025) development, long-term potential energy development, near-term terrestrial landscape and aquatic intactness, and potential mid-century (2060) climate change impacts were examined through the use of fuzzy logic modeling. Results for each analysis (i.e., land area in various classes) overlaid on the distribution of the core conservation elements—wildlife species, vegetation communities, and designated lands—assessed the proportion of each conservation element distribution in the various intactness or potential development classes. Lack of source data for future projections was common resulting in underestimates of what is likely to occur in the near-term future (2025) time frame.

Near-term development and intactness project from the present to 2025. Maximum potential (or long term) energy development has an indeterminate time frame. The potential energy development analysis considered all potential known traditional and renewable energy data sources; it is based on polygons representing energy zones rather than specific leases or applications. For this reason, maximum potential energy development, as discussed in Section 5.2 below, when overlaid on conservation elements' distributions may overestimate the impacts to species, habitats, and sites. Projecting into the future is a challenging endeavor and the results should be viewed critically as they possess many uncertainties and should not be relied upon for detailed site-level planning and management without additional data and analysis. Details on the relative quality of data sources for near term and potential development may be found in Appendix E. Tables listing data sources give the relative quality of each data set and a rating of overall model performance or certainty (based on best professional judgment). The results provide future scenarios for the ecoregion based on available projection data and show how the predicted changes may affect the various conservation elements of interest.

5.1 Projected Near-term Future (2025) Development

Projected near-term future (2025) development was built from the current development fuzzy logic model, which is comprised of four major development components—energy, agriculture, urban and roads, and recreational development (Figure 5-1). In reality, all of these factors are likely to change, but there were little predictive data available to use that provided meaningful projections into the future. The renewable energy development footprint included 2011 renewable energy project points and solar priority projects. (Note: a map of near-term renewable energy development locations relative to the distribution of the two desert tortoise species may be found in the Desert Tortoise Case Study Insert.) There were no data available for the near-term expansion of linear utilities. There were also no datasets for projected future for either intensive agriculture or grazing. Given climate change results and the overallocation of water resources, the future of agriculture is uncertain. Current recreation data were difficult to acquire and assemble; as a result, there were no changes made in recreation for the near-term. Future projections for urban development were based on model results from Theobald (2010), but there were no accompanying data on projected road building, which is a noteworthy deficiency as the effects of road impacts on many wildlife species and overall intactness is well known. Even with the lack of important topical data, some measurable changes were observed (Table 5-1). The Very High development class increased by 1.5% and both High and Moderately High classes gained approximately .5% over the near term future time period to 2025. The area covered by the four major development components expanded by over 887,000 acres region-wide during this time period. All of the results from the development model were incorporated into the near-term intactness models. The potential impact on conservation elements from near-term future development was examined by overlaying the near-term future (2025) intactness modeling results on conservation element distributions as described in Section 5.3 (and Appendices B and C).

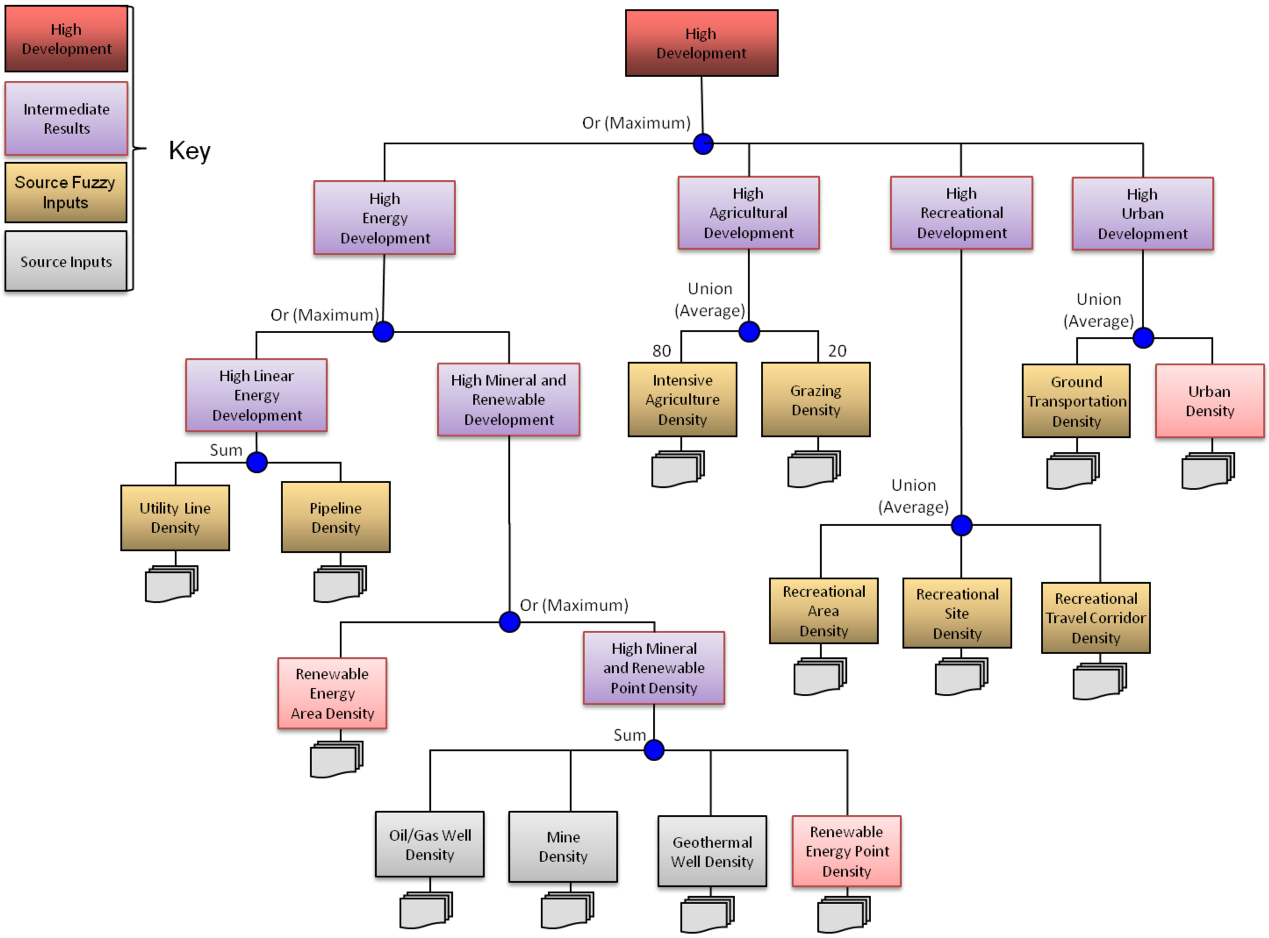


Figure 5-1. Fuzzy logic model for future near-term (2025) development for the Sonoran Desert ecoregion. Pink boxes depict the inclusion of additional data.

Table 5-1. Modeled change in land area (in 1000s of acres) for current to near-term future (2025) development for the Sonoran Desert ecoregion.

Category	Current	Percent	Near-term	Percent	Change
Very High	3,996	11.4%	4,531	12.98%	+1.5%
High	2,179	6.2%	2,328	6.67%	+0.4%
Moderately High	2,033	5.8%	2,236	6.40%	+0.6%
Moderately Low	5,652	16.2%	5,304	15.19%	-1.0%
Low	9,230	26.4%	8,868	25.40%	-1.0%
Very Low	11,825	33.9%	11,648	33.36%	-0.5%

5.2 Potential Energy Development

This section focuses on maximum potential energy development (mostly renewable energy) that could foreseeably occur beyond 2025. Maximum potential energy development was analyzed with a fuzzy logic model that included three major components—traditional oil and gas, wind energy, and solar energy (Figure 5-2). Potential for oil, gas, and geothermal development was created by simply buffering existing wells (not shown). Solar resource potential, defined as >5.5 kW/m^2 in areas with < 1% slope, was obtained from the National Renewable Energy Laboratory (NREL, www.**nrel**.gov/rredc/, Figure 5-3) and added to solar priority projects, selected features from California BLM on verified and preliminary renewable energy rights-of-way, revised solar energy zones (SEZs), and Arizona Restoration Design Energy Project data (RDEP). Potential wind development was also comprised of NREL data and defined by wind power density classes 3 and above at 50 m high (Figure 5-4).

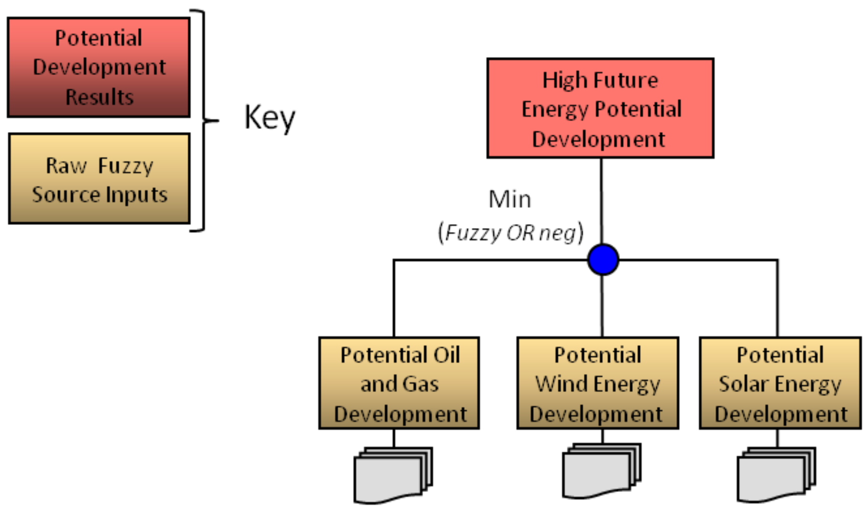


Figure 5-2. Fuzzy logic model diagram for maximum potential energy development in the Sonoran Desert ecoregion.

Summarized at 4km resolution, the final composite map for all three energy components showed about 32% of the area of the ecoregion subject to moderate or high potential energy production (Figure 5-5). Values from the fuzzy logic model were divided into three basic classes (High 1 to 0.33, Moderate 0.33 to -0.33, and Low -0.33 to -1) instead of the six classes that have been used in other fuzzy logic models (such as the intactness models and the model for near-term [2025] development); finer differentiation was not depicted or warranted as the subject data covered broad areas and were more speculative (that is, not based on actual plans for development). For the ecoregion, over 7 million acres (or about 21%) were classified as having High potential, about 3,900,000 acres (11%) Moderate potential, and the rest, almost 24,000,000 acres (68%) Low potential. These results, when overlaid with the distribution maps for all of the conservation elements, evaluated the potential impact for each element from potential energy development. As mentioned earlier, maximum potential development of energy resources may overestimate the impacts to species, habitats, and sites since full development is not likely to be realized. Designated lands were not included in this part of the analysis because most energy development is prohibited from these areas.

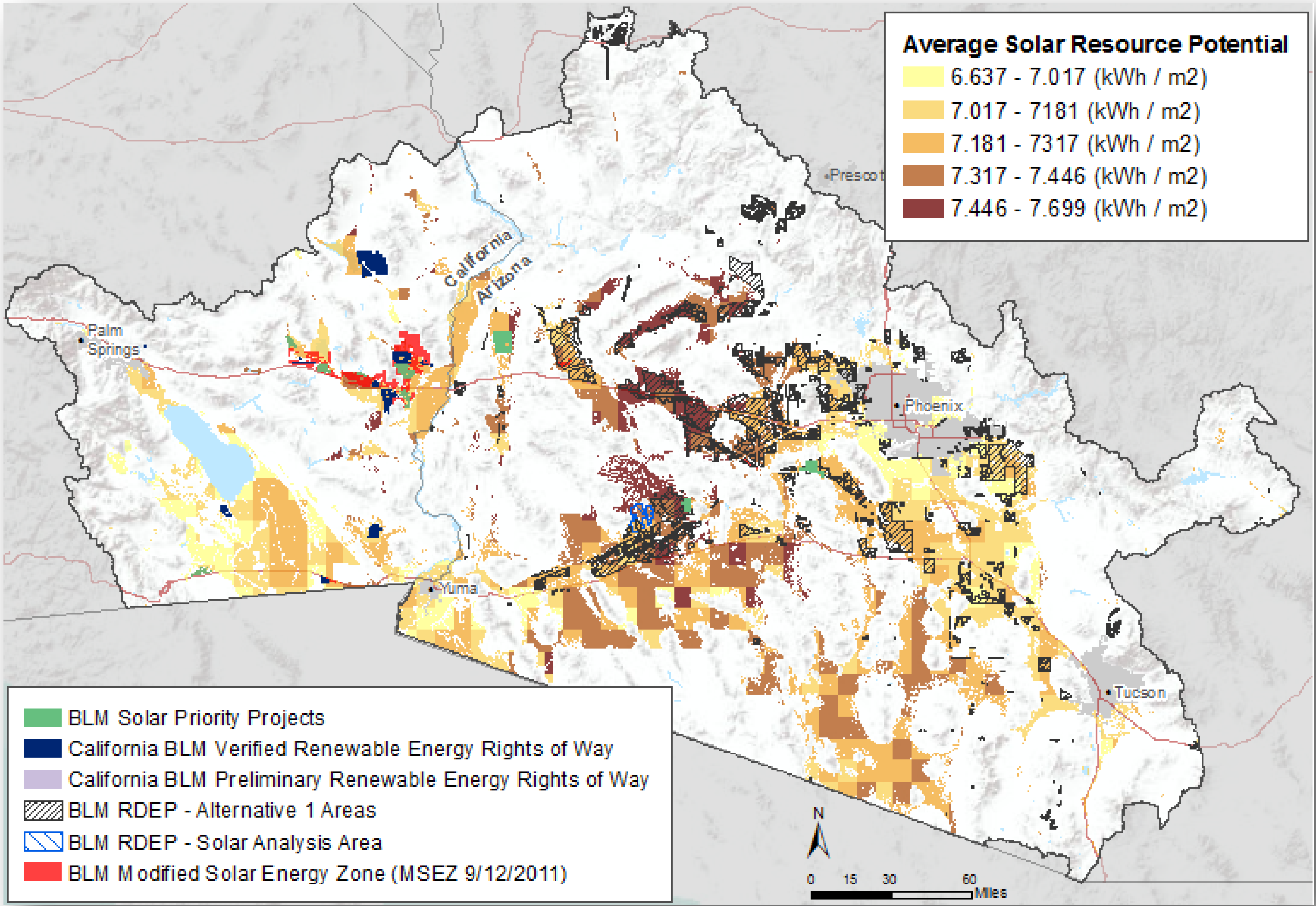


Figure 5-3. Solar energy source data for the maximum potential energy development model for the Sonoran Desert ecoregion including BLM solar priority projects (green), Arizona BLM RDEP areas (hatched), solar energy zones (SEZs in red), and NREL average solar resource potential polygons (yellow, orange polygons).

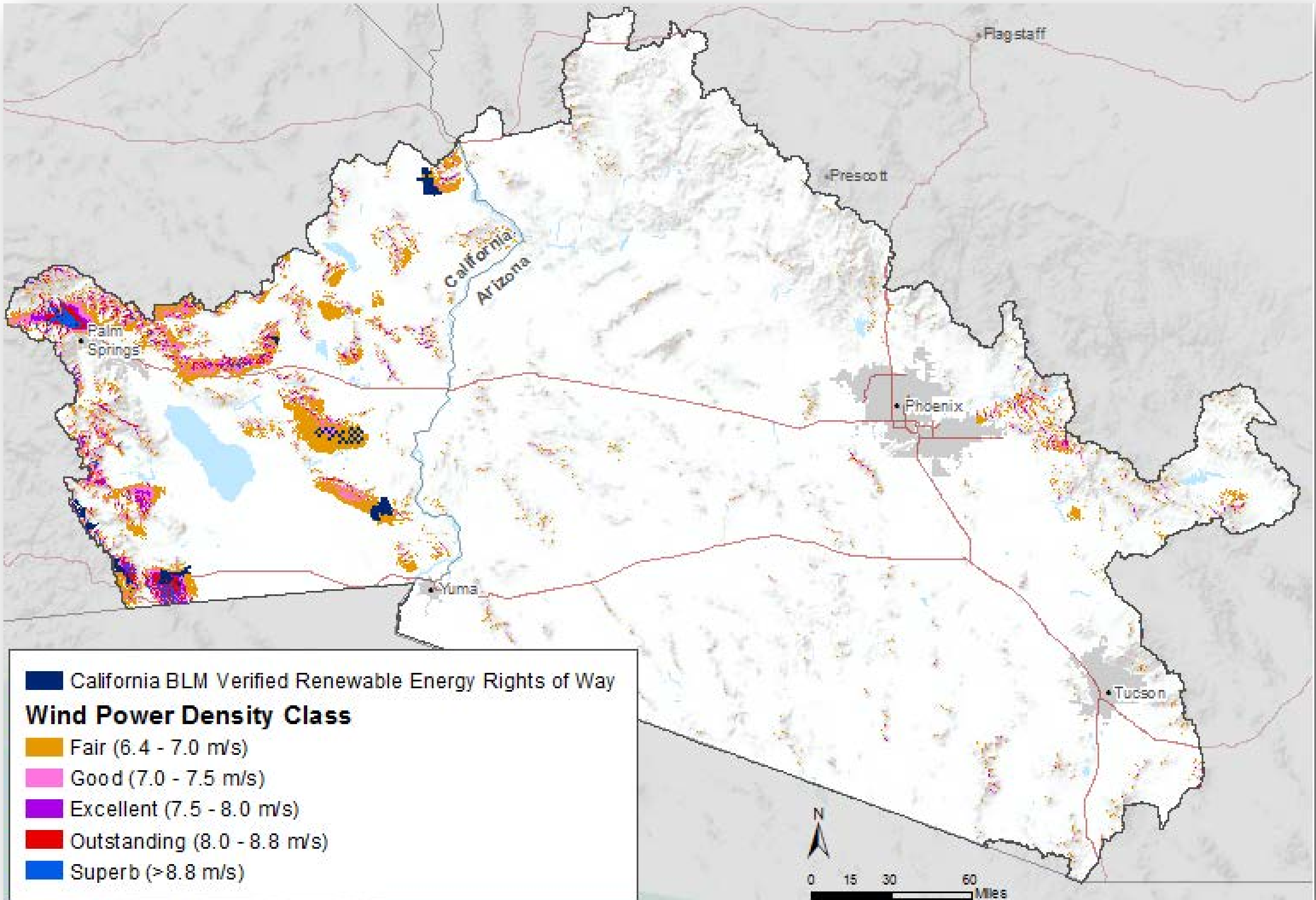


Figure 5-4. Wind energy source data (wind power density classes 3 and above at 50 m high) for the maximum potential energy development model for the Sonoran Desert ecoregion including California BLM renewable energy rights of way and five wind power density classes.

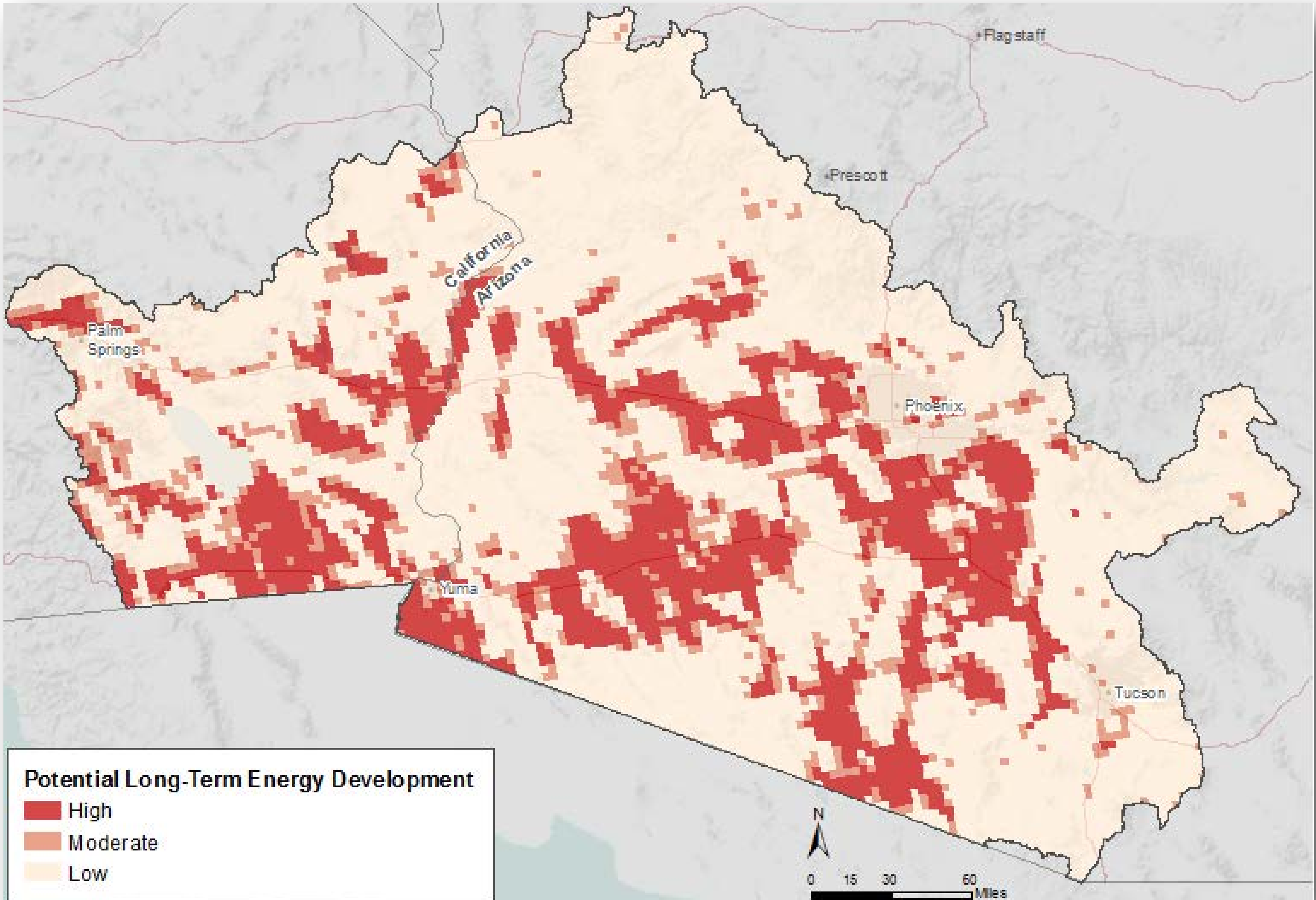


Figure 5-5. Map of maximum potential energy development for all three energy components (wind, solar energy, and oil and gas [not shown as source map]) in the Sonoran Desert ecoregion. Because of the more speculative nature of the data, values from the fuzzy logic model were divided into three basic classes (High 1 to 0.33, Moderate 0.33 to -0.33, and Low -0.33 to -1), rather than six classes as for the intactness models.

5.2.1 Impact of Potential Energy Development on Wildlife Species

Potential impact on species conservation elements from maximum potential (or long term) energy development varied greatly among species (Figure 5-6). Of the three mammal species examined, mule deer showed the greatest potential impact (with approximately 15% of its current distribution affected). Mountain lion was second with 8% and desert bighorn sheep followed with around 4% of its current distribution potentially under high impact from energy development. Of the two tortoise species, Mojave desert tortoise (*Gopherus agassizii*) was more highly affected than Sonoran desert tortoise (*Gopherus morafkai*) because of its occurrence in renewable energy zones. Although the lowland leopard frog was evaluated for near-term (2025) landscape intactness and status, it was not evaluated for maximum potential energy development because it was treated as an aquatic species.

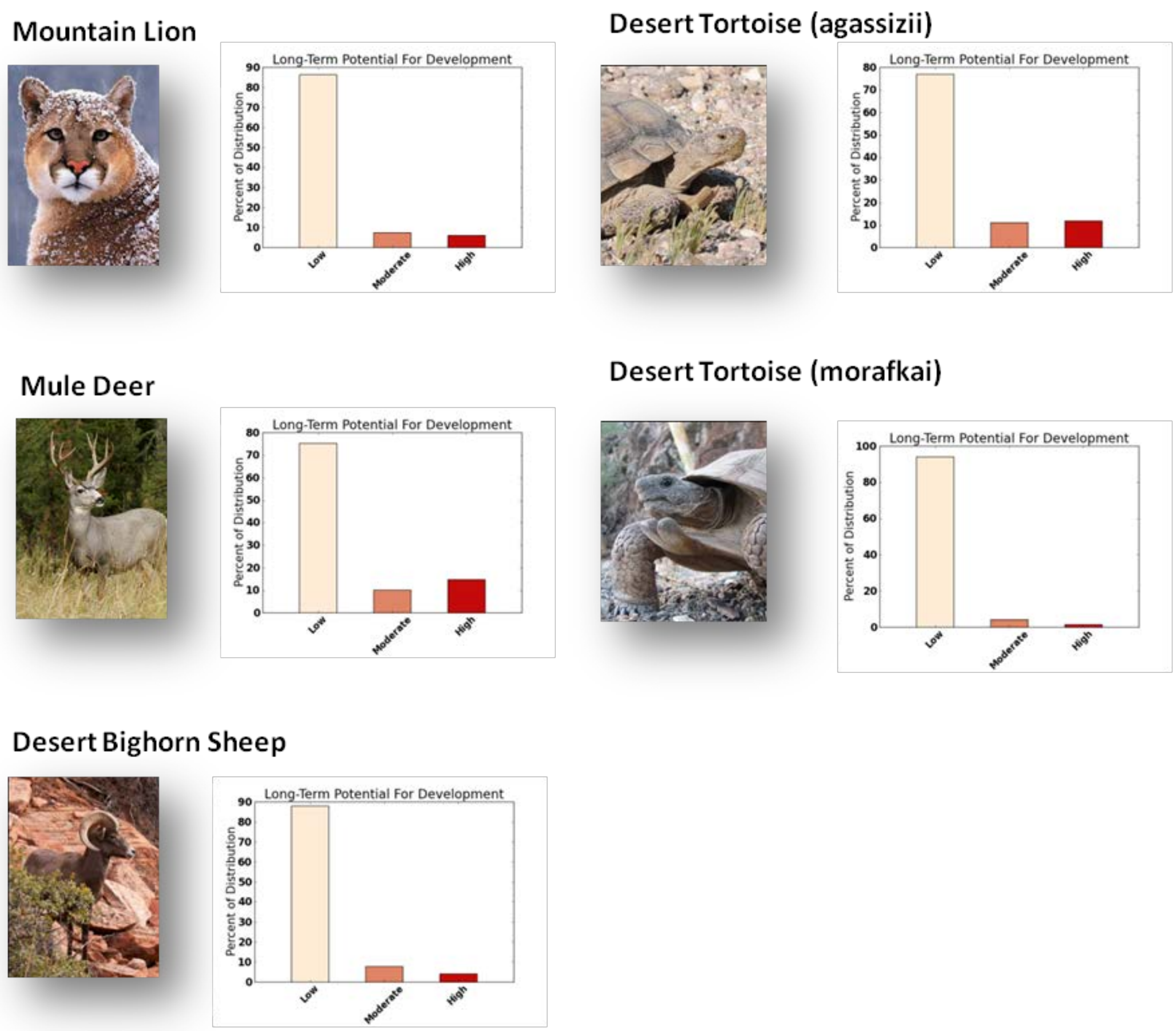


Figure 5-6. Impact from maximum potential (long term) energy development on the mammal and reptile conservation elements of the Sonoran Desert ecoregion. Values from the fuzzy logic model were divided into three basic classes (High 1 to 0.33, Moderate 0.33 to -0.33, and Low -0.33 to -1). For more information on the tortoise species, see the desert tortoise insert. For more details on mammal species, see Appendix C.

Between 70–80% of current bird species' distributions were considered to be under low threat from energy development (Figure 5-7). Le Conte's thrasher, a resident of creosote-bush flats, showed the highest level of threat with 18% and 12% of its current distribution under High and Moderate threat, respectively. Although the data over-represented Le Conte's thrasher distribution, the bird is rare even in optimal habitats, and it requires large blocks of intact creosotebush habitat to persist. Thorough inventories for species like Le Conte's thrasher or desert tortoise with large area needs should precede any planning in solar energy zones. All of the other birds had roughly 20% of their current distributions under potential threat from future development. Southwestern willow flycatcher distribution covers about 139,000 acres in the ecoregion (based on USFWS critical habitat data, [2005, 2011], http://ecos.fws.gov/speciesProfile/profile], which may or may not be occupied), and, according to the potential energy development model, the species could potentially lose 20,000 acres of this habitat, increasing the threat to its survival. Potential losses to riparian species from long-term energy development appear to be based on the potential development of NREL solar resource areas near the Colorado and Gila rivers.

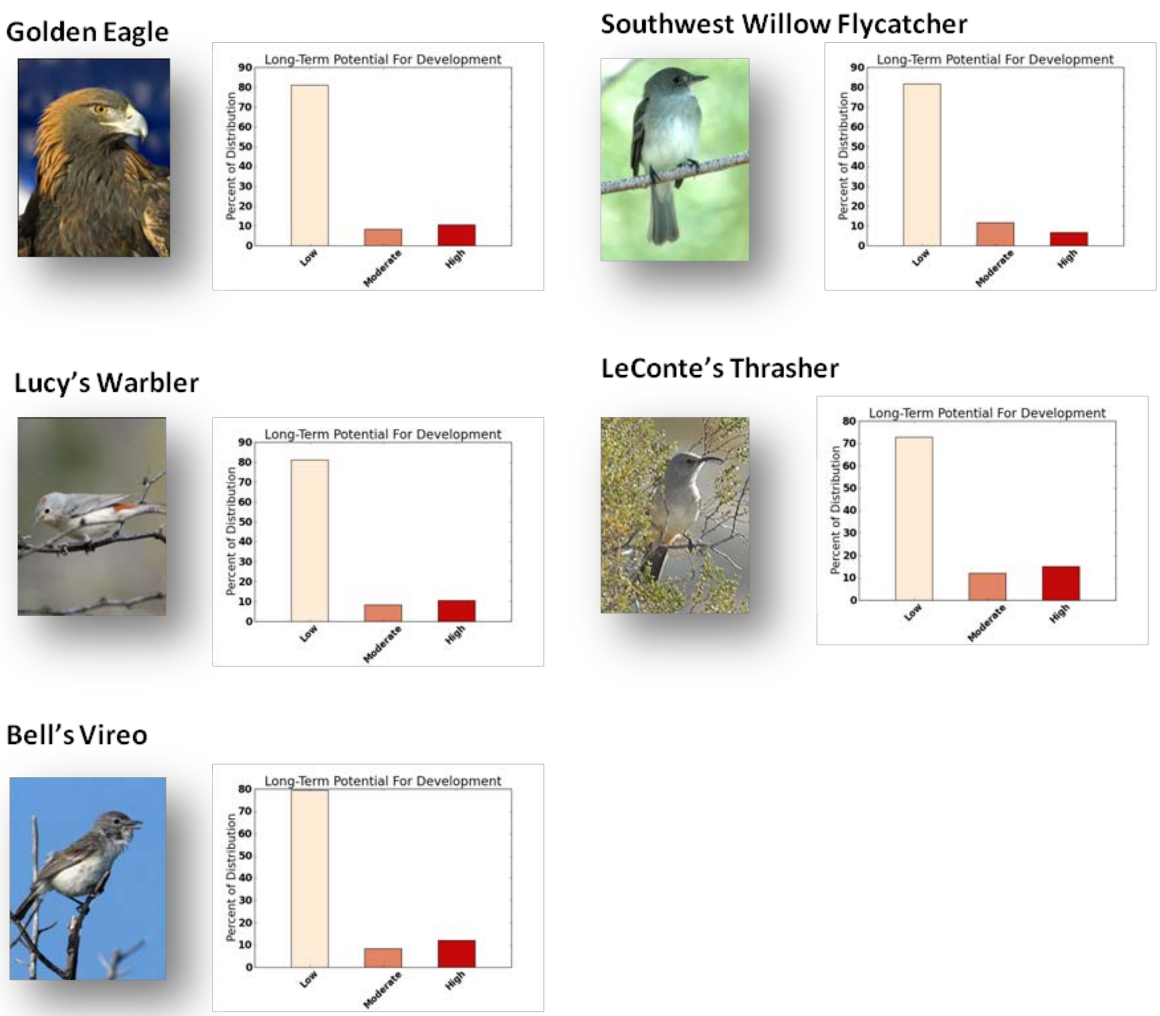


Figure 5-7. Impact from maximum potential (long-term) energy development on the bird species conservation elements of the Sonoran Desert ecoregion. Values from the fuzzy logic model were divided into three basic classes (High 1 to 0.33, Moderate 0.33 to -0.33, and Low -0.33 to -1). For background material on individual species, see Appendix C.

5.2.2 Potential Energy Development Impact on Vegetation Communities

Of the three vegetation communities examined, Sonoran-Mojave Creosotebush-White Bursage Desert Scrub showed the greatest potential impact with as much as 30% of its current distribution within the High class (Figure 5-8). Riparian vegetation also showed fairly high vulnerability with nearly 20% in the High category. The two classification systems for the two matrix vegetation communities, based on different interpretations of land cover imagery, showed the NatureServe version higher for the Sonoran-Mojave Creosotebush-White Bursage Desert Scrub and LANDFIRE existing vegetation data higher for the Sonoran Paloverde-Mixed Cacti Desert Scrub. As before with the riparian birds, direct impacts to riparian vegetation were mostly due to the overlap of NREL solar potential polygons with river networks, although upland development near riparian areas with associated roads, utility lines, and other infrastructure will also alter riparian habitat quality.

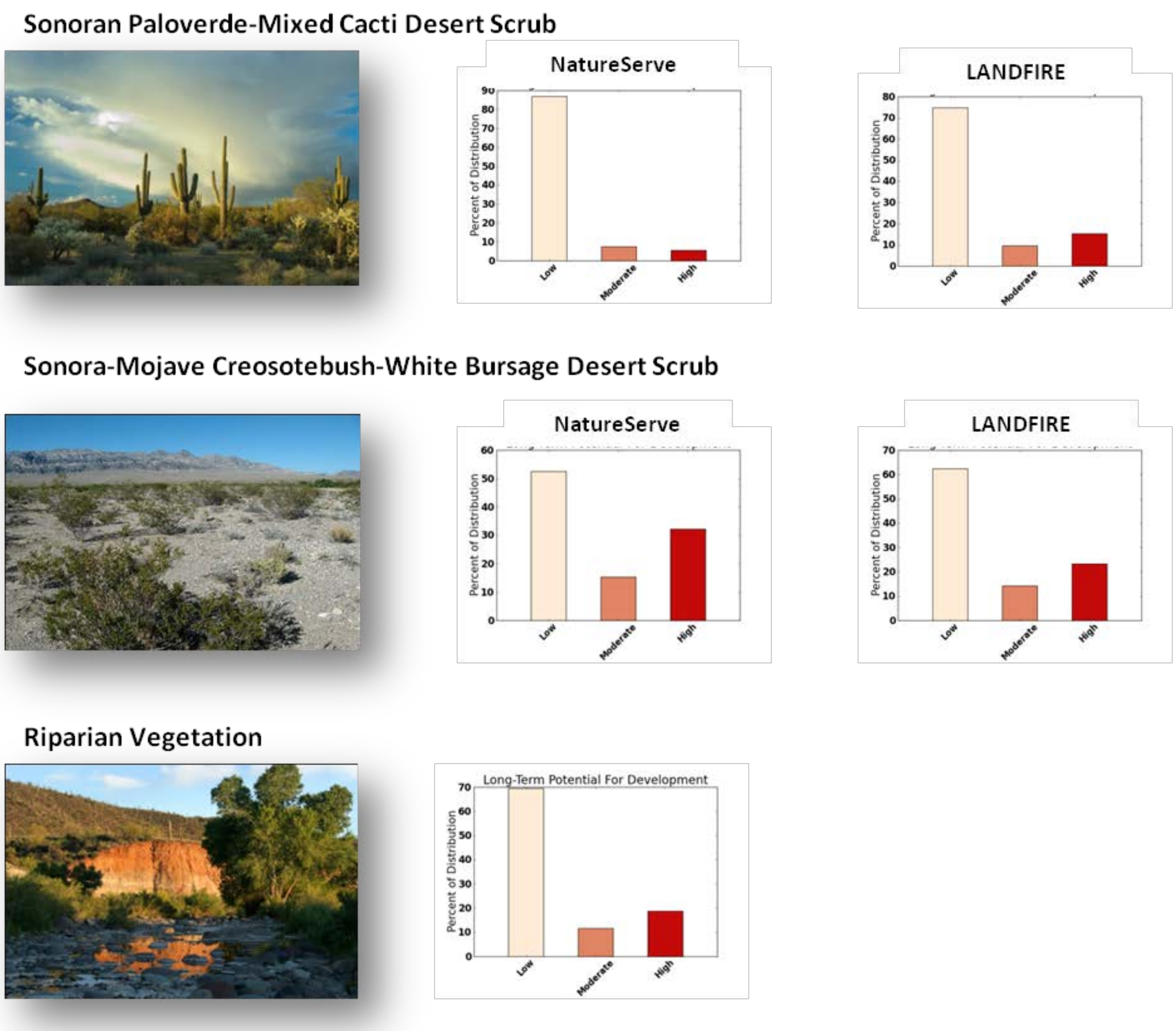


Figure 5-8.Histograms show impact from maximum potential (long-term) energy development on the vegetation communities of the Sonoran Desert ecoregion. Values from the fuzzy logic model were divided into three basic classes (High 1 to 0.33, Moderate 0.33 to -0.33, and Low -0.33 to -1). For more details on individual vegetation classes, see Appendix B.

5.3 Near-term Future (2025) Terrestrial Landscape Intactness

Near-term (2025) terrestrial landscape intactness (at both 4km and HUC5 reporting units) consisted of the same components and construction as the current intactness models with available projection datasets replacing those for current condition (Figure 5-9). Urban area, renewable energy, and invasive species projections (pink boxes in logic models) were updated for the near-term future terrestrial landscape intactness model. Projections on the spread of invasive species (Figure 5-10) were based on the potential expansion of Sahara mustard predicted by the MaxEnt model described earlier (in Chapter 3 and Section 4.3) using soil characteristics and future climate estimates from climate models presented in Section 5.4. The map (Figure 5-10) represents all invasive species, although Sahara mustard was the only species that could be projected into the future. The apparently limited expansion of Sahara mustard shown in the near-term future model results (red in Figure 5-10) may have occurred because the current distribution model may have over-represented the species' distribution, based as it was on general climate and soil characteristics.

FRAGSTATS was not rerun because there was not enough additional information on fragmentation and rerunning it would only have added additional uncertainty to the results. The near-term future intactness results were overlaid on the distribution data for each of the conservation elements to predict their change in status from the near-term change agents for which data were available.

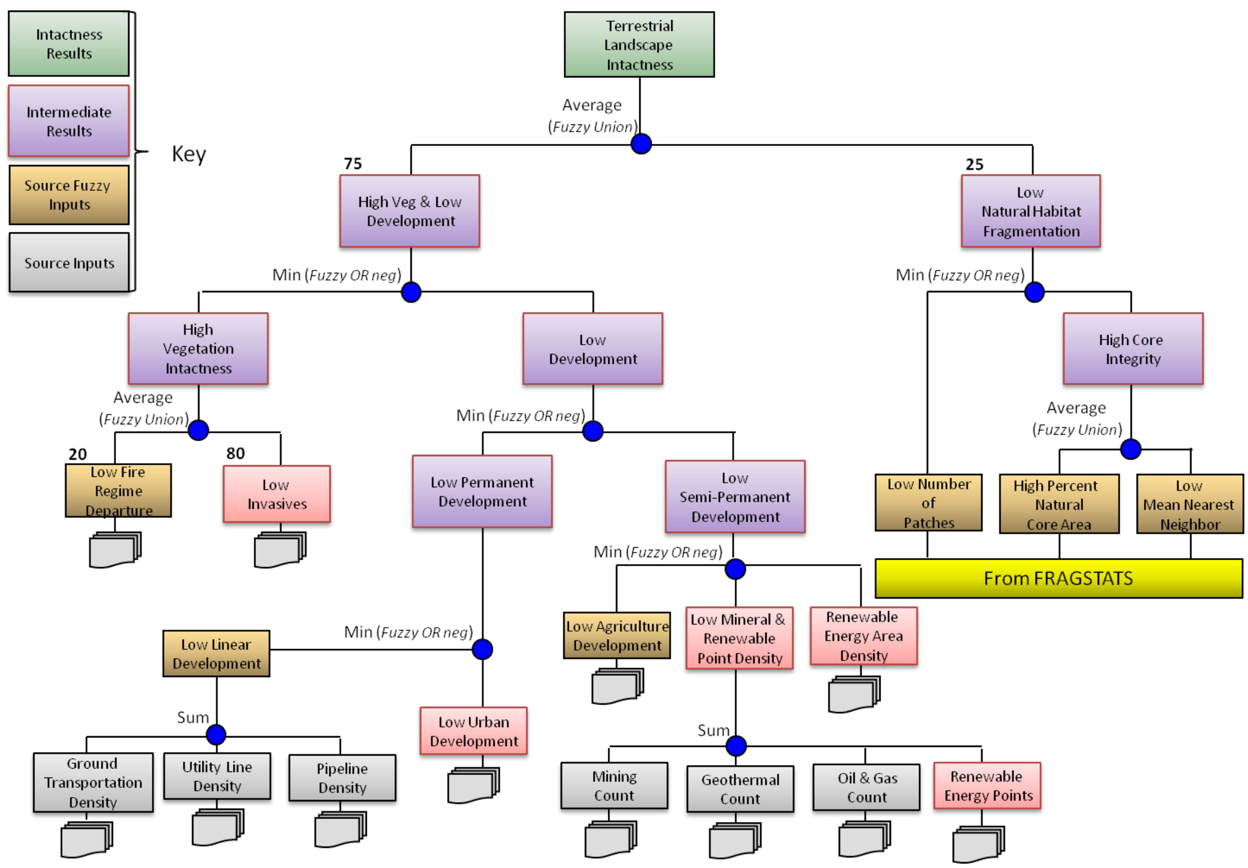


Figure 5-9. Near-term future (2025) terrestrial landscape intactness fuzzy logic model. Projection data inputs appear as pink boxes. Tables listing data sources and their relative quality and an overall confidence rating for the model may be found in Appendix E.

Overall, near-term future intactness in the ecoregion showed some declines with modest decreases in High and Moderately High intactness area countered by slight increases in the Low and Very Low classes (Figure 5-11, Table 5-2). Declines occurred in areas expected from the type of projected data input—near the Phoenix-Tucson urban corridor, the renewable energy zones, and along major interstate highways. The model could be improved with the addition of data on projected utility corridors, projected road density increases, and recreation. In Appendix E, tables list data sources represented in the logic model with their relative quality.

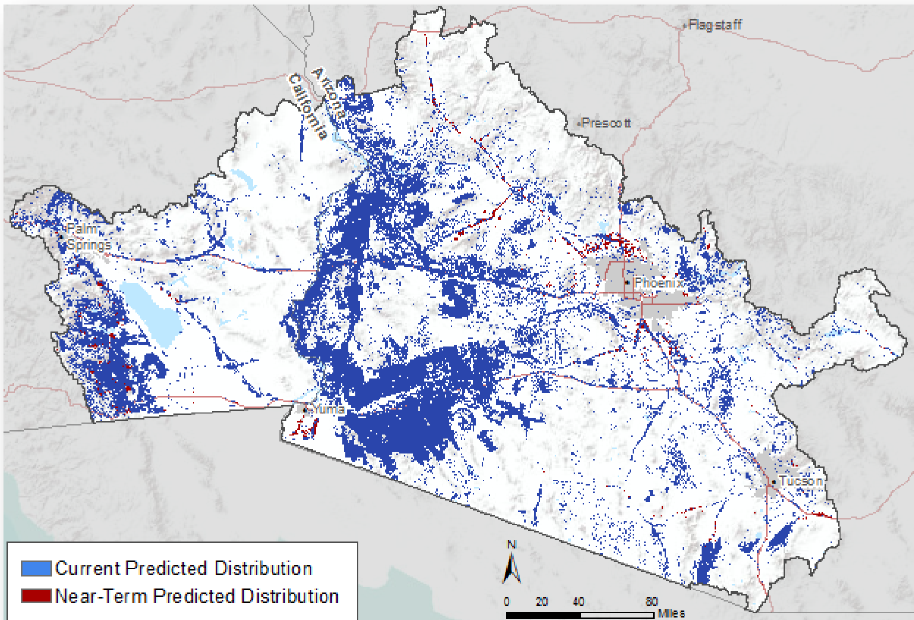


Figure 5-10. Current and near-term future (2025) predicted distribution of four invasive species selected as conservation elements. Expansion of invasive species (in red) is for modeled potential distribution of Sahara mustard only.

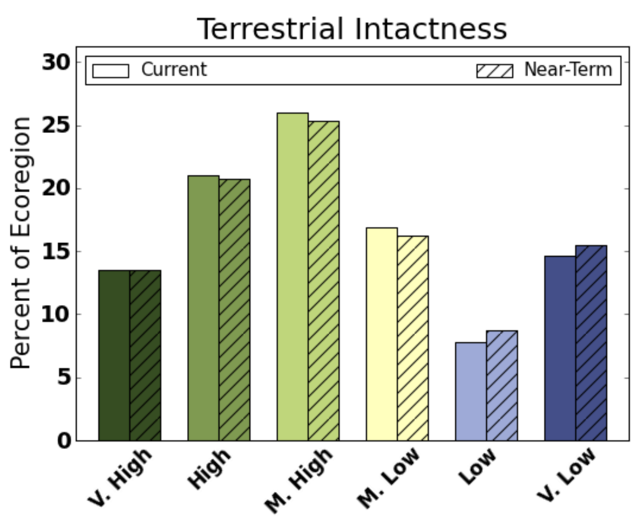


Figure 5-11. Histogram comparing current (solid color bars) and near-term future (hatched bars) terrestrial landscape intactness for the Sonoran Desert ecoregion showing small decreases in Very High and High intactness areas countered by slight increases in the Low and Very Low classes.

Table 5-2. Change in current to near-term future (2025) terrestrial landscape intactness (in 1000s of acres) for the Sonoran Desert ecoregion.

Category	Current	Percent	Near-term	Percent	Change
Very High	4,725	13.5%	4,713	13.5%	-0.03%
High	7,333	21.0%	7,234	20.7%	-0.28%
Moderately High	9,095	26.1%	8,840	25.3%	-0.73%
Moderately Low	5,910	16.9%	5,679	16.3%	-0.66%
Low	2,731	7.8%	3,036	8.7%	+0.87%
Very Low	5,121	14.7%	5,412	15.5%	+0.83%

5.3.1 Near-Term Future (2025) Status for Terrestrial Wildlife Species

Current and near-term status for each conservation element was based on the terrestrial landscape intactness models for the two time periods using the 4 km X 4 km resolution grid. Results pertain to the distribution area of each element at the finest scale (1:24,000) or resolution (30m pixels) available overlaid with the intactness results.

All mammals showed some declines (Figure 5-12) with mule deer and mountain lion distributions showing somewhat greater impact than desert bighorn sheep.

Mule deer and mountain lion showed similar response to near-term change (Figure 5-12 and Figure 5-13A) when using the same thresholds for the model variables. When the road threshold was applied to the model for mountain lion described in Chapter 4 (0.60 km/km^2, Van Dyke et al. 1986), the declines in mountain lion viability were more dramatic (Figure 5-13B). The declines are evident, not from the addition of potential roads data (projections on roads were not available), but because road densities representing true (or +1 in fuzzy logic) are constrained in the model to a level that does not negatively affect mountain lion (according to Van Dyke et al. [1986]). This is one example of the flexibility of a modeling process that allows quantifiable threshold information to be inserted as it becomes available.

All of the bird species showed declines in habitat quality in near-term future status, particularly the riparian species Bell’s vireo and southwestern willow flycatcher that are already in decline (Figure 5-14). Bell’s vireo is represented in the Sonoran REA as two distinct subspecies, Arizona Bell’s vireo (*Vireo bellii arizonae*) and least Bell’s vireo (*Vireo belli pusillus*). Arizona Bell’s vireo is state-listed as endangered in California (sensitive in Arizona), and least Bell’s vireo is both state and federally listed as endangered in California. Southwestern willow flycatcher is federally listed as endangered. Lucy’s warbler, also a sensitive riparian species at the northern extent of its range, does not fare as badly—possibly because of its greater adaptability to exploit alternative nesting habitats and food resources (see Appendix C). The fate of Le Conte’s thrasher parallels that of its habitat, creosotebush-white bursage, which continues to be converted and fragmented by urban and rural residential development and renewable energy development. Le Conte’s thrasher requires large contiguous patches of habitat and it will abandon blocks of creosotebush habitat undergoing fragmentation.

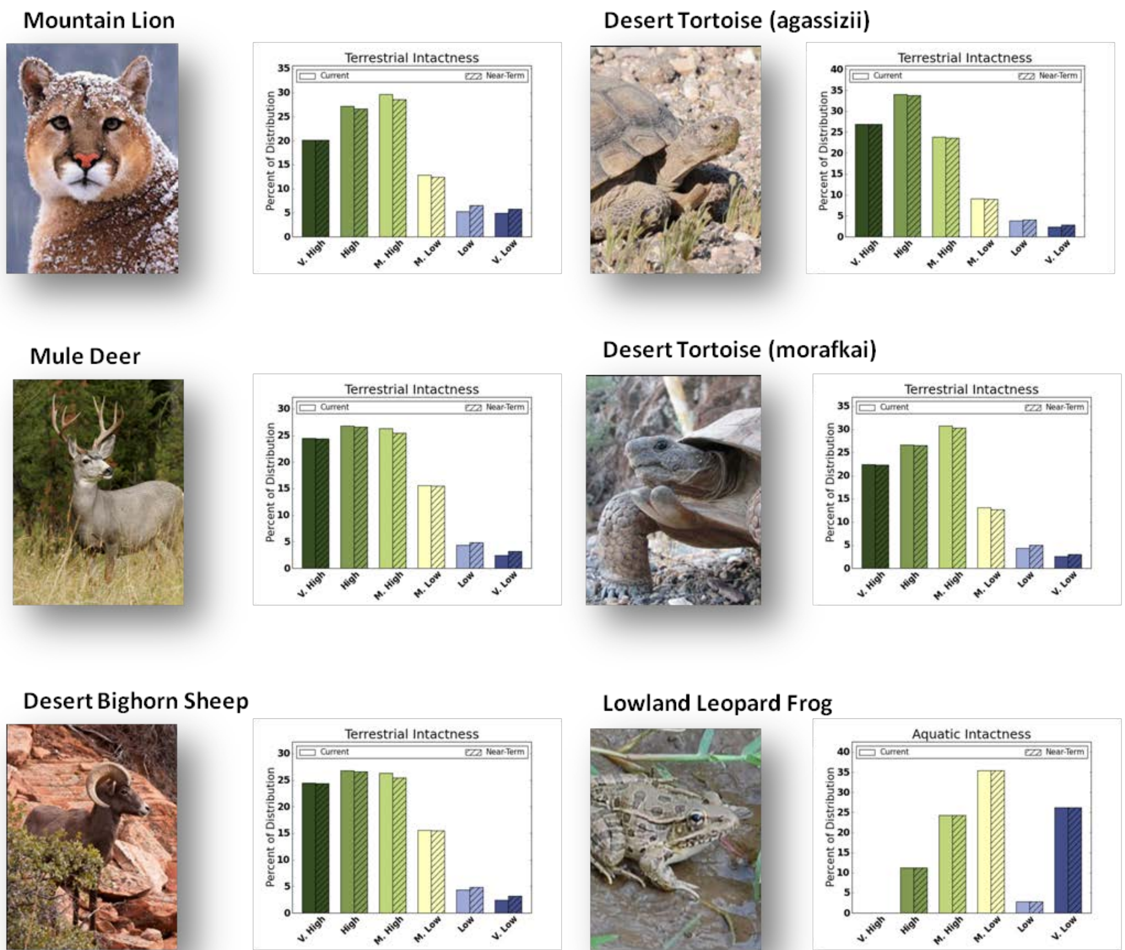


Figure 5-12. Comparison between current (solid) and near-term (crosshatched) future status for wildlife species conservation elements based on comparison of current distribution with current (solid) and near-term future (hatched) terrestrial landscape intactness.

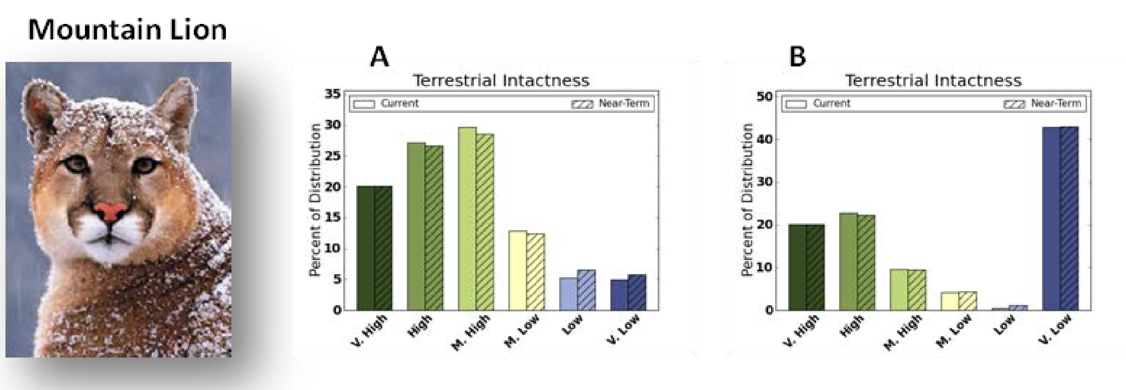


Figure 5-13. Comparison of current and near-term future status for mountain lion based on terrestrial landscape intactness for the (A) unconstrained model and (B) the constrained version imposing a road density threshold of 0.6 km/km^2 (Van Dyke et al. 1986).

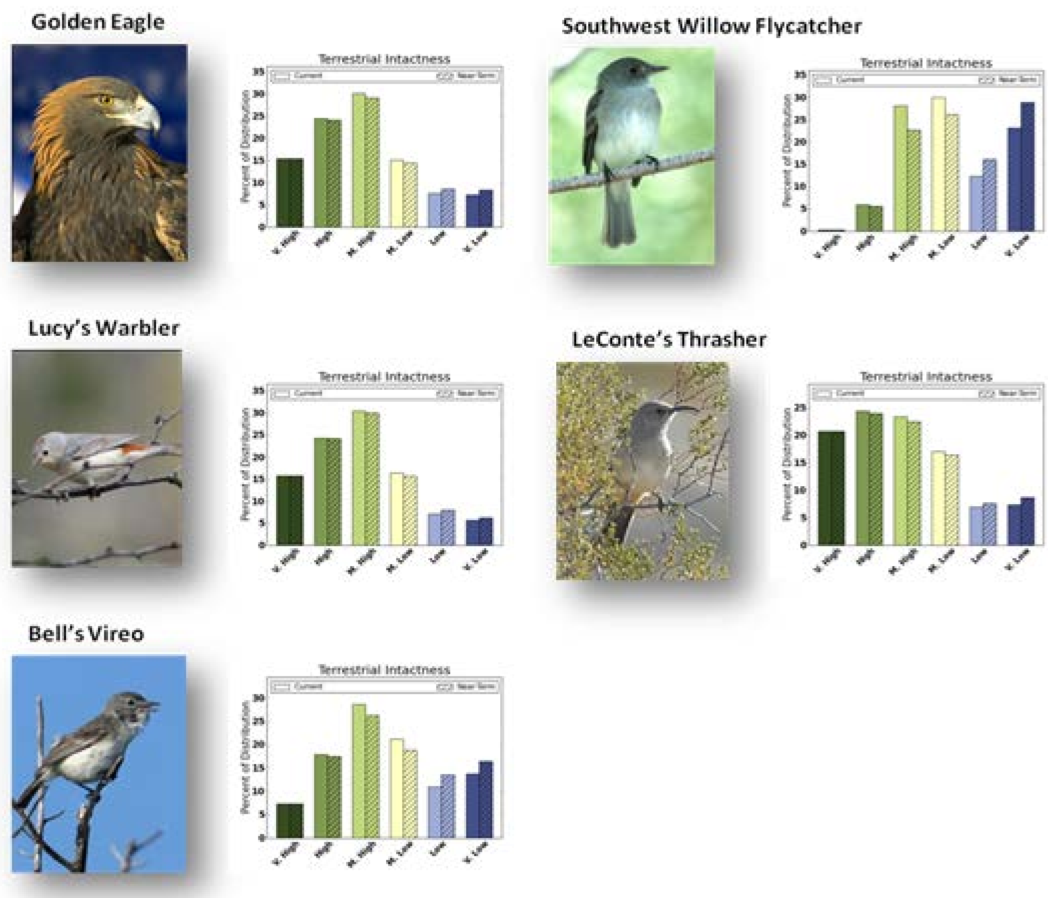
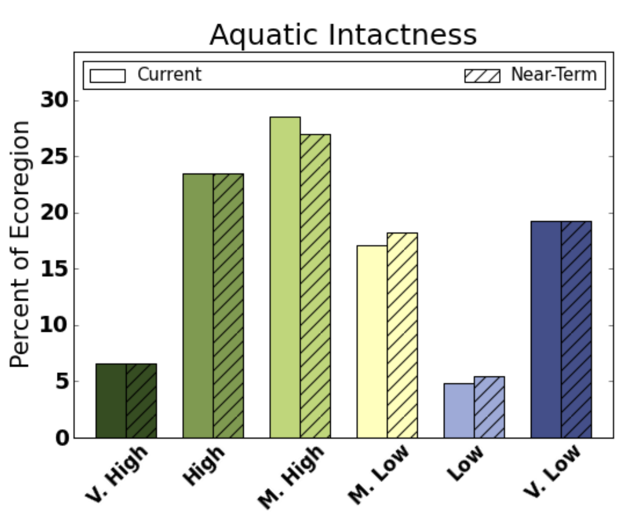


Figure 5-14. Comparison between current (solid) and near-term (crosshatched) future status for birds based on comparison of current distributions with current and near-term future terrestrial intactness.

5.3.2 Near-term Aquatic Intactness for Species Conservation Elements



The only change made in the aquatic intactness model was the addition of new urban areas for the 2025 time frame. No other data were available to populate the model whether it was planned dams and diversion changes, road construction, or chemical discharge and pesticide application changes. All of these elements affect aquatic systems, but there was no mechanism to predict them into the future (Figure 5-15).

Figure 5-15. Histogram shows comparison between current (solid bars) and near-term (crosshatched bars) aquatic intactness.

5.3.3 Near-term Future (2025) Status for Designated Lands

Results for near-term future intactness showed small percentage changes in the status of the existing designated protected lands in the Sonoran Desert ecoregion (Figure 5-16). Most of these changes are from the projected increase in invasive species, although some designated sites are already located near developed areas, some of which are expected to expand over time, further degrading lands around these sites. Information on the predicted near-term change in status for the remaining conservation elements (e.g., biodiversity sites, herd management areas) can be found in Appendix A.

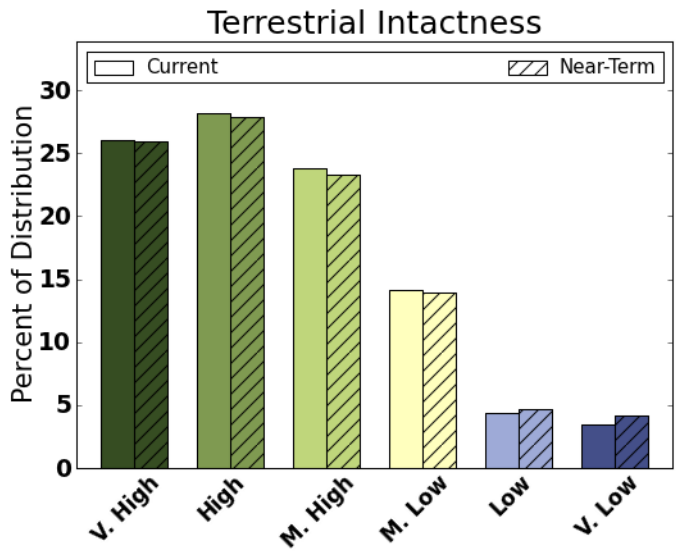


Figure 5-16. Current and near-term future (2025) status of designated lands in the Sonoran Desert ecoregion.

5.3.4 Near-term Future (2025) Status for Vegetation Communities

Near-term terrestrial intactness results showed habitat quality declines reflected as decreases in status for the matrix vegetation communities with the greatest declines observed for Sonoran-Mojave Creosotebush-White Bursage Desert Scrub (Figure 5-17), the vegetation community that is the focus of renewable energy development. Very little change is apparent in the Very High intactness categories for any of the vegetation communities. Overall ecoregion change in the Very High category was just −0.03%. This can be attributed to the fact that, based on the projected data used in the near-term logic model, most of the changes occurred in areas already affected or at the edges of expanding affected areas—in the Phoenix-Tucson corridor and along major highways. One might also assume that a high proportion of the remaining highly-intact areas are already well-protected (see also Figure 5-16). Riparian vegetation status showed some losses of intactness from the moderate categories to Low and Very Low intactness classes. Data were lacking in the model for a number of other potential stressors to riparian zones that are not expressed spatially (such as flow regime change or groundwater withdrawal) or that are evident only at a higher resolution (such as local clearing or riparian fire).

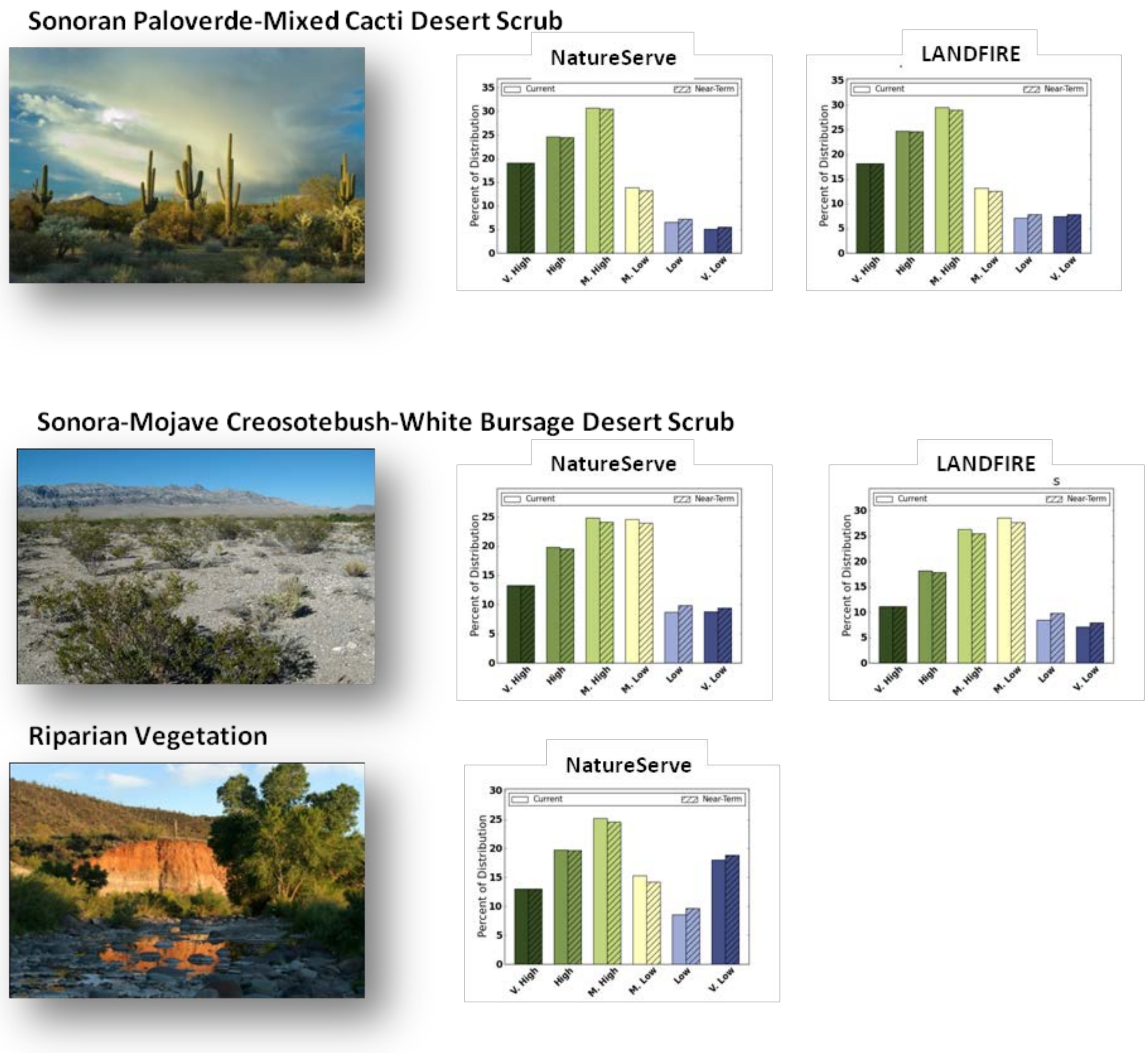


Figure 5-17. Histograms show the comparison between current (solid) and near-term (crosshatched) future status for vegetation communities for both the NatureServe and LANDFIRE landcover classifications for the Sonoran Desert ecoregion.

5.3.5 Application of Results for Near-Term Future Planning

As might be expected with any effort of this size and scope, the assessment raises as many questions as it answers. The REA provides a collection of data that can be queried and tested in innumerable ways. All that is required of the user is an understanding of the relatively coarse resolution of the mapped results and an ability to translate the results between scales, from regional to local. An understanding of the constraints and limitations of data at this scale is also necessary when considering current information as well as the near-term and long-term projections data. As has been noted, there was a general lack of data to populate the future development and intactness models. However, the value in having the logic model is that it provides a clear outline of the elements that must be acquired and inserted to improve the model results.

Several riparian species were selected as core conservation elements for the Sonoran Desert REA because of their importance and sensitivity. However, as discussed earlier, although the HUC and 4 km reporting units are appropriate for regional scale assessment, they are rather coarse for analysis of linear riparian features. On the other hand, riparian habitats are affected by upland disturbances and 4 km grid cells crossing riparian zones indicate nearby terrestrial changes as well as their effects on riparian areas.

An example of the projected future results for a riparian species will highlight the possibilities and problems involved in working with REA data. The results for southwestern willow flycatcher in Section 5.3.1, Near-term Status for Wildlife Species, indicate continued declines in status and potential habitat quality for a species already endangered (Figure 5-18). As presented in Chapter 4, status was determined by an overlay of the terrestrial intactness results with the species' distribution. The hatched bars in the histogram indicate that 12–13% of the species' distribution changed from the High, Moderately High, and Moderately Low categories to Low and Very Low. These changes are large enough to be visible when comparing the current and near-term terrestrial intactness status results for the species in a map detail of the Colorado River from Lake Havasu to Parker Valley in the south (Figure 5-19); the red star is the location of Parker Dam near the confluence of the Bill Williams River, which also contains southwestern flycatcher critical habitat. Portions of grid cells within the bird's distribution change from Moderately High and Moderately Low to Low and Very Low in the two larger polygons in the upper and lower left quadrants of Figure 5-19A and B. One thing that becomes apparent when examining the data that produced these results is that the USFWS critical habitat polygons for southwestern willow flycatcher overlap the watery expanse of Lake Havasu, meaning that part of the 139,000 acres of the species' habitat is over-represented (see caption Figure 5-19). The next question is: What components of the near-term future (2025) intactness model changed to create the change in future status for the species? The elements that changed in the logic model for near-term terrestrial intactness were renewable energy, invasive species, and urban development (pink boxes in Figure 5-8). The maps for near-term renewable energy development and the near-term spread of invasives (not shown) do not indicate any changes in this area near the Colorado River. The near-term (2025) changes come from modeled urban growth (Theobald 2010, Figure 5-20A).

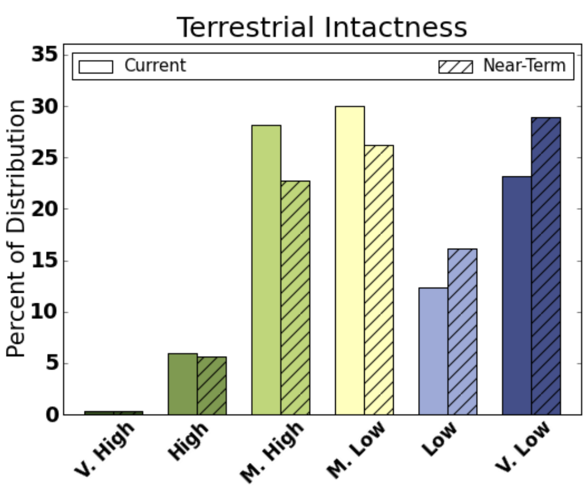
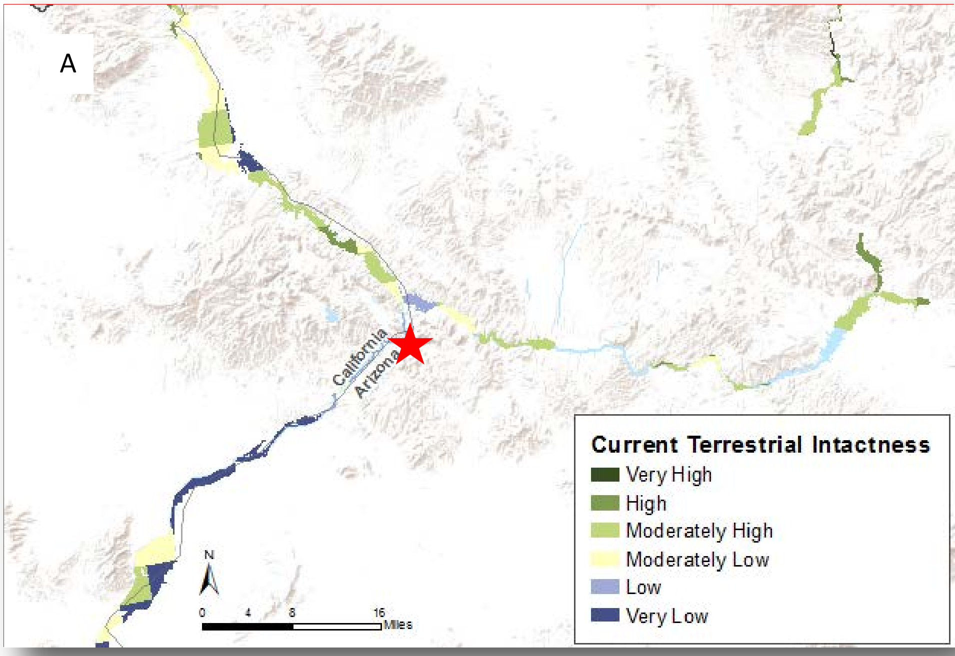


Figure 5-18. Histogram shows the changes in status between current (solid) and near-term future (2025, crosshatched) for southwestern willow flycatcher based on an overlay of current distribution with current and near-term future terrestrial intactness.



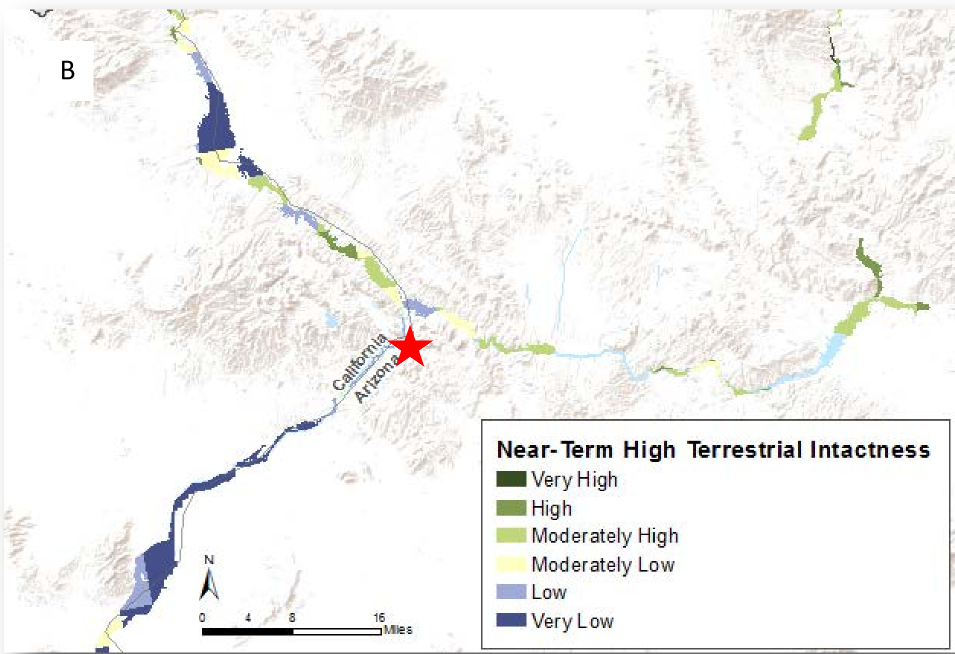


Figure 5-19. Maps comparing the (A) current and (B) near-term future (2025) terrestrial intactness-status results for the southwestern willow flycatcher in a map detail of the Colorado River from Lake Havasu to Parker Valley in the south. The red star is the location of Parker Dam near the confluence of the Bill Williams River, which also contains a significant amount of southwestern flycatcher critical riparian habitat. Changes in terrestrial intactness have occurred in the two larger polygons in the upper left and lower left quadrants of map 5-19B. USFWS critical habitat polygons for southwestern willow flycatcher overlap the watery expanse of Lake Havasu, meaning that a portion (19,300 acres) of the 139,000 acres of the species' habitat is over-represented. Users of the data may choose to use the NatureServe riparian data or remotely-sensed data for a higher-resolution comparison of riparian vegetation in areas of interest.

The modeled changes from urban growth projected for the lower left polygon on the maps (Figure 5-19A and B, Figure 5-20A) do not seem likely in the near term future as the location is an agricultural valley on the Colorado River Indian Reservation. On the other hand, the change in the polygon in the upper left quadrant, from Moderately High to Very Low intactness (Figure 5-19B) is more likely since it reflects projected changes in urban growth in grid cells in the vicinity of Lake Havasu City, Arizona and Havasu Lake, California (Figure 5-20A).

Although it is more speculative, projecting the status of the southwestern willow flycatcher further into the future (such as for maximum long-term energy development and climate change) may be linked in the same way to elements composing the models. As discussed in Section 5.2.1 (Impact of Potential Energy Development on Wildlife Species), according to the model for maximum potential energy development, southwestern willow flycatcher could lose as much as 20,000 acres of critical habitat (which may or may not be occupied) to long-term energy development. Based on the High and Moderate potential shown in the polygon in the lower left quadrant of the maximum potential energy development map (Figure 5-20B), potential losses to southwestern willow flycatcher along this section of the Colorado River appear to be based on the potential development of NREL solar resource areas (Figure 5-3); in this particular polygon, the areas of high potential for development lie on the east side of the Colorado River in agricultural land. It is possible to imagine that it may become profitable (more profitable than farming in the desert) for landowners to lease their property to solar energy firms just as they do now for wind turbines. This same polygon is in the Very High exposure category for long term potential for climate change (2060, not shown).

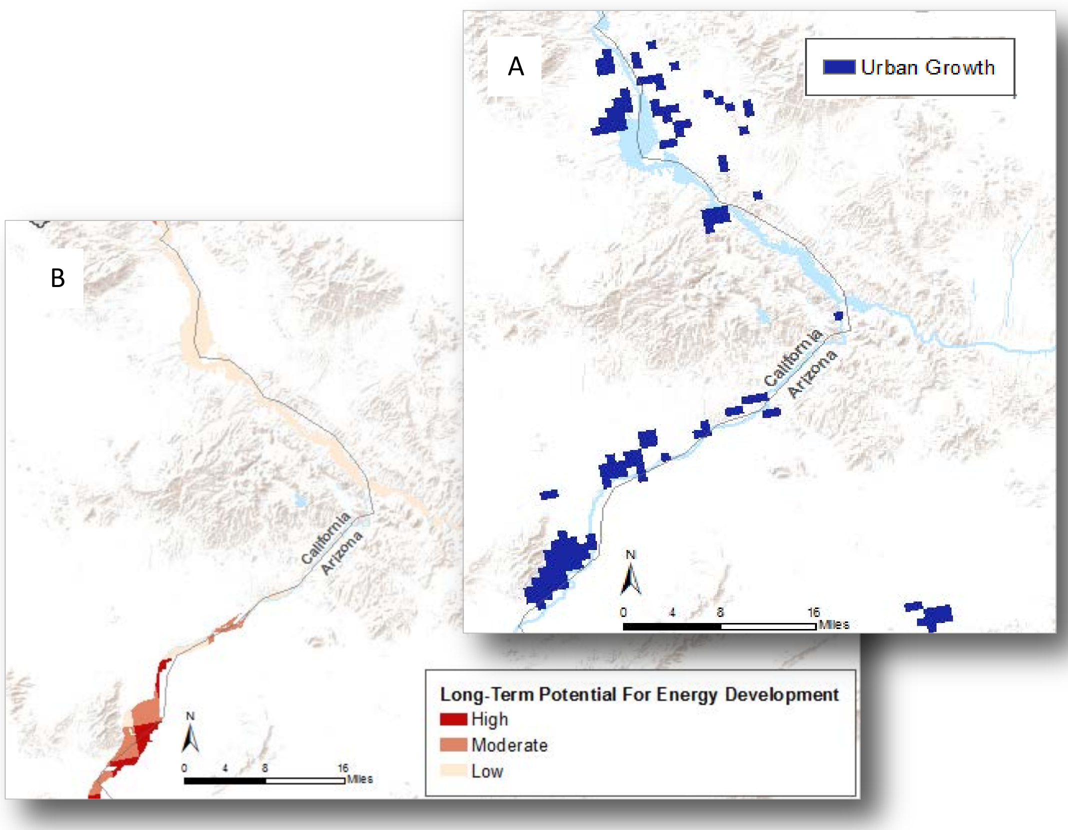


Figure 5-20. Map (A) Source data for modeled near-term future (2025) urban growth (Theobald 2010) showing projected growth pixels in the upper left (near Lake Havasu City) and lower left (Parker Valley). Map (B) Polygon at lower left shows high and moderate potential for change to southwestern willow flycatcher status from long term energy development based on overlap of NREL solar resource potential polygons.

This example shows the utility of examining the data in detail and becoming familiar with the strengths and weaknesses of the models and the underlying data sources. (Relative data quality and confidence in particular model results may be found in Appendix E.) Another important point related to the step-down process is that the models may not translate directly to on-the-ground realities or interpretations of species response. The different classes of intactness suggest corresponding levels of species status or condition, but the classes created for fuzzy logic model results do not have inherent ecological significance. The six intactness categories were selected to be easily understood and symmetrical around 0, so that degrees of "falseness" ranged from 0 to -1 and "trueness" from 0 to +1 (as explained in Section 3.2.3 Logic Models). While future users are free to change these categories, it may be simpler to retain the six intactness classes; the classes will gain ecological significance and meaning as they are calibrated with finer scale data and groundtruthing. With the top-down application of REA results, each user will create a personal crosswalk of meaning among the classes at various scales, both regional and local.

Another timely application of the near-term future results is in the planning, siting, and mitigation of renewable energy projects; renewable energy was an element of the logic model for which there were adequate predictive data in the form of solar and wind potential areas. An example of applying REA data and results to renewable energy planning is presented below for a portion of an NREL polygon and a Solar Energy Zone (SEZ), Riverside East, near Blythe, California. Riverside East contains nearly 148,000 developable acres; several applications had been authorized on 57,000 acres of this SEZ by the end of 2011. On the data portal, REA results for the matrix vegetation communities may be compared with mapped status and distribution for REA species of interest (represented here in Figures 21A and B and Figures 22 A and B) and the overlap noted for various status classes of habitats and species. For example, Figures 21A and B, depicting the SEZ and NREL areas outlined in red, compare the distribution of Le Conte's thrasher (Figure 21A) with one of its major habitats, creosotebush-white bursage (Figure 21B). Two areas of interest (in Very High and High intactness classes) are the three topmost circled dots north of Interstate 10—near a xeroriparian corridor, McCoy Wash—and the two dots on the northwest slopes of the Mule Mountains south of the interstate. (Note: the white area on the vegetation map near the third dot in the north is a playa likely to have some saltbush vegetation, which also supports Le Conte's thrasher). The fact that the distribution of Le Conte's thrasher is likely highly over-represented does not invalidate this analysis. Any of the REA species data may be over-, under-, or mis-represented; the species data are composed of generalized range maps, (largely un-validated) SW ReGAP models, or mapped expert judgment information based on field experience. REA data will have to be validated as it is used. Also, potential habitat may or may not be occupied, but unfragmented blocks of habitat (and any amount of xeroriparian habitat) have future value whether presently occupied or not, particularly for species with large area needs such as Le Conte's thrasher and desert tortoise. In addition, it is standard practice to survey potential development areas for species of concern, meaning that land managers are not likely to rely on generalized mapped data without field surveys.

Continuing the renewable energy analysis with desert tortoise potential habitat (Figure 22A), any of the dots pictured inside or outside of mapped potential habitat appear to be in areas that may support desert tortoise (Chuckwalla Valley). Again, comparison of REA results with finer scale data is necessary. There is congruence of Very High and High modeled tortoise habitat with the previously-noted areas of interest for Le Conte's thrasher near McCoy Wash and the northwest slopes of the Mule Mountains. For desert bighorn sheep (that appear to be absent from the entire SEZ area, Figure 22B), the obvious question to ask is why are there no bighorn sheep in the Big Maria and Little Maria Mountains? Are the Marias candidates for desert bighorn relocation? Could this area serve as a corridor for bighorn sheep movement from the south and southeast or is the interstate highway an impossible barrier to mitigate?

The test of the REA model results will be in their ultimate utility; the classes will gain ecological significance and meaning as they are applied and tied to local information. Higher resolution data and analyses may modify the results locally, but REA results will remain valid at the regional scale at which they were produced.

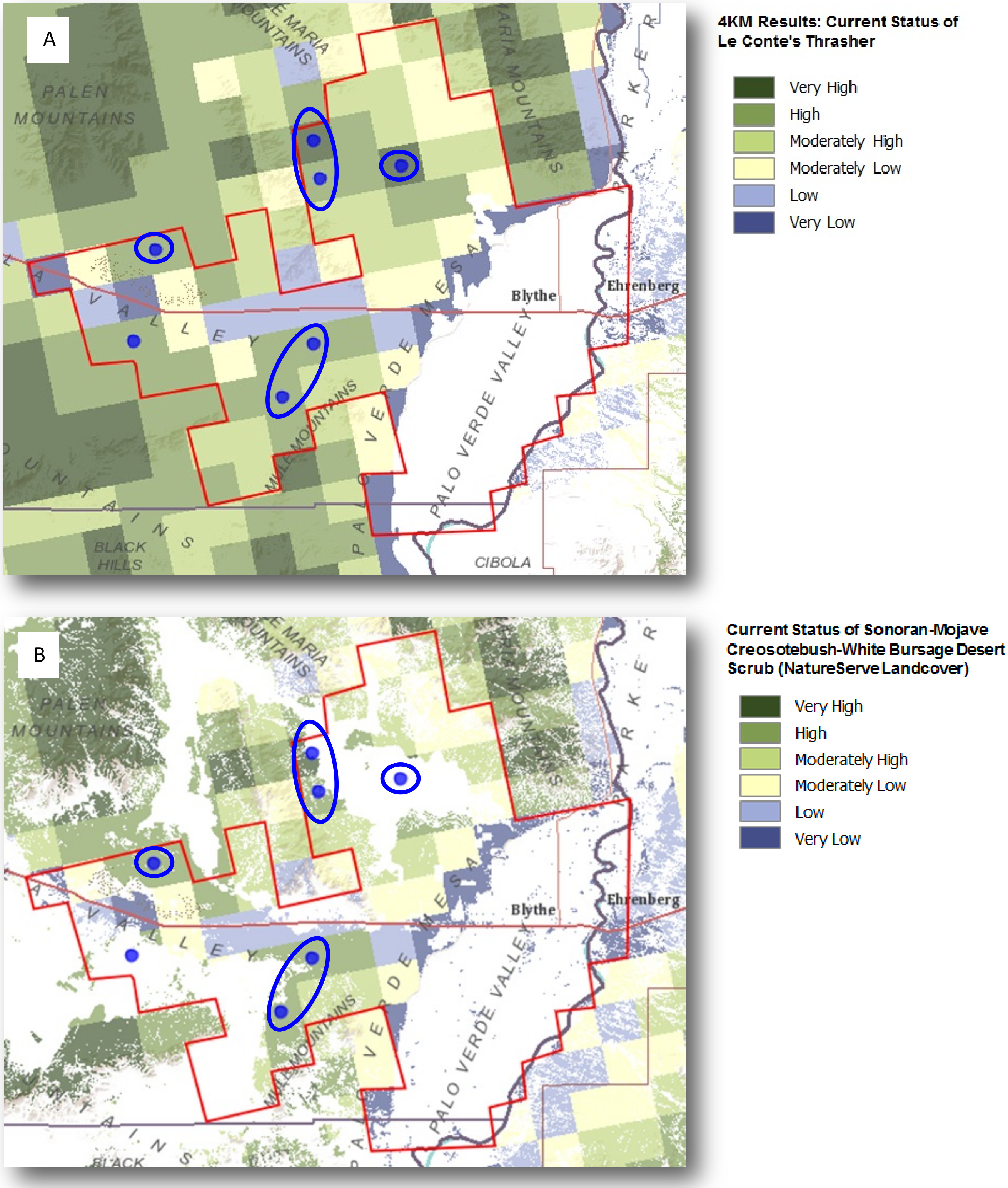


Figure 5-21. Maps depict a Solar Energy Zone (SEZ) and NREL polygon outlined in red and compare (A) distribution and status of Le Conte's thrasher with (B) distribution and status of one of the thrasher's major habitats, creosotebush-white bursage, with circled common areas of interest (dots) in royal blue.

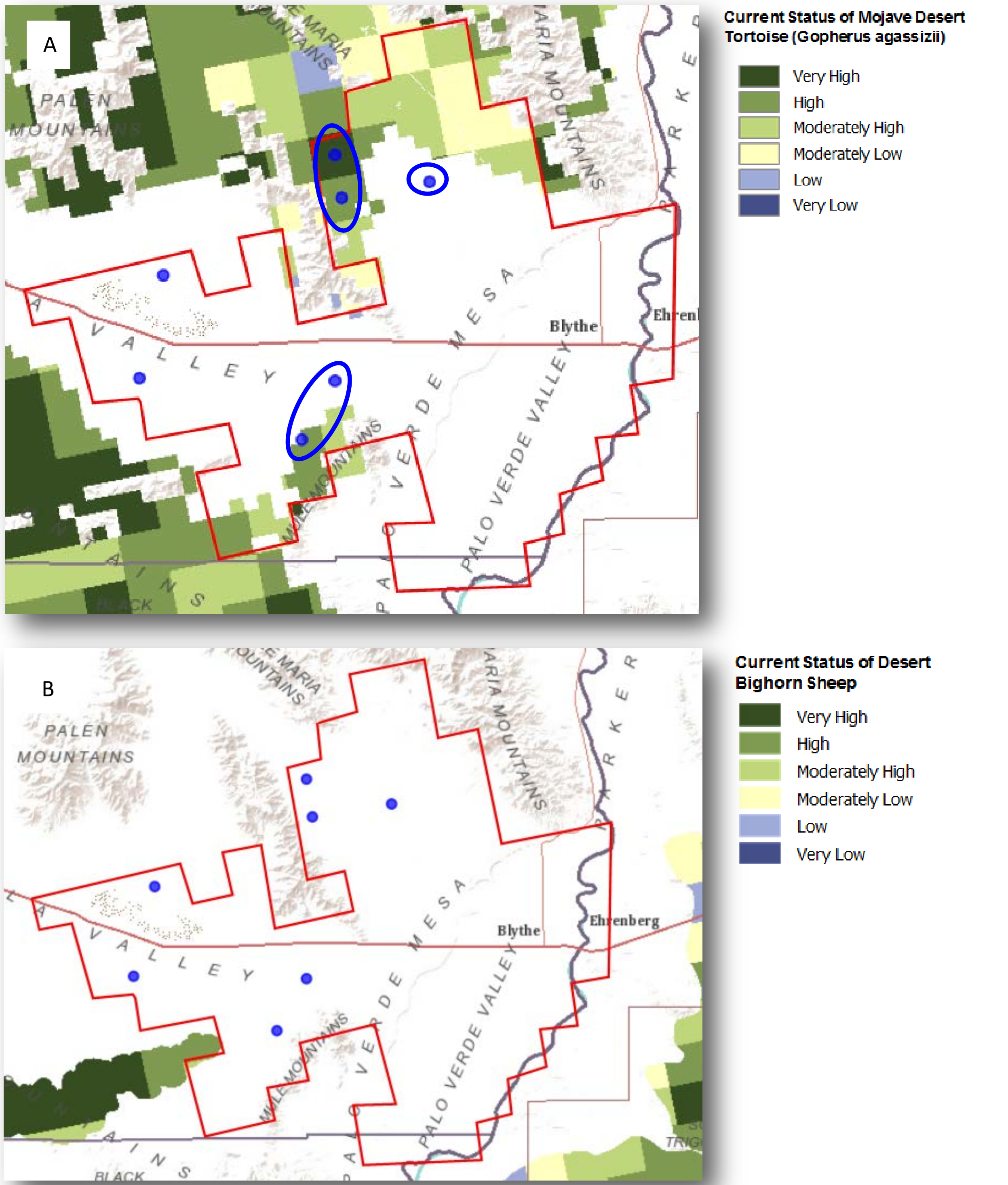


Figure 5-22. Maps compare (A) the distribution and status of the Mojave desert tortoise (*Gopherus agassizii*) with that of (B) desert bighorn sheep in a Solar Energy Zone (SEZ) near Blythe, California (boundary in red). Areas of interest and congruence with other REA species and habitats in Very High and High intactness classes are depicted as circled dots in royal blue.

5.4 Climate Change

Climate Change Management Questions

1. Where/how will the distribution of dominant native plants be vulnerable to or have potential to change from climate change in 2060?
2. Where are areas of potential species conservation element distribution change between 2010 and 2060?
3. Where are aquatic/riparian areas with potential to change from climate change?
4. Where are areas of potential surface water flow change?

Climate change results for the Sonoran Desert ecoregion are extensive and complex. This chapter focuses on answering management questions 1 and 2 (in box at left); answers to management questions 3 and 4 are available to view in Appendix A. This chapter presents climate projections for the Sonoran Desert, MAPSS results for projected vegetation change linked to the climate projections, and climate change exposure and vulnerability results for the REA conservation elements. Although three different future climate projections were investigated, only the ECHAM5-driven RegCM3 climate projections were selected to evaluate potential impact on the various conservation elements. ECHAM5 is the fifth generation of the ECHAM Global Circulation Model (GCM) developed at the Max Planck Institute (Hamburg, Germany) and it has been identified as one of the better models to simulate natural climate variability (Mote et al. 2010, Garfin et al. 2010). The GCM-driven RegCM3 regional climate model projections were provided by S. Hostetler (U.S. Geological Survey) as representative of the North American Monsoon (Hostetler et al. 2011), which is important to Sonoran Desert vegetation dynamics.

5.4.1 Climate Projections

As explained in detail in Chapter 3, Methodology, the climate model data provided by Hostetler were averaged for two time periods (2015–2030 and 2045–2060), but only data from the 2045–2060 time period were used to evaluate the conservation elements, which are presented later in this section. For both temperature and precipitation results, water bodies were left as holes in the MAPSS model runs since no vegetation can be simulated over water. Climate projections surrounding water bodies are also considered less reliable because they create local moisture and turbulence conditions unrepresentative of the surrounding landscape, especially in semiarid areas.

Differences in temperature projections—average annual temperature (Figure 5-23), seasonal summer temperature (July–September; Figure 5-24), and winter temperature (January–March; Figure 5-25)—were calculated between historical (1968–1999) and future time periods (2015–2030 and 2045–2060) as simulated by the ECHAM5-driven RegCM3 model. Results show that the ecoregion is expected to undergo general warming over the entire region with a > 2° Celsius increase by 2060 in some locations, particularly in the southwestern portion of the ecoregion. Average summer temperatures are expected to increase, but greater increases are projected to occur during the winter months. This temperature increase is somewhat less than another recent projected modeled increase of 2.5°–3.0° Celsius for the region by Abatzoglou et al. (2011), who used an ensemble of 13 GCMs; these authors also projected an increase in the number of frost-free days and an increase in the length of the frost-free season.

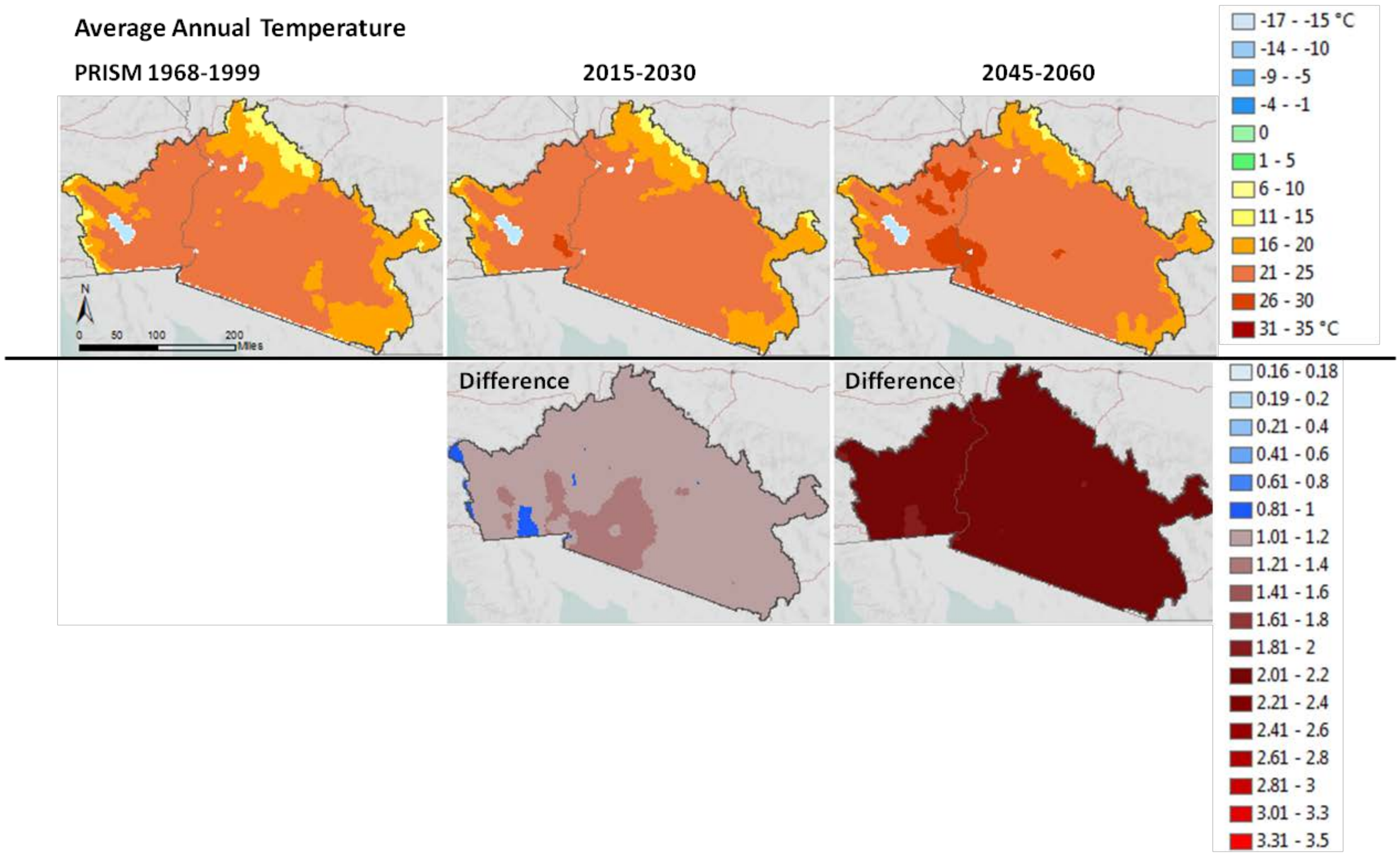


Figure 5-23. Map results for change in raw average annual temperature. Top Row: 1) Observed average annual temperature from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion.; 2-3) Bias-corrected future temperature using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1) and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average annual temperature. All colors on the difference maps are warmer than historic. Note: Bias correction was applied to the climate model results for more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the differences between future and historical temperature values simulated by RegCM3 (bottom row) and adding them to the historical PRISM baseline (top row).

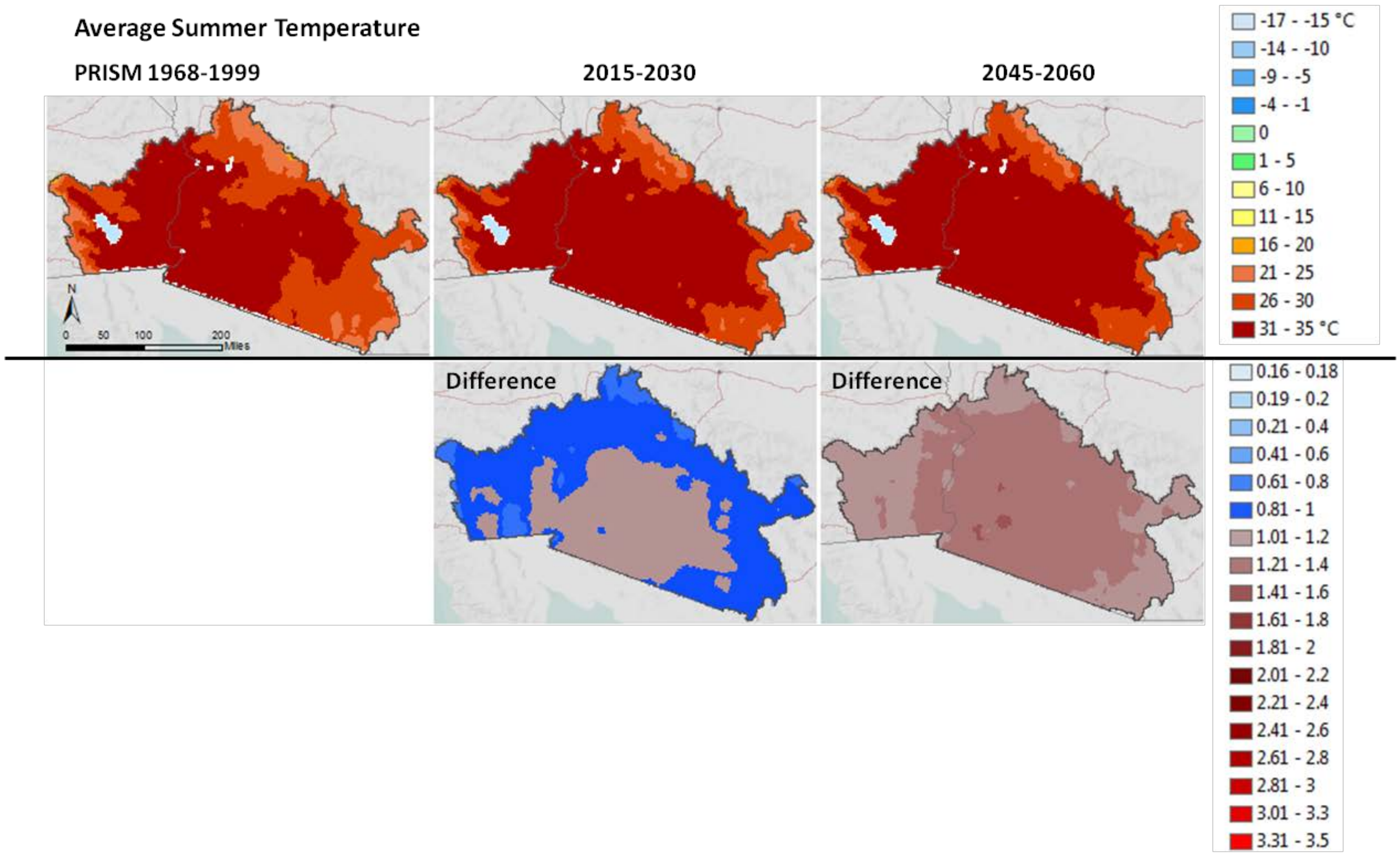


Figure 5-24. Map results for change in raw average summer temperature. Top Row: 1) Observed average summer (July–September) temperature from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion.; 2-3) Bias-corrected future summer temperature using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1), and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average summer temperature. All colors on the difference maps are warmer than historic. Note: Bias correction was applied to the climate model results for more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the differences between future and historical temperature values simulated by RegCM3 (bottom row) and adding them to the historical PRISM baseline (top row).

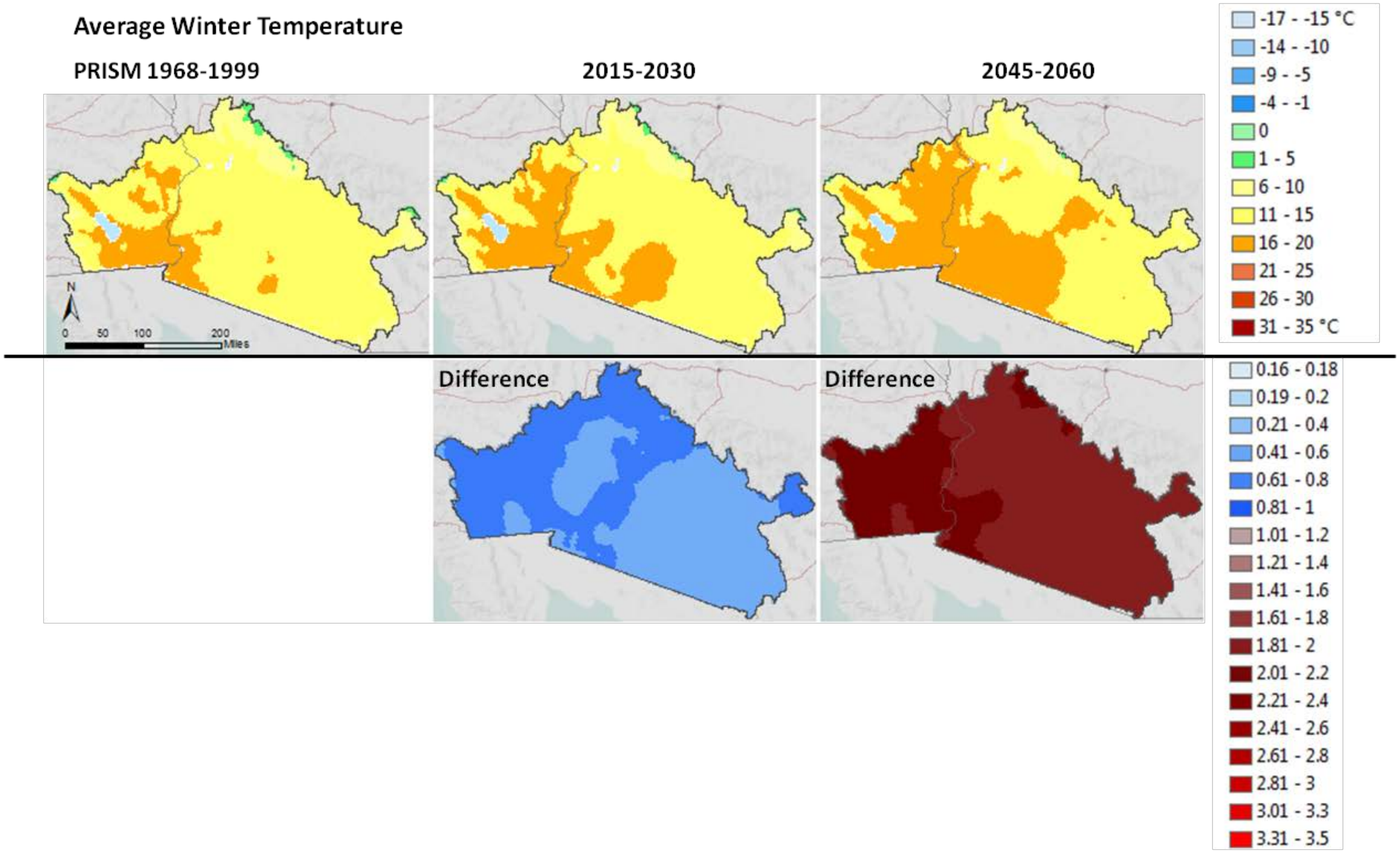
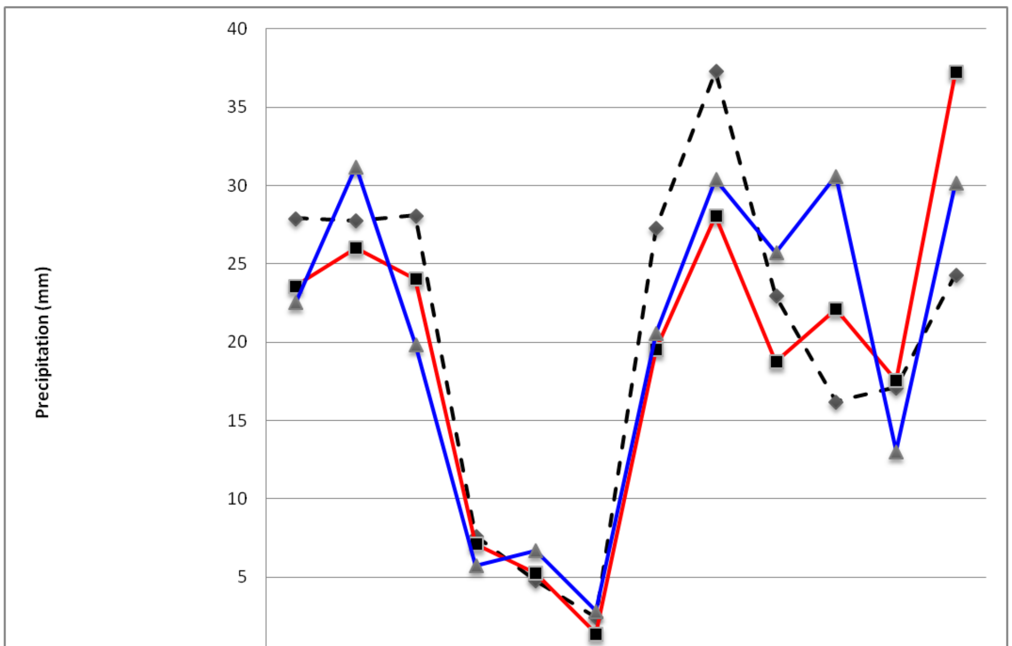


Figure 5-25. Map results for change in raw average winter temperature. Top Row: 1) Observed average winter (January–March) temperature from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion; 2-3) Bias-corrected future winter temperature using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1), and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average winter temperature. All colors on the difference maps are warmer than historic. Note: Bias correction was applied to the climate model results for more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the differences between future and historical temperature values simulated by RegCM3 (bottom row) and adding them to the historical PRISM baseline (top row).

It is generally accepted that climate models are less reliable in simulating precipitation than temperature because of field recording difficulties, scarcity of observations, large uncertainty in cloud generation, creating difficulties in model calibration. RegCM3 projections show significant declines in annual precipitation during the first time period with severe drought occurring in some areas (Graph, Figure 5-26, and Figure 5-27). Over the 2045–2060 timeframe, precipitation is projected to slightly increase over historical levels in parts of the eastern portion of the ecoregion, particularly during the fall (Oct–Dec). In contrast, Abatzoglou et al. (2011) predicted 20% drier conditions in November–March at mid-century (Abatzoglou et al 2011). The western region may remain drier than the historical period but not as dry as during the 2015–2030 time window.

Average summer precipitation (Figure 5-28) showed slightly more spatial variability than winter precipitation (Figure 5-29), especially during the 2045–2060 timeframe, even though both seasons tended to forecast drier conditions overall. Seager et al. (2007), using the ensemble mean of 19 GCMs (from the Intergovernmental Panel on Climate Change Assessment), looked at the difference between projected precipitation and evaporation in the Southwest region and warned of future droughts more intense than those recorded during the Dust Bowl of the 1930s and in the U.S. later during the 1950s. The degree of spatial and seasonal variation remains large, even when considering multi-model means. Historical records of precipitation show large natural variability and sensitivity to circulation patterns based on sea-surface temperature (e.g., El Niño Southern Oscillation). Such natural climate variability and its impacts have been well documented, but the understanding of the causes of shifts in circulation remains limited and thus difficult to include in climate models. With continuing natural variability in precipitation patterns, future patterns of change will be complex. However, there is general agreement that precipitation will decrease over much of the subtropics. In all of these systems, cloud formation and wind patterns are areas of uncertainty in model structure.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PRISM	27.91	27.76	28.09	7.64	4.79	2.43	27.31	37.31	22.96	16.21	17.11	24.3
ECHAM5 2015-2030	23.59	26.03	24.03	7.12	5.26	1.39	19.57	28.06	18.77	22.11	17.55	37.24
ECHAM5 2045-2060	22.53	31.21	19.87	5.73	6.7	2.83	20.59	30.4	25.73	30.61	13.03	30.17

Figure 5-26. Monthly precipitation for historical conditions (PRISM historical precipitation averaged over the 1968–1999 time period) and for two future time periods (monthly precipitation averaged over the 2015–2013 and the 2045–2060 time period) simulated by the RegCM3 regional climate model with ECHAM5 boundary.

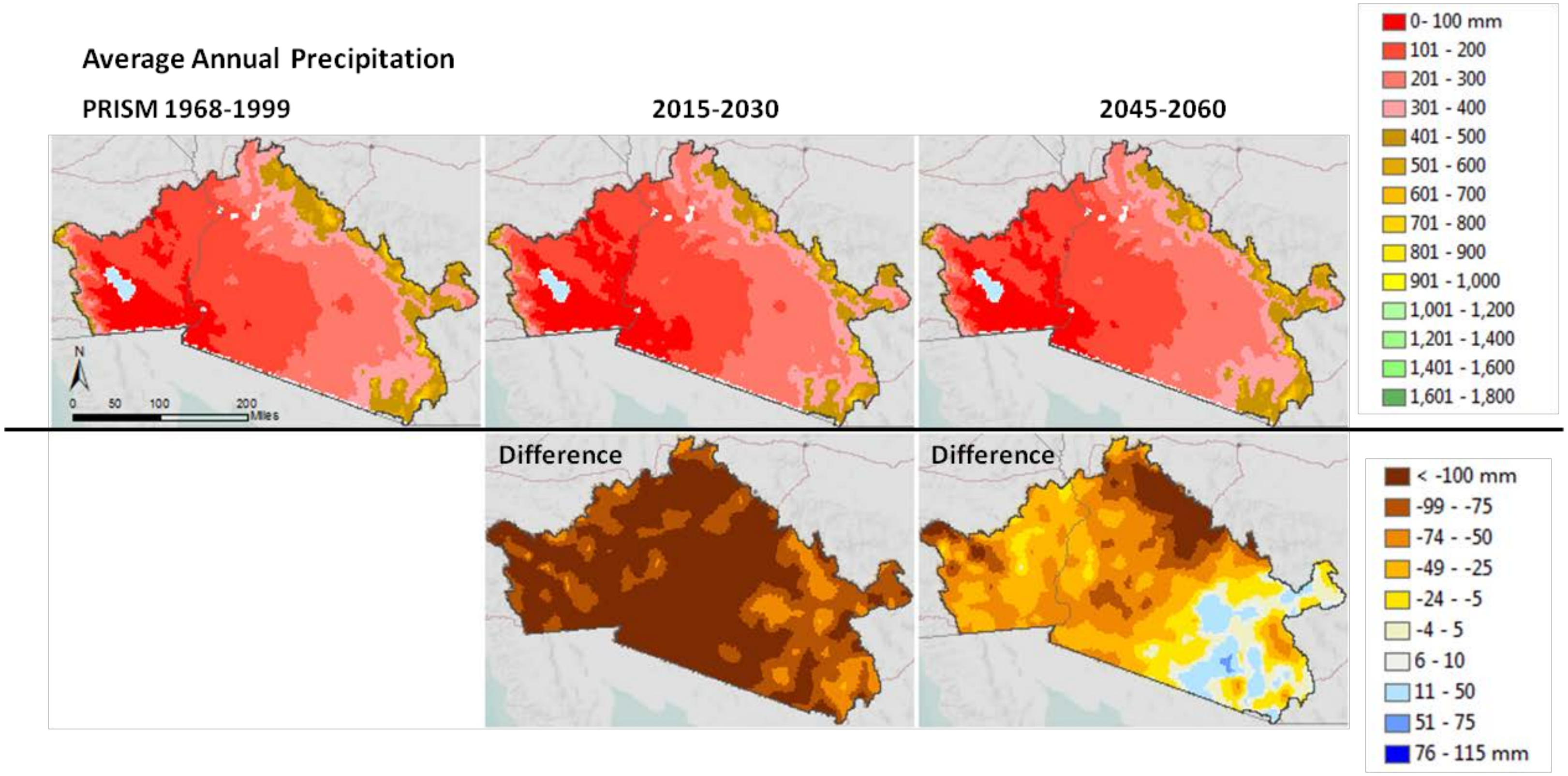


Figure 5-27. Map results for change in average annual precipitation. Top Row: 1) Observed average annual precipitation from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion.; 2-3) Bias-corrected future precipitation using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1), and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average annual precipitation. For the difference maps, brown color tones represent drier conditions and blue colors represent wetter conditions. Note: There was a large bias in the RegCM3 simulations of historical precipitation for this region. Consequently, the climate model results were bias-corrected to provide more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the ratios between future and historical precipitation values simulated by RegCM3 and multiplying them by the historical PRISM baseline.

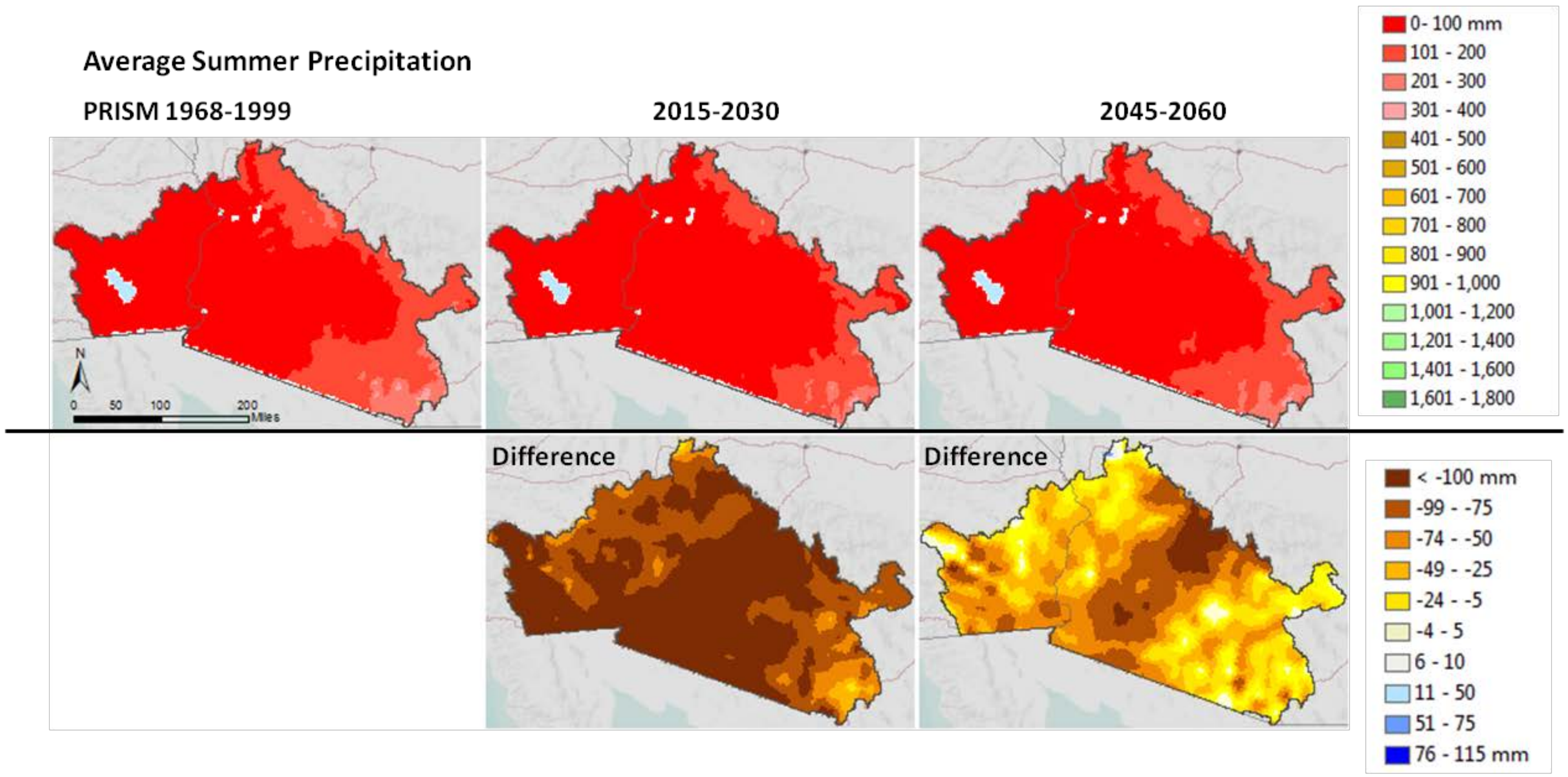


Figure 5-28. Map results for change in average annual summer precipitation. Top Row: 1) Observed summer precipitation (July–September) from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion.; 2-3) Bias-corrected future precipitation using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1), and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average summer precipitation. In difference maps, brown colors represent drier conditions and blue colors represent wetter conditions. Note: There was a large bias in the RegCM3 simulations of historical precipitation for this region. Consequently, the climate model results were bias corrected to provide more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the ratios between future and historical precipitation values simulated by RegCM3 and multiplying them by the historical PRISM baseline.

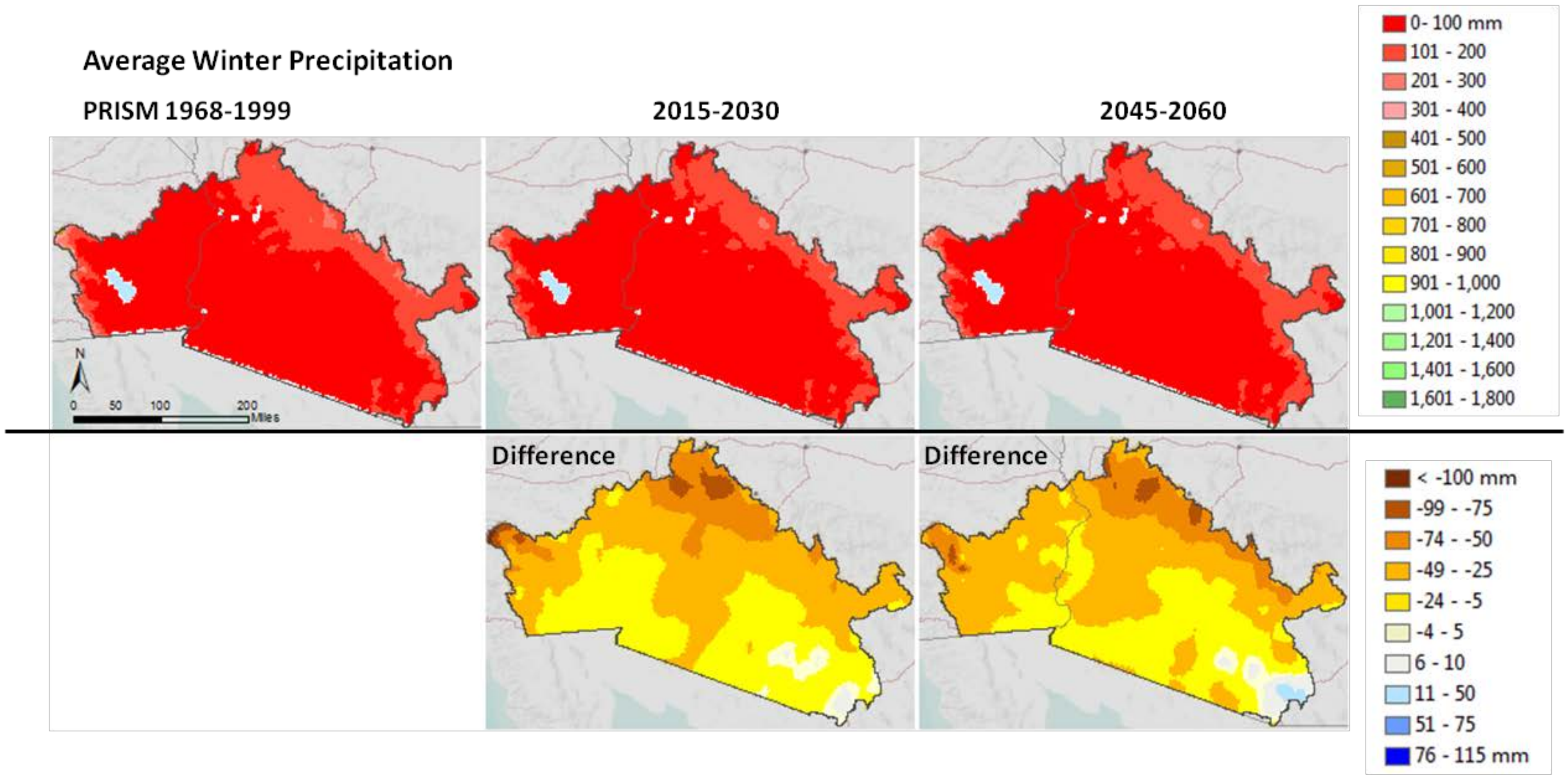


Figure 5-29. Map results for change in average annual winter precipitation. Top Row: 1) Observed winter precipitation (January–March) from PRISM averaged over the historical period (1968–1999 baseline) for the Sonoran Desert ecoregion.; 2-3) Bias-corrected future precipitation using the ECHAM5-driven RegCM3 regional climate model deltas modifying the PRISM baseline (1), and averaged for two future time periods. Bottom row: Simulated ECHAM5-driven RegCM3 regional climate model differences between historical (1968–1999) and future (2015–2030; 2045–2060) average winter precipitation. For the difference maps, brown color tones represent drier conditions and blue colors represent wetter conditions. Note: There was a large bias in the RegCM3 simulations of historical precipitation for this region. Consequently, the climate model results were bias corrected to provide more realistic climate input to the vegetation model. Future climate projections (top row 2-3) were generated by calculating the ratios between future and historical precipitation values simulated by RegCM3 and multiplying them by the historical PRISM baseline.

5.4.1.1 MAPSS Modeling Results

Four different MAPSS model variables (see Chapter 3 Methods) were provided for the REA—Leaf Area Index (LAI), Potential Evapotranspiration, Runoff, and Change in Vegetation cover. Simulated LAI slightly declined overall in most areas, suggesting a decline in water availability caused canopy thinning and/or a shift to sparser, more drought-resistant vegetation. Because the biogeography model (MAPSS) relies on fixed LAI thresholds to determine vegetation types, some shifts in vegetation cover were simulated (Figure 5-30). Only a few areas at higher elevations (where current vegetation is limited by low temperatures and not by water availability) displayed small increases in LAI (light grey-green pixels on the difference maps). An increase in Potential Evapotranspiration (PET) confirmed an overall drying trend concurrent with a decline in plant growth over most of the ecoregion (green areas on the map). Only at higher elevations are there signs of increased productivity where cooler temperatures reduce the drying effect (Figure 5-31). Surface runoff showed a slight increase over the near term—with less vegetation and as the soil surface became drier and less permeable to rainfall—and a slight decrease over the 2045–2060 time frame as more moisture penetrated the soil profile (Figure 5-32). Mountainous areas in the eastern portion of the ecoregion showed the greatest decline in runoff indicating a greater use of available water as temperatures rise.

One of the main projections from the MAPSS model is a potential shift in major vegetation types through time based on changes in plant functional groups. MAPSS uses the historical climate baseline (generated by the PRISM model) to predict the types of vegetation that would be supported under the given set of climate and soil conditions without human influence (see Chapter 3, Methods, Climate Modeling for more details). MAPSS does not take into account human management of natural landscapes or its long term legacy (e.g. water management, logging, grazing, etc.). It only uses climate and soil data to simulate potential vegetation cover. With a long history of human use in the ecoregion, the MAPSS historical simulation should not be expected to reflect exactly what is on the ground today.

Considerable change in vegetation is predicted between 1968–1999 and 2045–2060 (Table 5-3 and Figures 5-33 and 5-34). Since the MAPSS model is a static biogeography model, it is run independently for each of the two time periods. Therefore, results for an earlier period do not affect the outcome of a later run. Normally, any dry or wet periods have repercussions on the following year's vegetation response. In this case, the static vegetation model just simulates what potential vegetation the average climate can support during the period of interest.

Potential vegetation change simulated by the MAPSS biogeography model represents broad (global) vegetation classes based on climate and soil conditions (Figure 5-33 and 5-34). Three broad vegetation classes are depicted for the Sonoran Desert in the PRISM historical baseline time period: 1) desert subtropical in the Colorado Desert (western portion), 2) C_4 grasses in the eastern Sonoran Desert ecoregion, and 3) shrubland subtropical xeromorphic in the higher elevation areas surrounding the ecoregion (Figure 5-33, Table 5-3). Projections of change in these classes do not necessarily mean the identified potential vegetation type will establish during the time period of interest, only that the climate during that period is estimated to be suitable for the growth of that type. The projections may also indicate trends where vegetation mortality may occur if plants show no acclimation or adaptation potential. Some important regional vegetation classes, such as cacti in the Sonoran Desert, are not represented at all in the model because they photosynthesize in a different way from other plants (by utilizing CAM [or crassulacean acid metabolism] in photosynthesis). Many other factors not represented in the MAPSS model will affect future vegetation type such as fire, invasive species, dispersal ability, or recruitment.

The model projections show very dry annual and summer conditions during the 2020s, and slightly wetter conditions around 2050 (although still drier than historic mean). Winter precipitation increases slightly over both time periods. Winter and warm season rainfall influence germination and distribution of many Sonoran Desert plant species. With warmer, somewhat drier conditions, desert subtropical vegetation, such as creosotebush-white bursage in the Colorado Desert of California and southwestern Arizona, is projected to expand in the 2015–2030 time period, but then recede in 2045–2060 replaced by an expansion of semi-desert C_4 grasses (see Glossary). Even this drought resistant community has limits. Creosotebush is susceptible to prolonged drought and its distribution is correlated with winter precipitation (Marshall 1995, Munson et al. 2011). Munson et al. (2011), in a study of the effects of climate variability on Sonoran Desert vegetation communities over the last century, found that the cover of creosotebush decreased with increased aridity and a decrease in winter precipitation (below 135 mm). They also noted that in years with high temperatures the cover of foothills paloverde and ocotillo decreased and cacti increased in the Arizona Upland. Recent drought in the early 2000s also caused nearly complete mortality of white bursage and other subshrubs in the California portion of the Sonoran and Mojave Deserts (McAuliffe et al 2010).

The interpretation of the projected expansion of C_4 grasses is more complex. C_3C_4 dominance is a function of the inter-relationship of seasonal precipitation, growing season temperature, and atmospheric CO_2 levels (Ehleringer 2005). C_3 grasses (which include native grasses as well as invasive species such as red brome) dominate in a region where summers are dry and most precipitation falls in winter and early spring (such as in the Mojave Desert and western Sonoran Desert), but areas with summer precipitation (like the eastern Sonoran Desert) favor C_4 grasses (Ehleringer 2005). Projected temperature increases with climate change are predicted to favor warm-season C_4 grasses (Ehleringer et al. 1997, Morgan et al. 2011). Cool season C_3 grasses are expected to benefit from rising CO_2 levels (Ehleringer et al. 1997, Morgan et al. 2011), if reduced winter precipitation does not lead to a decline in their distribution (Ehleringer 2005). On the other hand, increasing CO_2 is expected to have a fertilizing effect and to increase water use efficiency, which may offset the possible declines in C_3 grasses from reduced winter precipitation (Morgan et al. 2011).

Besides the changes in the distribution of grasses, the MAPSS results project an increase in shrub savanna subtropical mixed vegetation (Table 5-3), represented by mesquite savanna and juniper-oak savanna found in the transition to higher elevation ecoregions surrounding the Sonoran Desert. Chaparral, also found in these transitional ecotones (both maritime and interior) and on some interior mountain ranges, shows no change in the model results (shrubland subtropical Mediterranean, Table 5-3). Eight other vegetation types, in addition to desert subtropical vegetation mentioned earlier, declined in area by 2045–2060 (Table 5-3).

Other investigators have found warming trends in winter and spring, decreased frequency of freezing temperatures, lengthening of the frost free season and increased minimum temperatures in the Sonoran Desert (Abatzoglou et al. 2011). With warming expected to continue at faster rates throughout the 21st century along with a possible decline in the summer monsoon, biotic interactions and competition between shallow- and deep-rooted species, photosynthetically heat-adapted species, and invasive grasses will drive the reconfiguration of what is currently known as the Sonoran Desert. Potential ecological responses may include increased incidence of fire, expansion of invasive species, loss of woody plant cover, and changes in the regional boundaries of the Sonoran Desert ecoregion. The ecoregion may contract in the south-east and expand northward, eastward, and upward in elevation. The distributions of characteristic plant species within Sonoran Desert ecosystems may also change, including a possible decrease in the iconic giant saguaro (Weis and Overpeck 2005, Ryan and Archer 2008).

In summary, land managers should begin to prepare for changes in the known ecoregions, shifts in vegetation composition, diversity and growth, losses in net primary production, intensification of the hydrologic cycle (more intense runoff), reduced streamflow and native fish diversity, increased soil erosion, increases in nonnative species, and increased frequency and intensity of fire (Archer and Predick 2008).

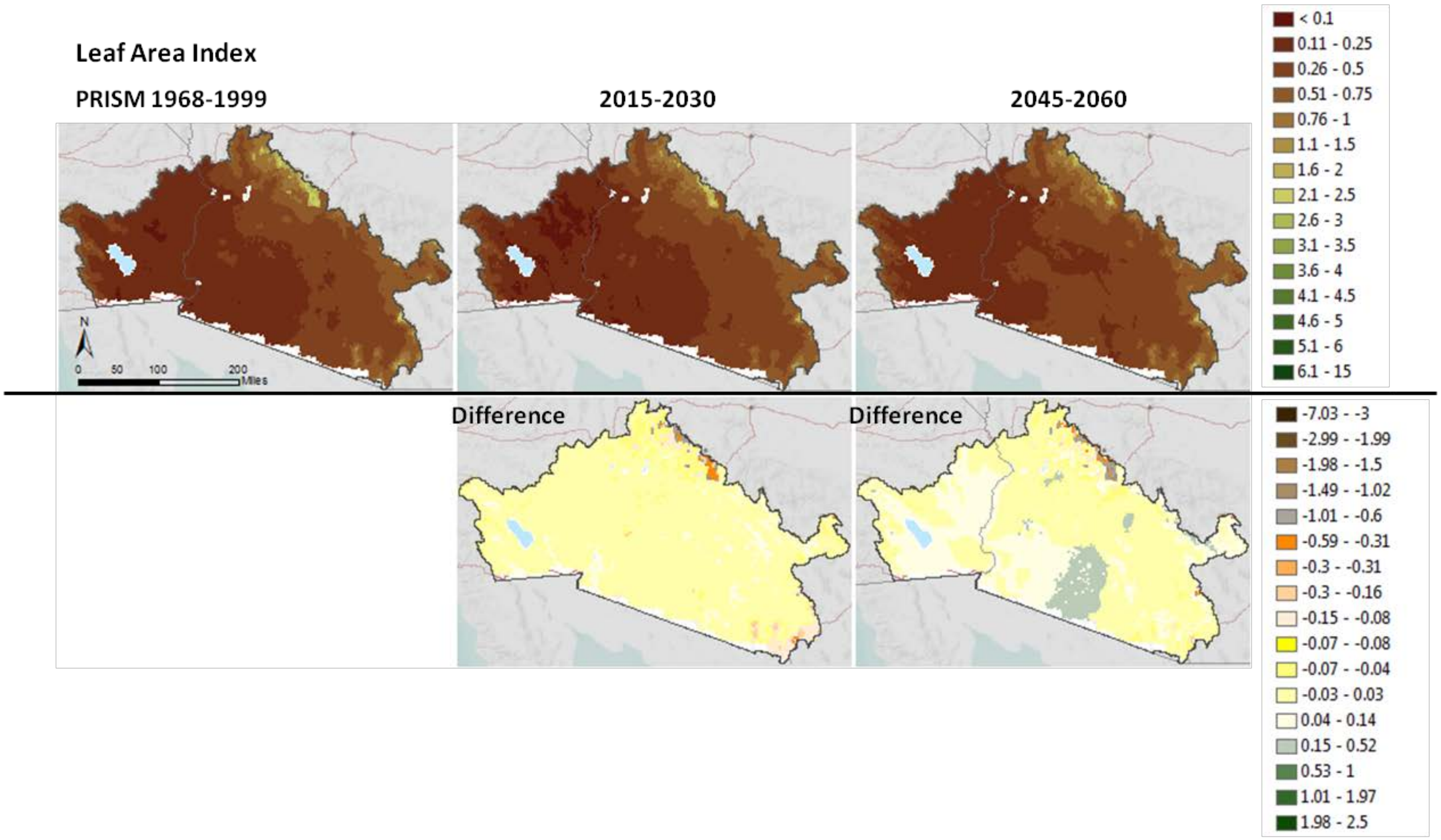


Figure 5-30. Leaf Area Index (LAI) simulated by the static biogeography MAPSS model for the Sonoran Desert ecoregion for historical and future (2015–2030 and 2045–2060) time periods. The top row shows LAI values and the bottom row differences between historical and future projections.

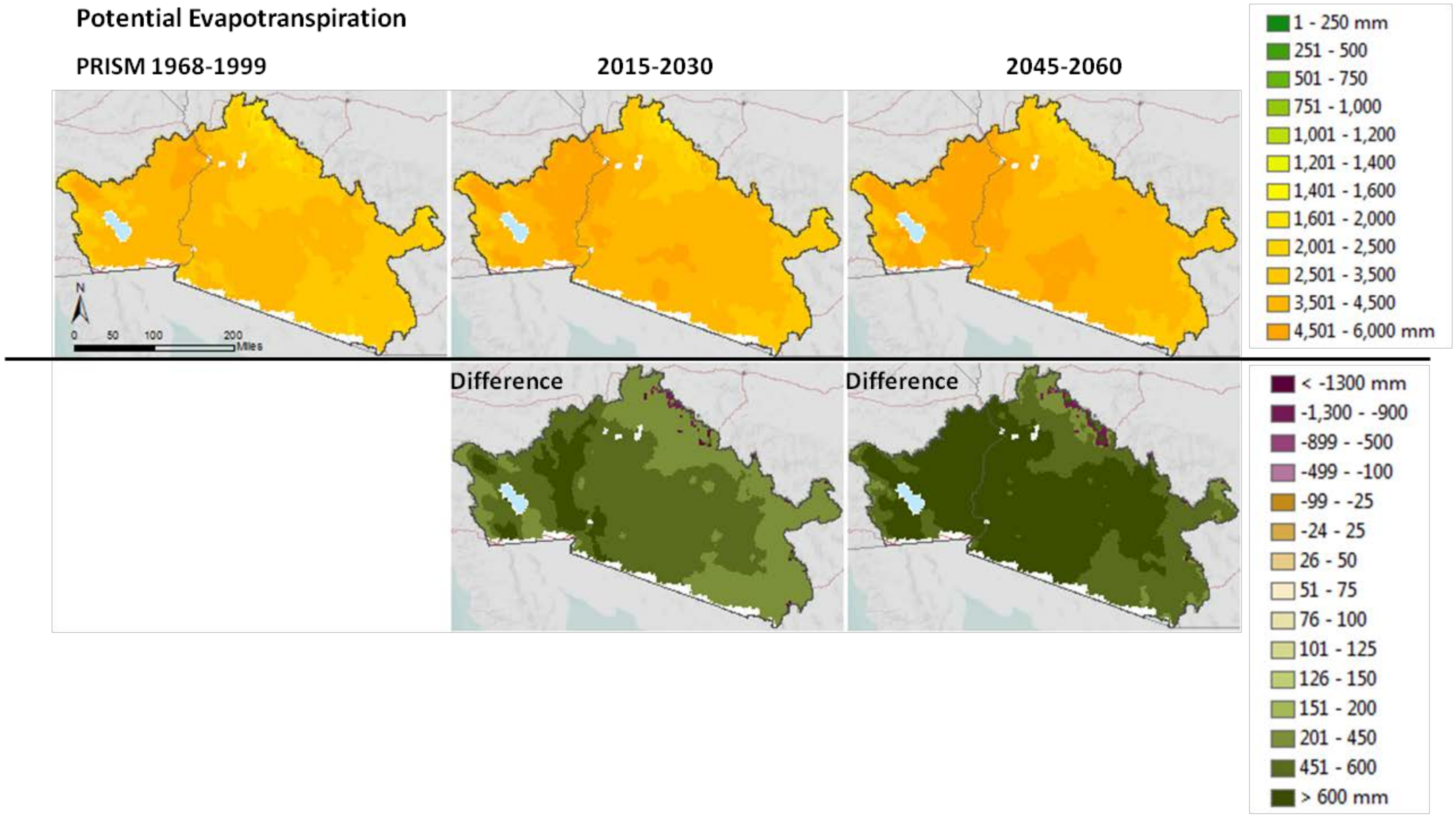


Figure 5-31. Potential evapotranspiration (PET) simulated by the static biogeography MAPSS model for the Sonoran Desert ecoregion for historical and future (2015–2030 and 2045–2060) time periods. The top row shows LAI values and the bottom row differences between historical and future projections.

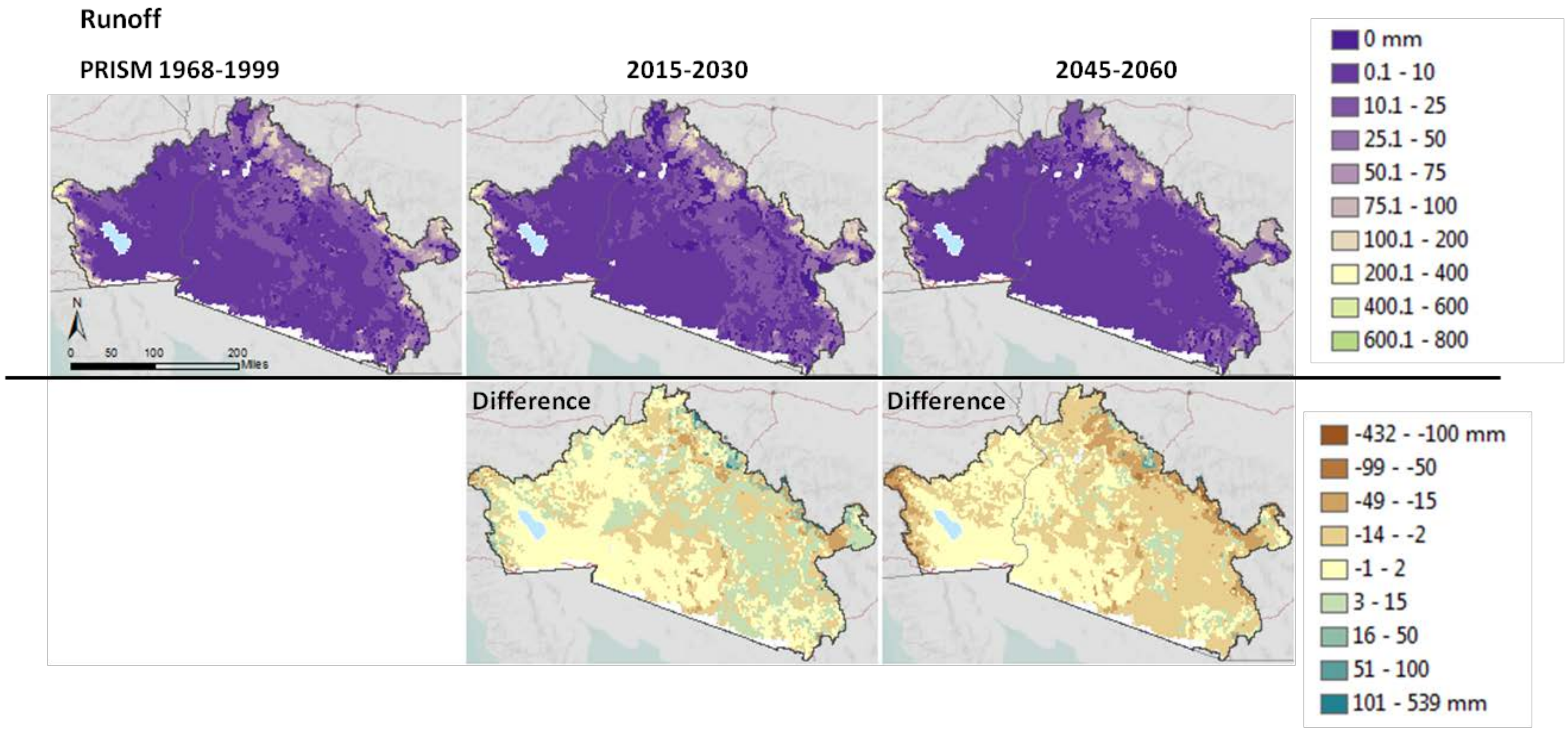


Figure 5-32. Surface runoff simulated by the static biogeography MAPSS model for the Sonoran Desert ecoregion for historical and future (2015–2030 and 2045–2060) time periods. The top row shows LAI values and the bottom row differences between historical and future projections.

Table 5-3. Change (in 1000s of acres) in major vegetation type as simulated by the biogeography MAPSS model for the Sonoran Desert ecoregion.

PRISM	2045 to 2060	Potential Change (ac)	Vegetation Type	Example Species
593	253	-340	Tree Savanna Mixed Warm	oak savanna
24	0	-24	Tree Savanna Evergreen Needle Continental	ponderosa pine
40	4	-36	Tree Savanna PJ Continental	pinyon pine, western juniper
4	0	-4	Tree Savanna PJ Maritime	California oak and coastal sage, west Sonoran boundary
40	20	-20	Shrub Savanna Evergreen	sagebrush, saltbrush
178	435	257	Shrub Savanna Subtropical Mixed	mesquite savanna, juniper-oak savanna
5,903	5,851	-51	Shrubland Subtropical Xeromorphic	oak-juniper woodland, mountain mahogany-oak scrub
47	47	0	Shrubland Subtropical Mediterranean	chaparral
16	0	-16	Grass MidC3C4	wheatgrass, ricegrass
75	0	-75	Grass ShortC3C4	bluegrass, grama
8	759	751	Grass ShortC4	muhly grass, blue grama
22,350	26,687	4,337	Grass SemiDesertC4	galleta, grama
5,365	585	-4,780	Desert Subtropical	creosotebush, palo verde

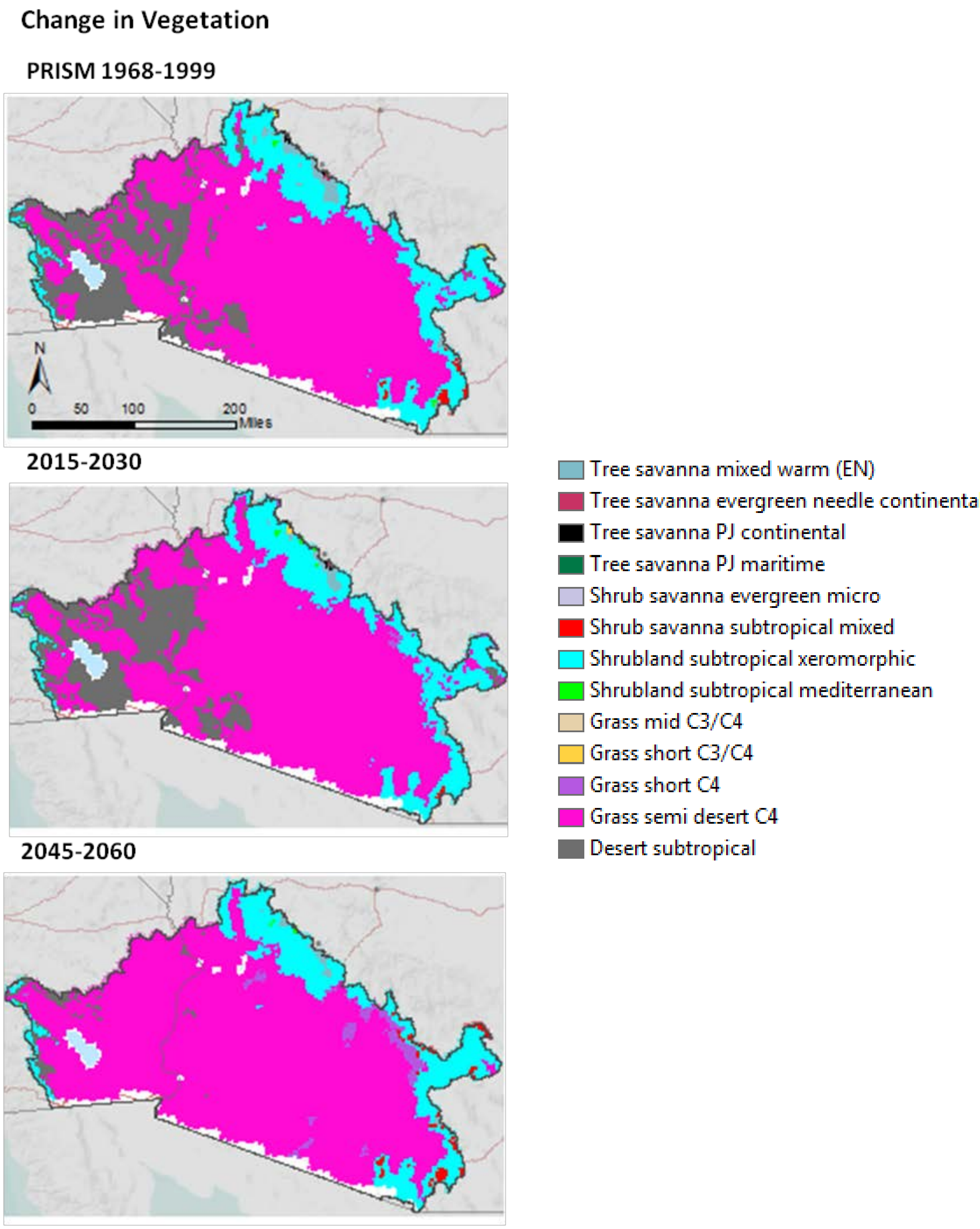


Figure 5-33. Vegetation distribution simulated by the MAPSS biogeography model for the Sonoran Desert ecoregion over the historical period (1968–1999) and two future time periods (2015–2030 and 2045–2060).

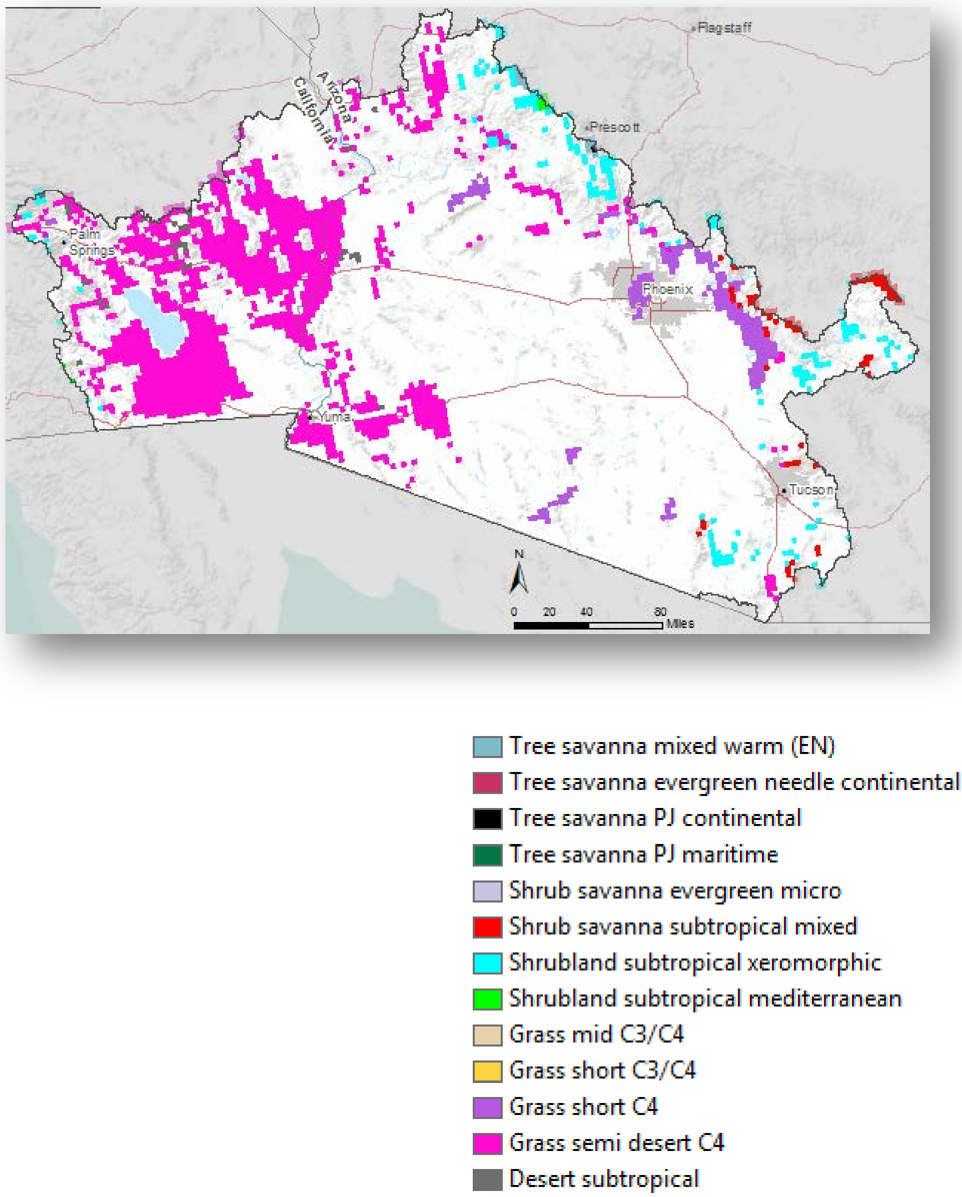


Figure 5-34. Areas of vegetation change (showing just the pixels that changed) between the historical period (1968–1999) and one future period (2045–2060) based on the MAPSS biogeography model for the Sonoran Desert ecoregion.

5.4.1.2 Uncertainty in Climate Change Modeling

Uncertainty can be examined in different ways and from different perspectives. First, impacts models depend on the reliability of the climate data that they use. It is important to note that while climate projections diverge after 2040, models generally agree for the first half of the century and the choice of a particular climate model or scenario is less important if the management goal is limited to the next 2 or 3 decades. Beyond 2040, it becomes critical to rely upon experts who can select climate models based on less than perfect criteria. For example, it is common to choose climate models that best simulate past climate dynamics, particularly paying attention to the most important local climate feature (as was done for this REA with the choice of the RegCM3 model that recognizes the summer monsoon for the U.S. Southwest). Three GCMs driven by the RegCM3 regional model were analyzed for this project: ECHAM-5, GFDL and GENMOM. The data portal contains the results of each model, including associated MAPSS results; access at http://www.blm.gov/wo/st/en/prog/more/climatechange.html. Users can delve into these models to gain a deeper understanding of the range of potential results from various models.

Model verification is obviously impossible for future projections and one is reduced to putting one's confidence in the ability of climate models to reproduce faithfully past climatic changes. However, there is no guarantee that a model that reproduces the past well will simulate the future accurately. Current models include our current understanding of past climate dynamics that may change drastically as atmospheric and stratospheric composition change as well as the planet's albedo. General circulation models (GCMs) were designed to simulate the planet's climate and their results compare well to climate observations at the global scale. The accuracy of global models declines at the local scale due to their inherent coarse spatial resolution that averages diverse vegetation cover and complex topography so important to conservation practitioners. Downscaling techniques (statistical or dynamic) bring GCM results to the scale of concern, but their accuracy is limited to that of the original projection. Furthermore, feedbacks from the biosphere to the atmosphere continue to be woefully under-represented in global models and regional model feedbacks to the GCMs have not even been developed yet. The uncertainty of climate projections result from the imperfect knowledge of 1) initial conditions such as sea surface temperatures that are difficult to measure, 2) the levels of future anthropogenic emissions, which are unknowable since they are dependent on current and future political decisions and social choices, and finally 3) general system behavior (such as clouds and ice sheet melt) that continues to be the subject of basic climate research and that constitutes the "known unknowns" of the climate system. Finally, surprises such as the unexpected Larsen B ice shelf rapid collapse in Antarctica, one of the "unknown unknowns", also cause climate scientists to continually improve existing models. It is important to understand that as change occurs (e.g. ice free poles, glacier disappearance, new wind patterns, change in ocean currents), the basic assumptions at the core of the climate models may become obsolete, reminding us again that there is no assurance that a model that reproduces the past well is going to be reliable when projecting the future. Climate scientists learn constantly from every new observation and they update their models accordingly as new observations bring new knowledge. Moreover, the accuracy of the emission scenarios used by the Intergovernmental Panel on Climate Change (IPCC) depends entirely on political decisions and social choices that, by definition, are impossible to predict.

Extreme events (e.g. long, intense droughts, floods, and hurricanes) are also difficult to predict by climate models. Along with a greater risk of drought, there is an increased chance of intense precipitation and flooding due to the greater water-holding capacity of a warmer atmosphere such that both wet and dry extremes should become more severe. These extreme events, while unpredictable, are often what shape our landscapes. Past extreme events such as the drought of the 1930s that caused the Dust Bowl certainly affected natural ecosystems and human land use, but recently, records of extreme events have been increasing in the U.S. For example, the drought of 1999–2002 that spawned fires, dust storms, and pinyon pine mortality across the southwestern states may have been an indication of climate destabilization. These extremes are consistent with what climate scientists have been expecting. Extreme events certainly pose a challenge to land managers who are typically more comfortable thinking about chronic linear change rather than abrupt and unpredictable change.

At the local scale, practitioners need to be aware of the uncertainty of climate baselines and projections due to: 1) the variable density of meteorological stations in or close to their area of concern and the length of records from these stations reducing the reliability of historical records; 2) the topographic complexity that can cause local decoupling from regional climatic trends (see next paragraph below); 3) the relative proximity of their sites to large terrain features that can affect local conditions and not be simulated well by climate models; 4) the proximity to water (stream or coast) and its importance for cooling influences and groundwater availability; 5) the influence of human activities in or near the conservation site (pollution levels and cloud condensation nuclei, fire ignition source, urban island heat effect); 6) the natural climate variability and the records of extreme events that, once known, can increase the understanding of ecosystem vulnerability to future climate disturbance.

There is inherent natural variability in the expression of climate (e.g. cold air drainage, inversions in deep valleys), which is often influenced by the complexity of the regional terrain. At a fine scale, this means localized climate refugia–narrow swales, moist draws, etc. Close examination of a reasonable resolution (30 m) digital elevation model (DEM) can provide some insight as to locations that are more likely to provide refugia (Figure 5-35). These sites are found at a much finer scale than the analytical grid of the climate change work. At a coarser level, places on the landscape in and around rugged terrain will experience higher natural levels of climate variability.

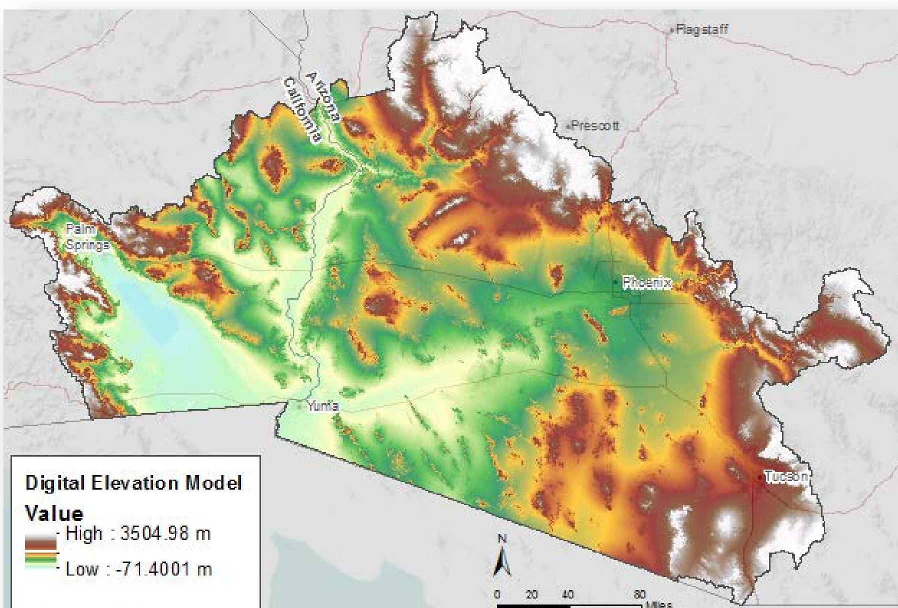
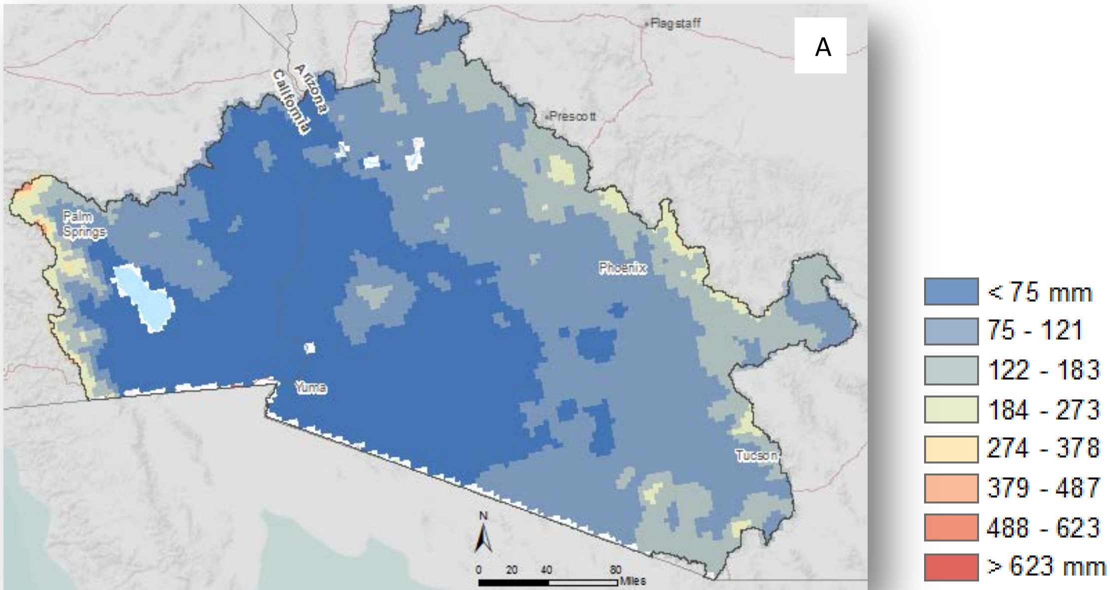


Figure 5-35. Digital elevation model (DEM) for the Sonoran Desert ecoregion

Calculating the pixel standard deviation of annual average temperature and annual average precipitation separately based on the PRISM historic data provides map products that highlight areas on the landscape that are prone to more variability for these primary climate variables (Figure 5-36). The natural variability of precipitation for this arid landscape is quite small at lower elevations, but the range of variability increases to a modest degree as elevation increases.



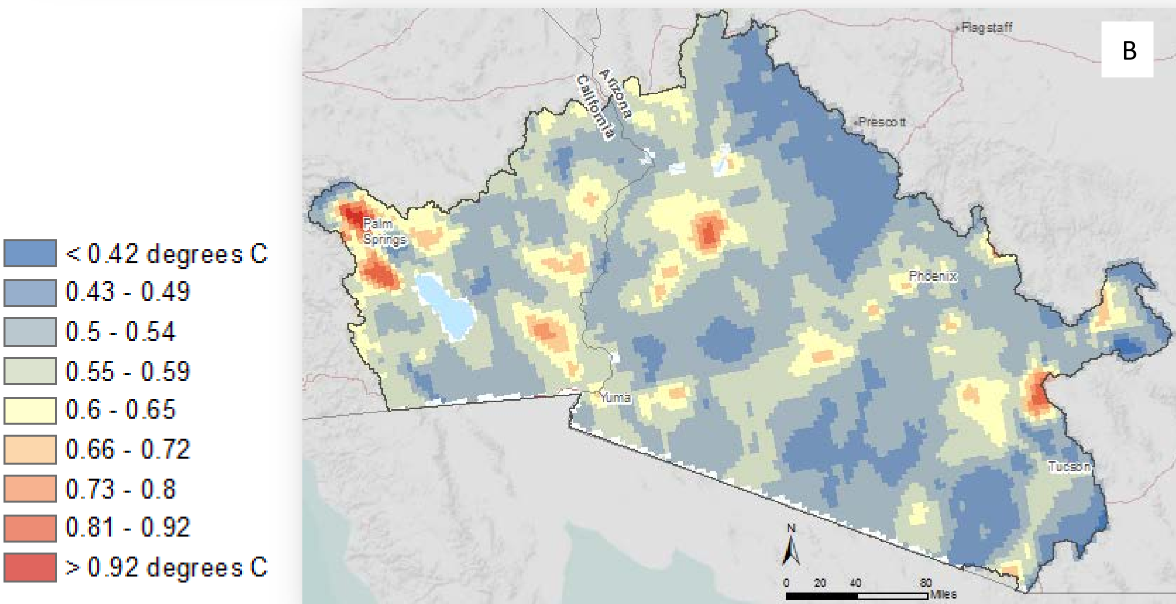


Figure 5-36. Uncertainty depicted as standard deviation of (A) precipitation and (B) temperature data from PRISM historic conditon (1968–1999).

The range of variability is more pronounced for the temperature data. Here, the valleys express higher levels of temperature variability from year-to-year (areas that are orange). These areas are highly influenced by the close proximity of the various mountainous areas. These results allow us to infer that: 1) plants and animals living in areas with a naturally variable climate have likely evolved mechanisms to cope or adapt to that variability; and 2) climate forecasts in these areas will tend to be less reliable compared to locations where year to year variability is less pronounced.

5.4.1.3 Assessing Climate Change Exposure for Conservation Elements

To simplify the numerous future climate projections and MAPSS modeling results, a number of key findings from these analyses were assembled into an overall relative climate change map. The different classes of potential for climate change were then overlaid on the distributions of specific conservation elements to assess their relative exposure to climate change and to respond to four different climate-change-related management questions (MQ D6, J1, J2, and J3, see Table 2-1). The fuzzy model inputs included potential for summer temperature change and potential for winter temperature change averaged into a single factor, and change in precipitation, runoff, and vegetation change simulated by the MAPSS model (Figure 5-37). Direction of the change was not important—only its degree of departure from the historic baseline. Details regarding change in temperature by degrees or actual predicted changes in precipitation can easily be assessed from the additional datasets provided in the body of the text. The model logic stated that all 4 km x 4 km pixels with potential to change primary vegetation type get the highest change score while the rest of the landscape received an average value based on the combination of the other factors. Departure in temperature in either season dominated that intermediate product that is then averaged with the two water functions (purple box plus two gold boxes in the intermediate results in the logic model below). Appendix E presents quality of data sources and level of confidence in the overall model.

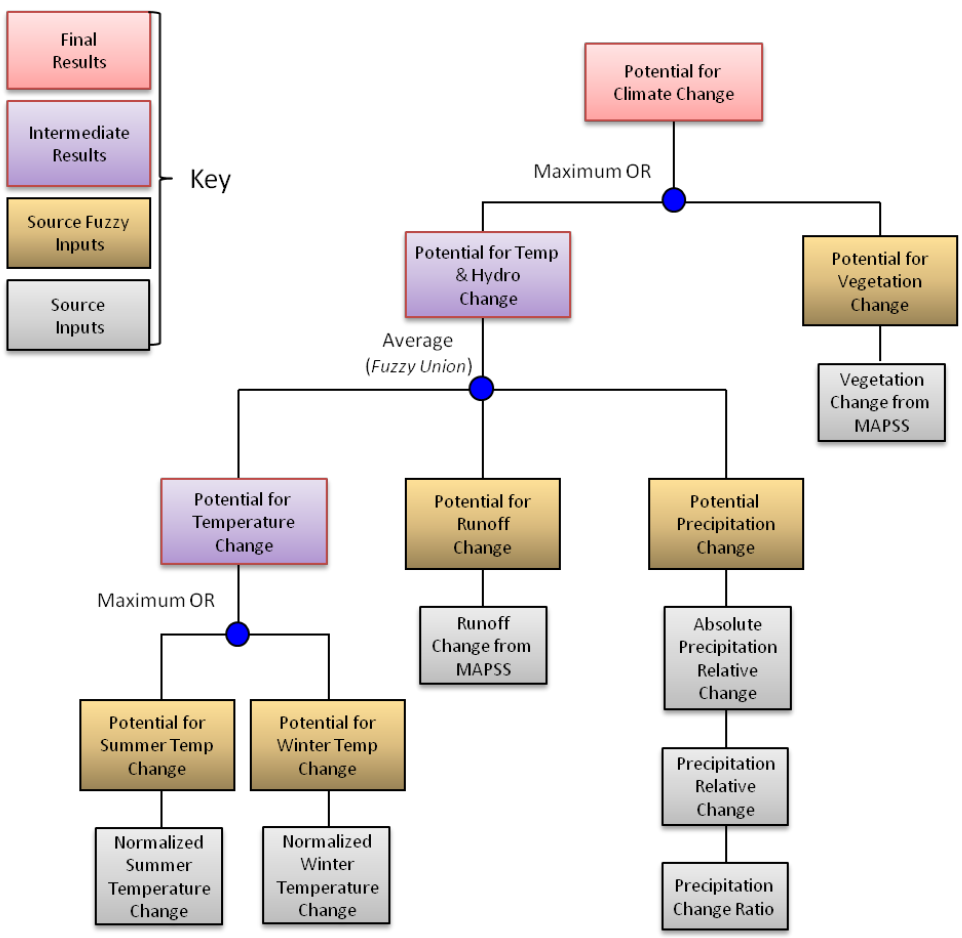


Figure 5-37. Fuzzy logic model for integrating climate change data to assess potential exposure of conservation elements to climate change in the Sonoran Desert ecoregion.

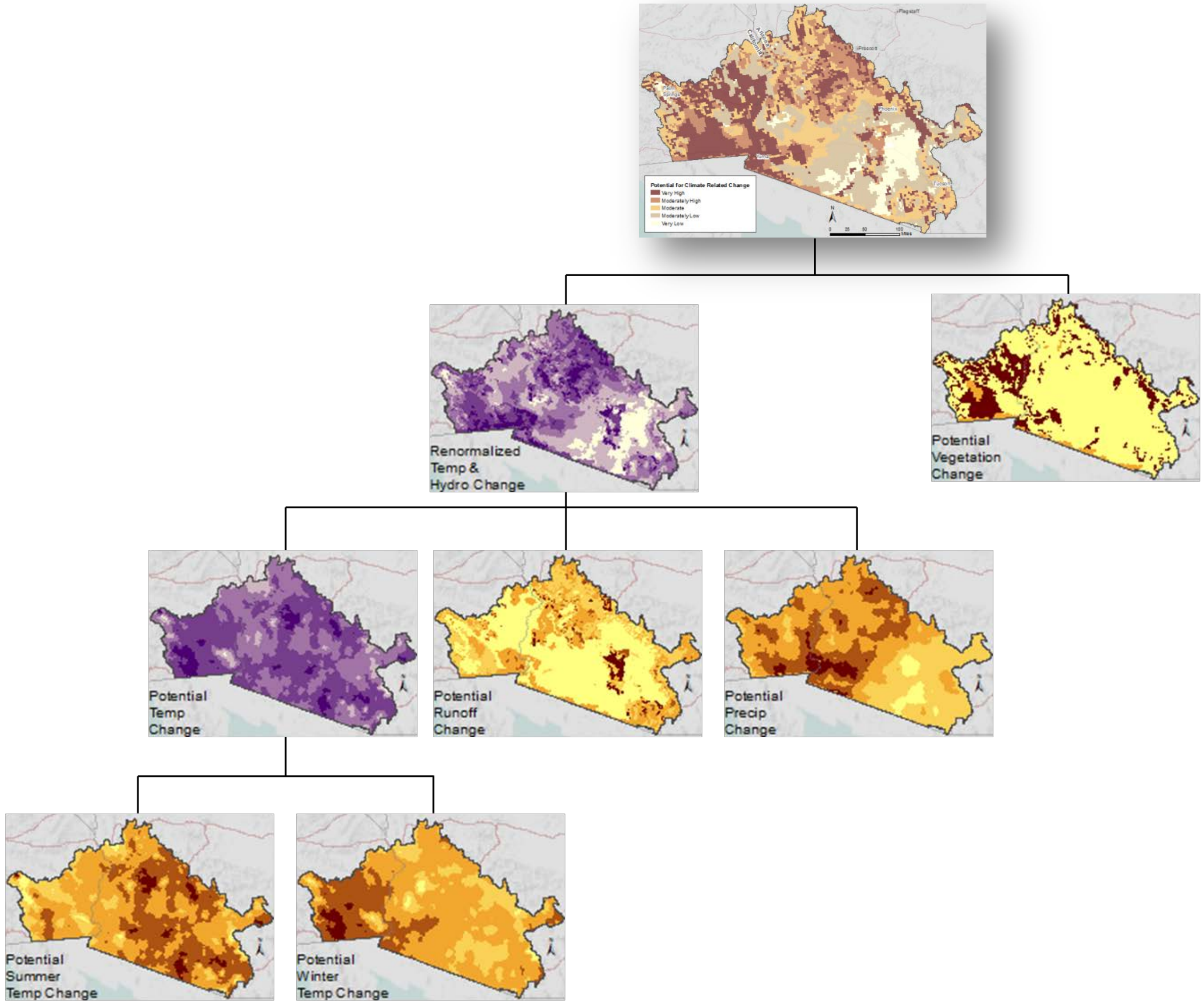


Figure 5-38. Map outputs for each step in the climate change fuzzy logic model for the Sonoran Desert ecoregion.

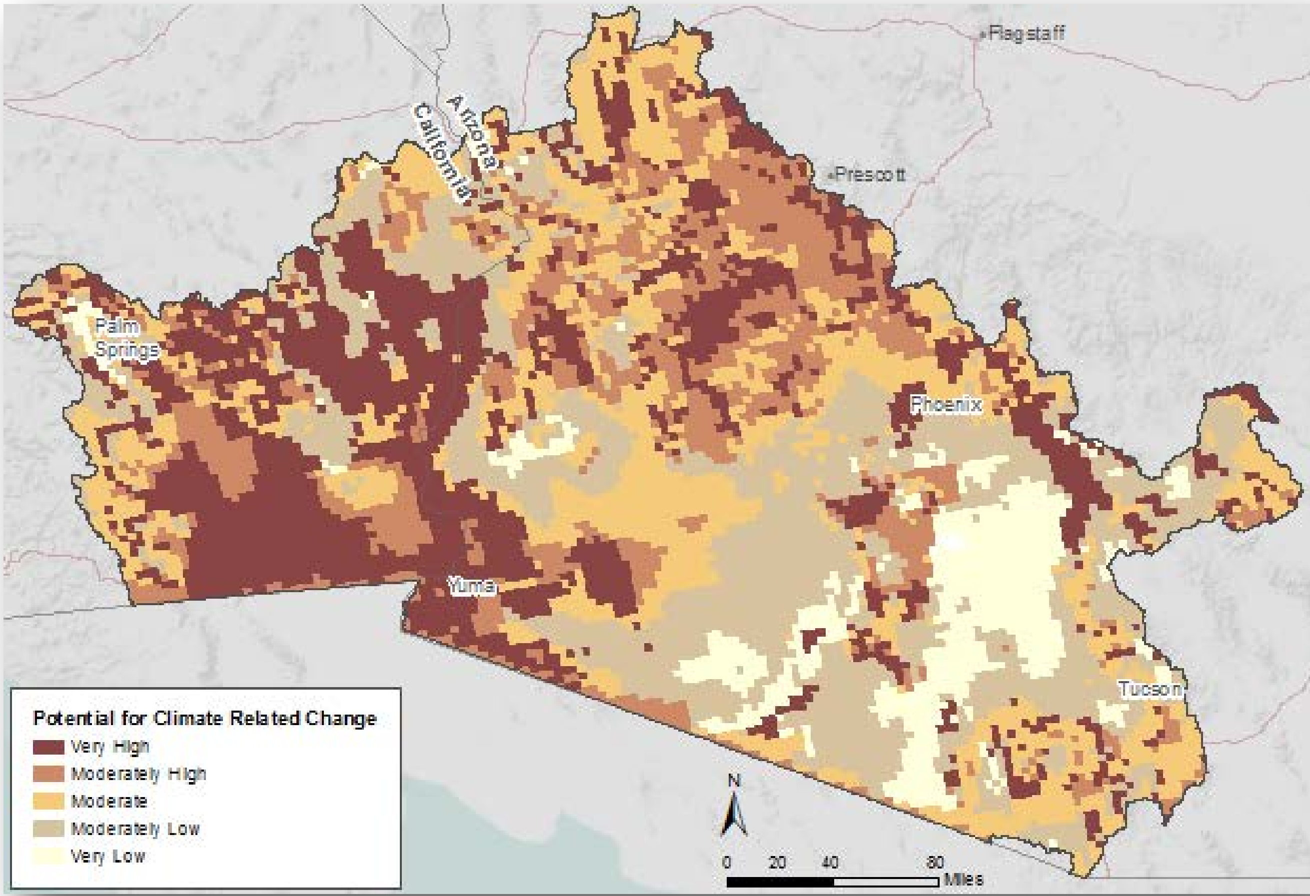


Figure 5-39. Final climate change potential map for the Sonoran Desert ecoregion. Fuzzy model inputs included potential for summer and winter temperature change averaged into a single factor and change in precipitation, runoff, and vegetation change simulated by the MAPSS model. Map shows five separate climate change exposure classes (Very High, High, Moderate, Moderately Low and Low) for the 2045–2060 time period.

Results from the fuzzy logic model show the contributions made by the various model components (Figure 5-38) to the final climate change potential map (Figure 5-39). Areas most likely to show the greatest changes are those that are predicted to change in their vegetation type or that scored high from a combination of the other factors.

The climate change model results, when overlaid with species' and vegetation communities' distribution maps, indicate the conservation elements' exposure to climate change. Exposure is just one aspect of ecosystem and species' vulnerability to climate change. Vulnerability is defined by the United Nations' Intergovernmental Panel on Climate Change (IPCC 2001) as…"(t)he degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, [*as well as*] its sensitivity and its adaptive capacity." See also the definition in Glick et al. (2011). The sensitivity of a species or system to climate change can be considered in terms of a "dose-response" relationship describing its exposure, resulting impacts, and its response (decline or adaptation, Füssel and Klein 2006). The development of vulnerability indices requires the implementation of species-specific indicators of sensitivity and species response or capacity to adapt, along with thresholds of impact that may indicate subsequent species decline (Carter et al. 2007). Füssel (2007) notes that time must be factored in as well. Sensitivity represents immediate or short-term effects on a system or species, while resilience or adaptation must be considered over a longer time frame to assess the species' ability to maintain basic functions and possibly return to its original state. Although no readily-available metrics yet exist to quantitatively describe the vulnerability of an ecosystem or species to climate change (Füssel and Klein 2006, Adger 2006, Carter et al. 2007), the pressing need to identify vulnerable species and to manage for mitigation under various climate change scenarios has prompted the development of more qualitative approaches to project species' vulnerability (Glick et al. 2011, Young et al. 2011).

The REA climate change results presented here for individual conservation elements are modeled from available spatial data and focus on the exposure of species, habitats and sites to projected climate change. However, some non-spatial species sensitivity information was obtained for some of the REA wildlife conservation elements from a Climate Change Vulnerability Index (CCVI) developed for the Nevada/Mojave region (NNHP 2011). CCVI is a product of assessment teams employing literature review, professional judgment, and expert review through workshops (Young et al. 2011). In this CCVI, the range and abundance of eight of the 11 REA wildlife species conservation elements selected for the Sonoran Desert ecoregion (mule deer, desert bighorn, Lucy's warbler, southwestern willow flycatcher, Le Conte's thrasher, Bell's vireo, golden eagle, and Mojave desert tortoise) were classified as *Presumed Stable* to the effects of climate change by mid-21st century. *Presumed Stable* is defined as: "Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change." Mountain lion, Sonoran desert tortoise, and lowland leopard frog were not listed in the Nevada assessment. In addition, in a climate vulnerability assessment for the U.S. Department of Defense for species of concern on Arizona's Barry Goldwater Range, Bagne and Finch (2010) gave species a number score based on vulnerability or resilience to climate change across a number of functional traits. Of the three REA species on their list, Sonoran desert tortoise scored highest and most vulnerable with a score of 7 out of 10. Desert bighorn scored moderately vulnerable at 4.3, and Le Conte's thrasher more resilient at 2.4. For Mojave desert tortoise, Barrows (2011) modeled projected changes in tortoise distribution within Joshua Tree National Park and found the species to be sensitive and to have low capacity for adaptation to climate change, thus vulnerable in areas of high climate change exposure. With added vulnerability information such as these various results, one can analyze the vulnerability of particular species and communities with known sensitivities by overlaying the REA species' distributions with the climate change exposure map (Figure 5-39) and reassessing the exposure results with added vulnerability information. Bringing additional species sensitivity information to this analysis will allow the identification of locations where the species may experience various degrees of vulnerability to climate change as well as locations of possible refugia.

For the body of this report, results were posted in histograms as five climate change exposure classes for the 2045–2060 time period (Very High, High, Moderate, Moderately Low and Low). Results correspond to the percent of each species' or community's distribution potentially affected by climate change. An overlay map for each conservation element relative to climate change exposure can be found in Appendices B and C; the maps and source data may also be examined in greater detail on the data portal.

Each of the mammal and reptile species showed a unique signature to the climate model results (Figure 5-40). For the mammals, mountain lion showed the highest potential exposure to climate change with nearly 30% of its current distribution under the Very High category. Its major prey, mule deer and desert bighorn sheep, showed slightly less distribution area under the highest climate exposure category, but all three mammal species showed roughly 40% of their existing distributions under Very High or Moderately High exposure to climate change by 2045–2060. These mammals will be more likely to overcome some changes because of their wide-ranging nature and potential for dispersal, but increasing fragmentation or a reduction in the availability of their primary food or water sources may exacerbate the moderate direct effects of climate change on their habitat.

The Mojave desert tortoise (*G. agassizii*) exposure to climate change is very high with almost half of its current distribution under Very High or Moderately High exposure categories. The Sonoran desert tortoise (*G. morafkai*) has less exposure with roughly 30% of its current distribution within these same categories. Unlike the mammals, physiological impacts and dispersal limitations are more likely in the tortoise species. For example, temperature during egg maturation dictates the sex of the offspring (Spotila et al. 1994). With an increase in temperature, modifications in depth or aspect of burrows will be required if tortoises are to adapt to increasing ambient temperatures in the environment. (See more details on the desert tortoise species in the Desert Tortoise Case Study Insert.)

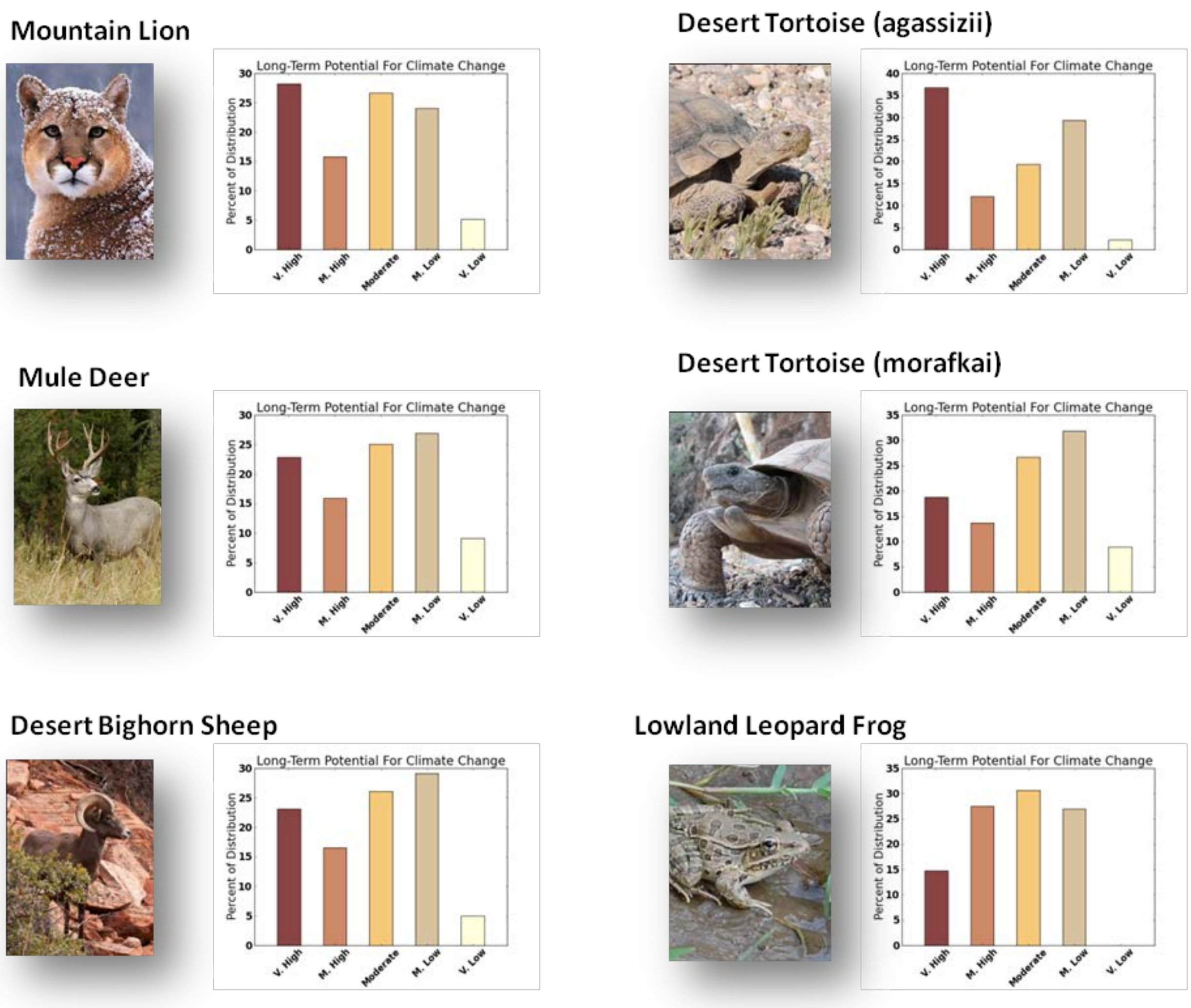
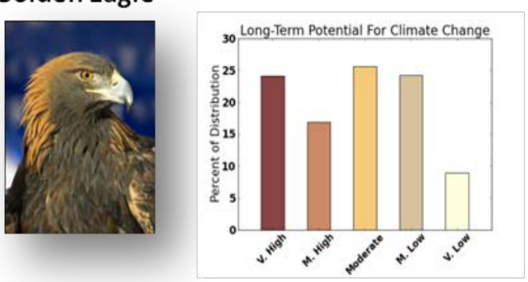


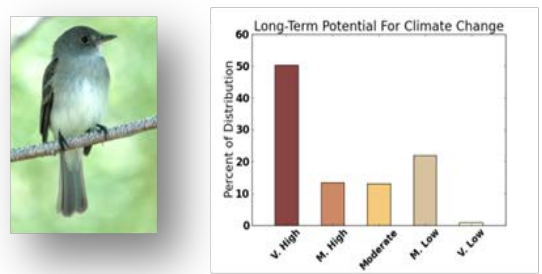
Figure 5-40. Potential exposure to climate change for mammals, reptiles, and the lowland leopard frog of the Sonoran Desert ecoregion.

Among bird species (Figure 5-41), 50% of the current distribution of the southwestern willow flycatcher is in the Very High climate change exposure category, followed by Le Conte's thrasher (34%) and golden eagle (24%). Bell's vireo showed the least exposure to climate change impacts, but it still had 30% of its current distribution in the Very High and Moderately High categories.

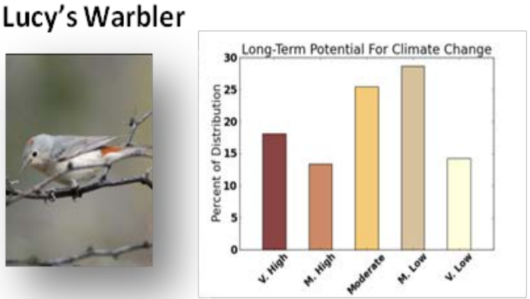
Golden Eagle



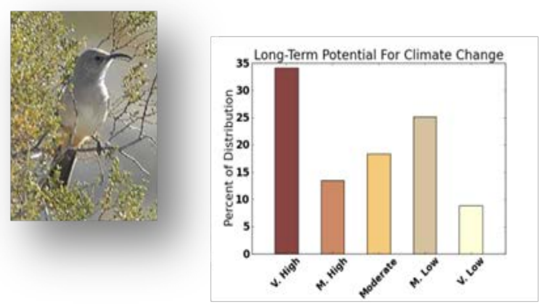
Southwest Willow Flycatcher



Lucy's Warbler



LeConte's Thrasher



Bell's Vireo

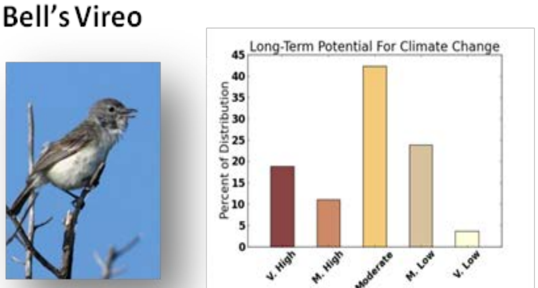


Figure 5-41. Potential exposure to climate change for birds of the Sonoran Desert ecoregion.

The vegetation community that showed the greatest percent area change under high climate change exposure was Sonoran-Mojave Creosotebush-White Bursage desert Scrub, followed by riparian vegetation and Sonoran Paloverde-Mixed Cacti Desert Scrub (Figure 5-42). With the vegetation communities, caution must be taken when interpreting these results as high exposure does not definitively mean decline; it means higher probability of change. Munson et al (2011), in a study using historical climate data in protected areas of the Sonoran Desert, project similar changes in vegetation communities; they found that with increasing mean annual temperatures there was a decline in velvet mesquite in mesic areas, a decline in foothills paloverde and ocotillo in more xeric foothills areas, and a decline in creosotebush in xeric shrublands.

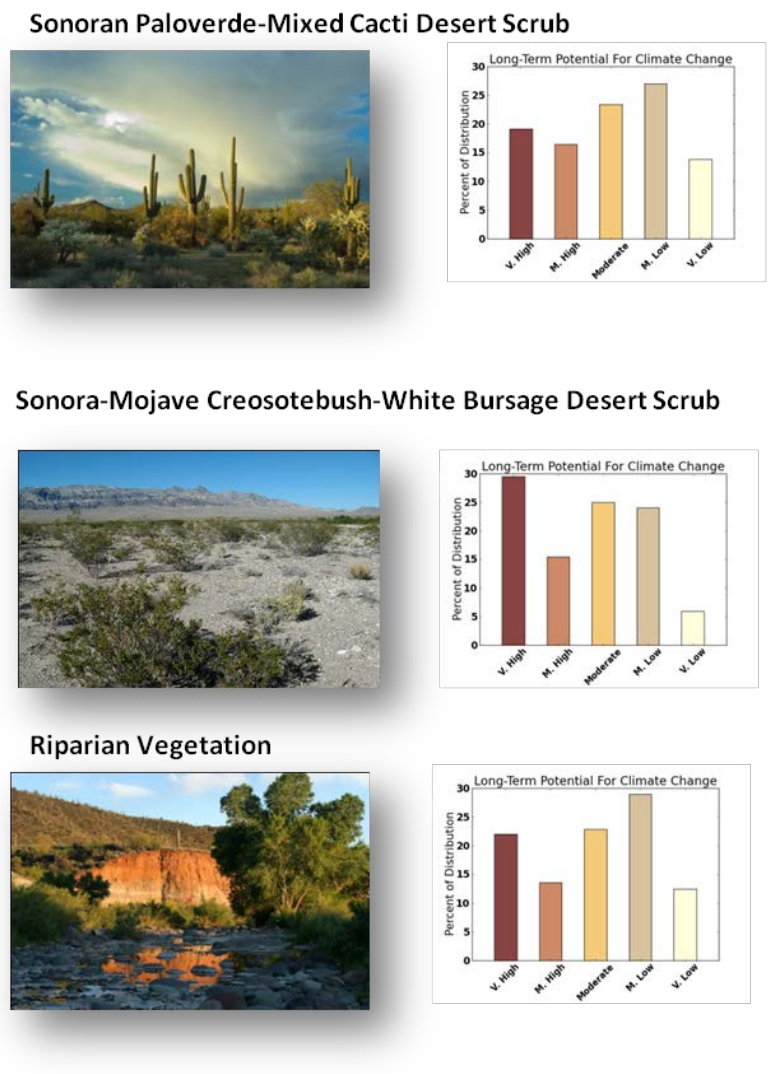


Figure 5-42. Potential exposure to climate change for the vegetation communities of the Sonoran Desert ecoregion.

Finally, existing designated sites showed fairly high vulnerability to climate change by 2060 with 42% of this category's land area under Very High or High exposure and nearly another 25% under Moderate exposure (Figure 5-43). 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. Future planning will be necessary to anticipate and mitigate possible changes to these valued designated sites.

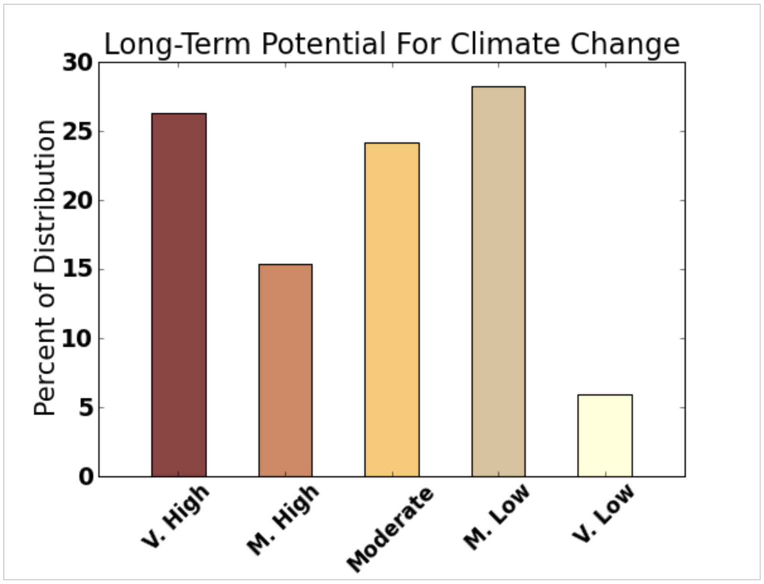


Figure 5-43. Potential exposure to climate change for the designated protected lands of the Sonoran Desert ecoregion.

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Photo: Riparian fire on the lower Colorado River, BLM.

VI. Summary Findings and Applications

This chapter presents REA findings designed to help managers visualize the REA products and how they may be used at various scales. The focus of this example is on BLM lands not currently protected, but the models are flexible enough to analyze all areas at the ecoregion, state, or field office scales. These sections identify intact landscapes rich in conservation elements and landscapes where change agents currently affect conservation elements and where changes may occur in the future. This summary presents ways to use the integrity/intactness results with composite species information as an introduction to more local step-down management or planning. Understanding the relationship of these data provides basic ecoregion-level information to begin to identify broad areas of opportunity for development, restoration, conservation, or connectivity that may be examined at multiple scales, both regional and local.

6.1 Using REA Results for Regional Planning

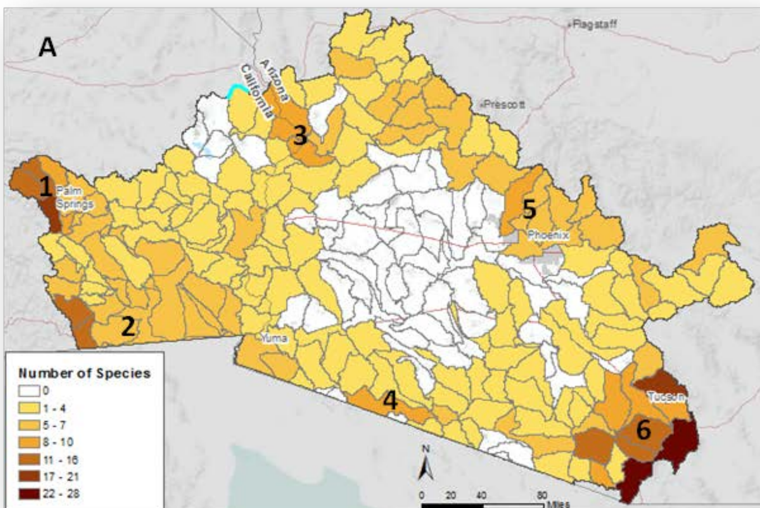
The REA Statement of Work (SOW) required an assessment of regional ecological integrity (condition or health). As defined in the SOW, ecological integrity is "the ability of ecological systems to support and maintain a community of organisms that have the species composition, diversity, and functional organization comparable to those of natural habitats within the ecoregion (Karr and Dudley 1981)." The wildlife species selected as core conservation elements for the REA were intended to be wide-ranging species that represented other species and multiple habitats and that served as indicators of the condition of the ecoregion. See Section 2.4.2 for the landscape species selection process. Besides having broad representation, indicator species should be habitat specialists that express site fidelity for breeding, nesting, or wintering (to reduce interannual variability in sampling) and also be sensitive and responsive to a range of disturbances. However, the ecoregion-wide scope in these REAs did not lend itself well to accommodate an approach using indicator species. Perhaps using more homogeneous subunits, such as Environmental Protection Agency (EPA) level IV ecoregions (Griffith et al. In Preparation a and b), and selecting sets of species guilds at sites on a disturbance gradient within these smaller units would allow the addition of a biological component to the spatial measure of terrestrial ecological integrity.

During the course of the REA, it became apparent that there are few measurable spatial indicators and metrics available for individual species to incorporate into such an effort. Our present state of knowledge required using the condition of vegetation communities, habitats, or landscapes as surrogates for the condition of the species and ecological processes in the region. With BLM approval, the REA focused on landscape intactness, an attribute that could be defensibly supported by existing geospatial datasets and reasonably tracked through time. Although different species may possess different tolerances to regional habitat conditions, species assemblages and natural patterns and processes are typically increasingly compromised by the cumulative effects of the change agents that affect their habitats. Terrestrial and aquatic landscape intactness models served as the foundation against which to assess current and future conservation element status.

This reliance on landscape intactness to represent ecological integrity meant that the presence or absence of a particular species, species rarity, or species richness did not factor into any metric of integrity. High species richness or concentrations of rare or endemic species do not indicate high ecological integrity (Odum 1985, Scott and Helfman 2001). Richness is limited by the partitioning of energy among species (Currie 1991, Hawkins et al. 2003); some of our most valued and intact landscapes support few species (Currie 1991, Hughes et al. 2004). On the other hand, although areas of high species richness should be evaluated separately from integrity or intactness, they are still important for conservation and management decision making. Much of the BLM's management and planning is species-centric. This chapter examines the use of regional concentrations or hotspots of species and resource values as one avenue to regional planning.

6.1.1 NatureServe Natural Heritage Elements

NatureServe summarized Natural Heritage data for the ecoregion by 5th level HUCs enumerating all G1-G3 species (critically imperiled, imperiled, and vulnerable, respectively, throughout their range, Faber-Langendoen et al. 2009) and threatened and endangered species occurring within each HUC. The map identifies specific areas within the ecoregion that are species-richness hotspots for these sensitive fine-filter elements (Figure 6-1A). The richness function map layers represent locations from which occurrences have been recorded, rather than where the species currently occurs. The greatest concentration of these species is along the western border of the ecoregion where the Sonoran Desert meets the Peninsular Ranges of southeastern California, but other concentrations can be observed elsewhere (e.g., southeast of Tucson). Comparing these species concentrations to the same areas on the terrestrial landscape intactness map shows that many of the HUCs with high concentrations of sensitive species do not coincide with areas of High or Very High landscape intactness (green areas in Figure 6-1B). This is not unexpected when one considers that human activities tend to put species at risk, but it is interesting to see the regional pattern.



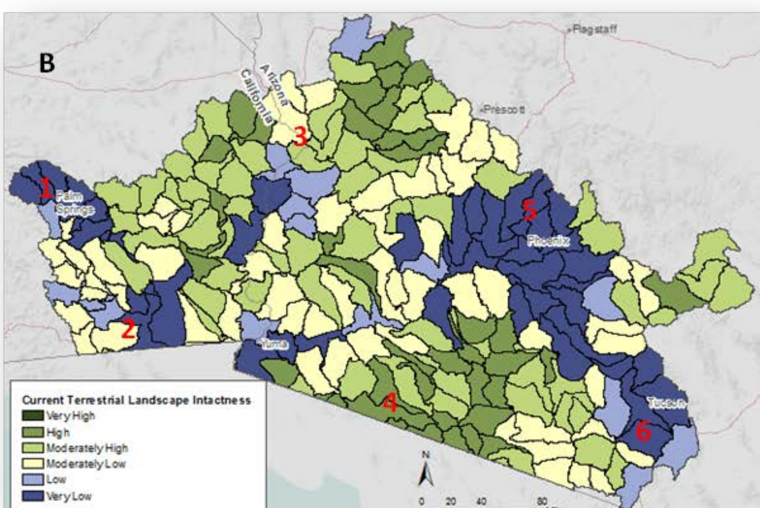
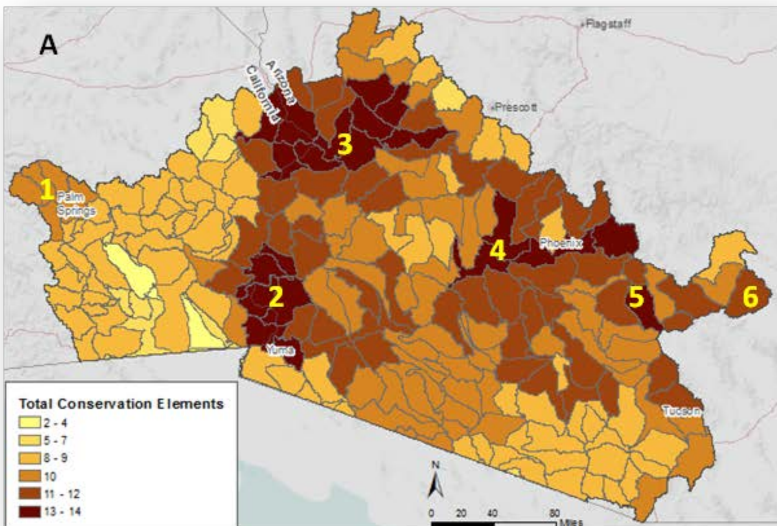


Figure 6-1. (A) Map shows number of G1–G3 species from NatureServe heritage data for the Sonoran Desert ecoregion organized by 5th level HUC and (B) current terrestrial landscape intactness model results. Numbers link areas of high concentration of sensitive species with corresponding areas of relative intactness in the two maps. Summary maps for NatureServe data for all species are provided in Appendix C.

6.1.2 Concentrations of Conservation Elements

As done in the previous section for the heritage data, the collection of REA conservation elements (CEs) was reported by HUC to create CE concentrations or hotspots to compare against regional terrestrial landscape intactness. The list of 15 conservation elements included 11 species, 3 ecological systems and Herd Management Areas (HMAs). The number of conservation elements contained within a single HUC ranged from 2–14. Highest ranking HUCs (those that contained the largest numbers of conservation elements) displayed mixed intactness results. As before, comparisons of concentrations of conservation elements with terrestrial landscape intactness indicated that many of the HUCs with high concentrations of conservation elements show relatively low landscape intactness (Figure 6-2A and Figure 6-2B).



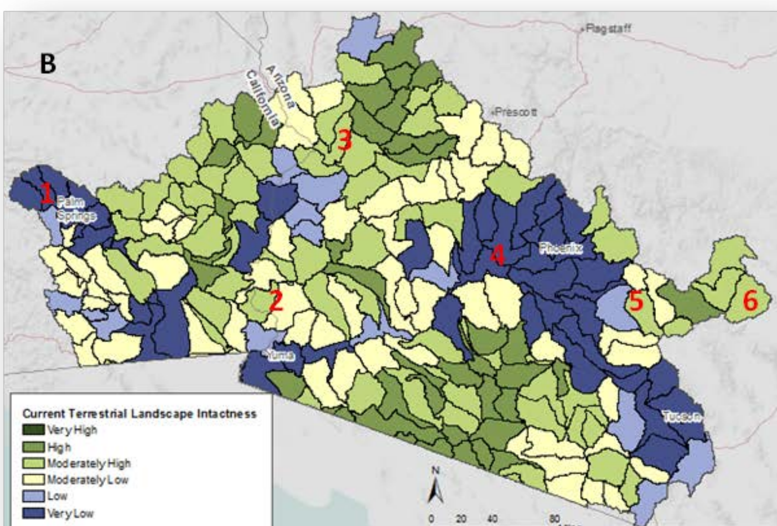
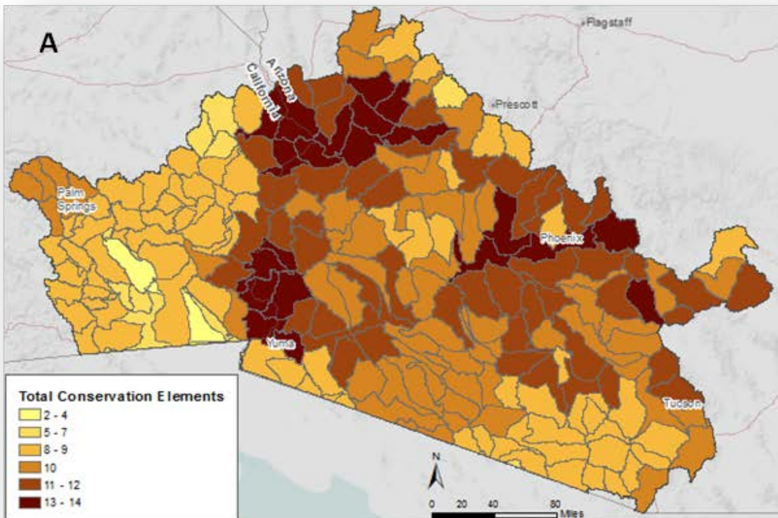


Figure 6-2. Map (A) shows numbers of conservation elements for the Sonoran Desert ecoregion organized by 5th level HUC and (B) current terrestrial landscape intactness model results. Yellow and red numbers link both maps to compare areas of high concentrations of CEs with corresponding areas of relative intactness.

Mapping the conservation element (CE) concentrations at the 4 km reporting unit reveals an improvement in spatial detail with the increase in resolution of the reporting unit (Figure 6-3B). The most apparent difference at the 4 km scale is the ability to detect some of the stream networks and with them the contribution of the aquatic conservation elements to the CE concentrations. The 4 km resolution shows a more textured result when mapped and compared to landscape intactness reported by HUC. The 4 km results are at a scale and detail that more closely matches recognizable topographic changes (mountain ranges) and areas of management interest. When 4 km results such as these are compared to regional intactness mapped at the 4 km unit (as in Figure 6-5A in Section 6.2.1 below), management may be aimed at grid cells with higher levels of intactness or neighboring grid cells of lower intactness that might be candidates for restoration.



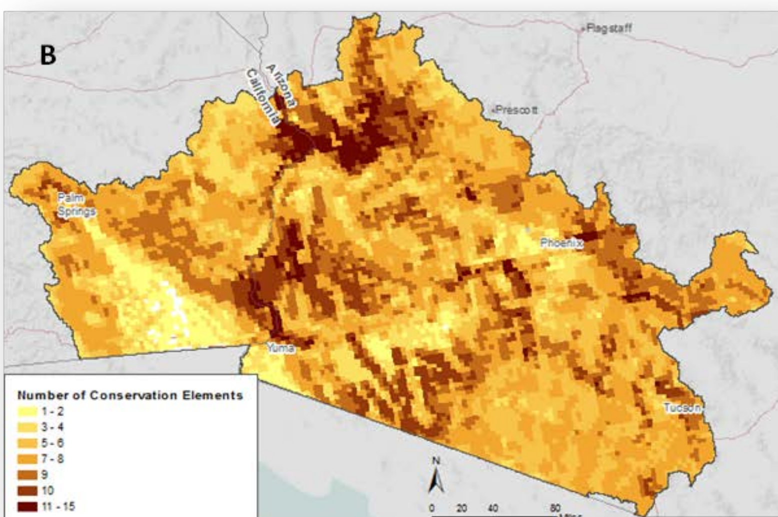


Figure 6-3. Number of conservation elements for the Sonoran Desert ecoregion organized by (A) 5th level HUC and (B) by 4km grid. Spatial detail improves at the 4 km scale showing topographical differences (mountain ranges and basins) and the Colorado River (and with it the contribution of the riparian conservation elements to the CE concentrations).

The sections that follow present an example of organizing REA results for regional planning, an activity that precedes or accompanies local planning using higher resolution data. The 4 km map of concentrations of conservation elements (Figure 6-3B) will be compared to various regional views of intactness and current and future change agents.

6.2 Regional View of Landscape Intactness: Current and Future Risk to Conservation Elements

6.2.1 Comparing Concentrations of Conservation Elements with Regional Levels of Intactness

Three different maps were used to represent the concentrations of *resource values* (see Glossary) and to reveal patterns across the region—1) REA conservation elements enumerated by 4 km grid cell (Figure 6-4A); 2) the number of globally critically imperiled and vulnerable species (NatureServe G1–G3 by 5th level HUC, Figure 6-4B); and 3) the number of USFWS threatened and endangered species recorded by 5th level HUC (Figure 6-4C). Comparing maps 6-4A–C, one can see that Maps 6-4A and 6-4C share two areas in the central region, and maps 6-4B and 6-4C share two hotspots of globally imperiled species and threatened and endangered species at the far eastern and western ends of the region. These additional areas of interest were added to map 6-4A to create one map (6-4D) to represent all three of the of the resource value categories; the map with all the resource values included (6-4D) is used in the following sections when comparing concentrations of conservation elements with intactness maps and maps of future condition. Hotspots occur in the central portion of the ecoregion near the Colorado River and in the boundary areas transitional to adjacent ecoregions—the California coast range, Mojave Desert, Mogollon Rim, and Madrean Archipelago. Protected areas were masked out on the hotspot and intactness maps (green areas) to focus on remaining lands subject to development pressures.

To compare these concentrations of conservation elements to the condition of surrounding habitats, areas of moderately high to high intactness outside of protected areas have been outlined (in pink) on the intactness map (Figure 6-5A) and the higher concentrations of species and other conservation elements outlined in royal blue on the map in Figure 6-5B. A comparison of the two maps shows some broad areas of interest between the two layers. As a first cut in this example, one is drawn to the northern apex of the region, the eastern and western corners, and areas of high intactness or species concentrations near protected areas 1, 2, and 3. The two pink circled areas of higher intactness west of protected area 1 (Kofa National Wildlife Refuge) are both military areas (Yuma Proving Ground and Chocolate Mountains National Gunnery Range) that retain some benefits to wildlife outside of military activities. They create linkages between Kofa, multiple wilderness areas (e.g., Little Picacho, Indian Pass, and Trigo Mountains) to the southwest, and the larger Chuckwalla Desert Wildlife Management Area (DWMA) and Area of Critical Environmental Concern (ACEC) to the west. Greater opportunities may exist for conservation/restoration in the higher intactness-species concentrated area between protected areas 2 (Sonoran Desert National Monument) and 3 (Organ Pipe Cactus National Monument and Cabeza Prieta National Wildlife Refuge) where smaller protected or quasi-protected areas (e.g., Coffeepot Botanical Area, Barry M. Goldwater Air Force Range) could be supplemented to create more robust linkages between the two National Monuments. This is just an example of one route to evaluating these results; in planning situations, of course, there may be valid reasons to restore or protect areas of lower intactness or lower numbers of resource values. The remaining open areas on either side of the Phoenix-Tucson megalopolis (two blue ellipses to the right of 2 in Figure 6-5B) may be just as important as the areas of higher intactness—particularly east of Phoenix in the ecotone between the Sonoran Desert and the Arizona-New Mexico Mountains (e.g., Dripping Springs Mountains); here there are areas of moderately high intactness remaining as well as concentrations of resource values.

The vast amount of information produced by this REA can and must be examined in multiple ways and at multiple scales. In Chapters 4 and 5, individual species distributions were overlaid with landscape intactness to estimate conservation elements' current and future status. To accompany the spatial mapped results, it is useful for managers to have tabular summaries of conservation elements and areas in various intactness classes.

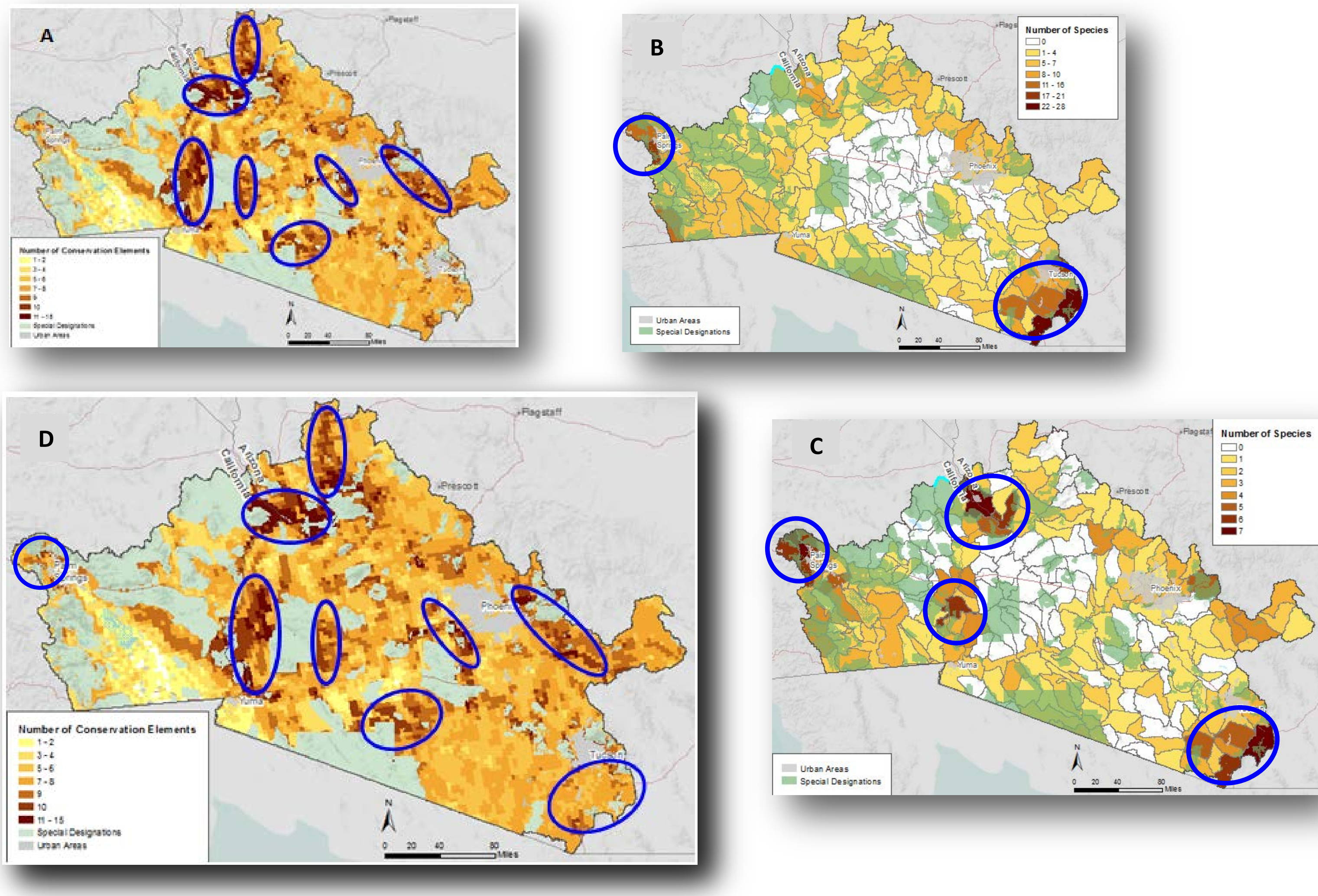


Figure 6-4. Maps of (A) concentrations of conservation elements; (B) globally imperiled species, and (C) USFWS-listed threatened and endangered species, all with highest concentrations circled; and (D) map A with additional areas of interest at western and southeastern ends added from maps B and C. Protected areas are masked out in green.

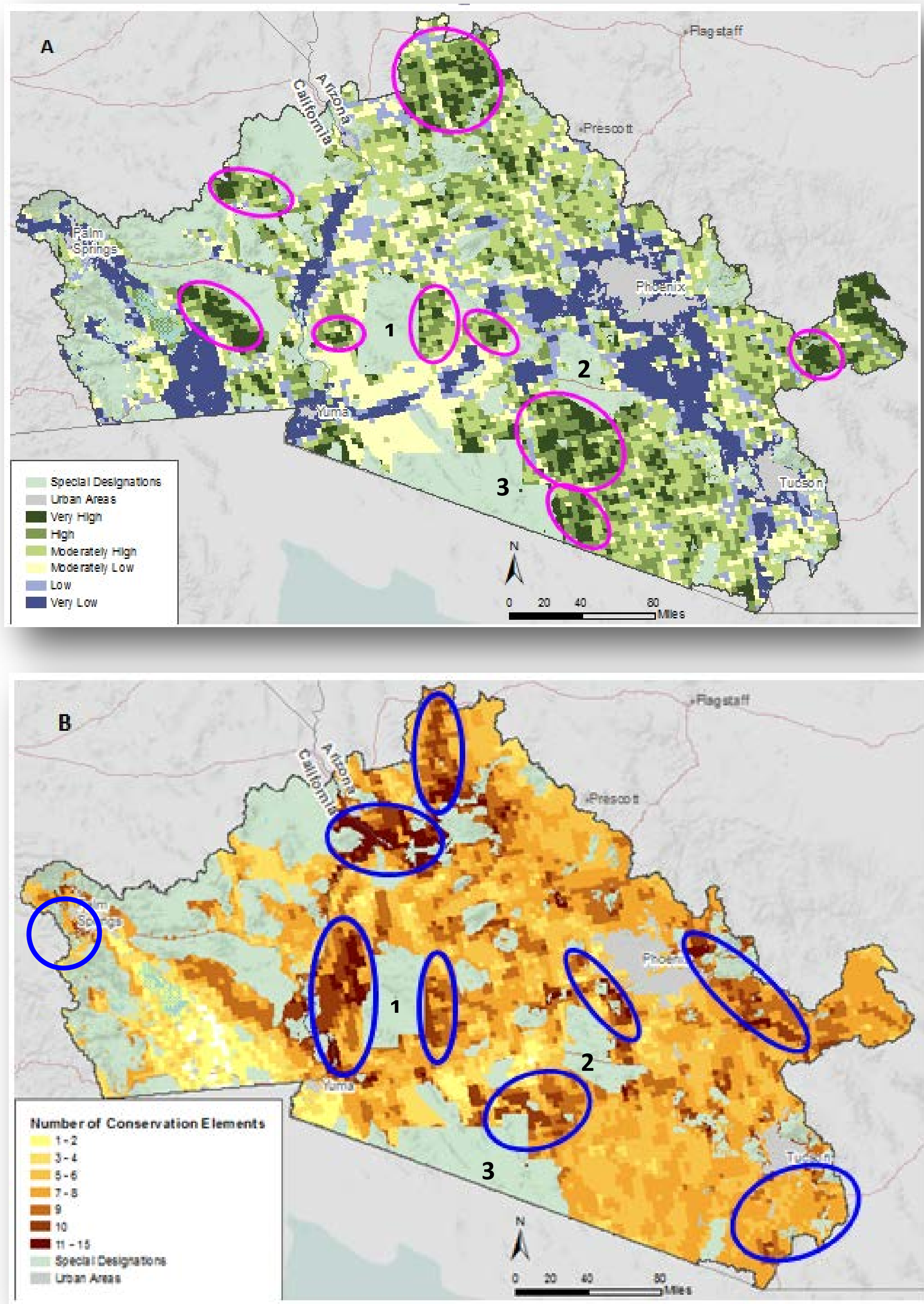


Figure 6-5. Maps of (A) terrestrial intactness for the Sonoran Desert ecoregion and (B) concentrations of conservation elements and resources of concern. Protected areas masked out in green. Numbers mark areas discussed in text. Areas of higher intactness outlined in pink in (A) and higher concentrations of species outlined in blue in (B).

Table 6-1 shows the results for all lands within the Sonoran Desert ecoregion. In this example, the matrix is organized into six different categories. The colored panels indicate High, Medium, and Low intactness classes (red, blue, and yellow, respectively) from left to right with increasing numbers of conservation elements from top to bottom (darker color tones for the higher concentrations of conservation elements). An accompanying map using the same color scheme is provided in Figure 6-6. Acres within each category may be viewed in different ways to assess management options and to inform policy decisions. For example, areas in dark red are those locations that contain high concentrations of conservation elements and the highest levels of landscape intactness. One could view these areas as places of high potential conflict or high protection value. Areas in the light yellow category (Low intactness and low concentrations of conservation elements) may be places where ongoing development is more acceptable assuming specific issues (protection of a rare species) are properly managed. Areas in dark blue (places with high concentrations of conservation elements combined with moderate intactness) may be the best locations for restoration to get the greatest return on investment.

AREA IN ACRES FOR ALL SONORAN DESERT LANDS BY NUMBER OF CONSERVATION ELEMENTS AND INTACTNESS CLASSES

NUMBER OF CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	15.2%		22.3%		16% 11,615	139,321	**150,936**
1	47,334	124,097	100,676	47,443	15,443	209,473	**544,466**
2	83,935	79,102	158,957	115,873	43,143	383,516	**864,526**
3	111,678	106,951	182,244	338,651	102,376	482,626	**1,324,525**
4	206,988	356,554	429,391	490,433	234,490	545,279	**2,263,135**
5	303,069	711,776	1,043,486	621,471	303,854	864,320	**3,847,975**
6	397,828	905,708	1,176,486	725,201	425,894	679,541	**4,310,659**
7	698,480	1,180,297	1,461,101	893,516	445,625	695,834	**5,374,853**
8	866,974	1,568,736	1,819,039	1,125,388	494,645	559,752	**6,434,534**
9	1,191,783	1,339,546	1,576,441	843,879	409,474	319,976	**5,681,098**
10	761,805	707,706	755,138	466,525	171,261	185,819	**3,048,255**
11	51,397	157,870	256,984	158,144	45,032	31,629	**701,056**
12	3,954	55,350	55,350	55,350	15,814	19,768	**205,587**
13		35,582	75,118	19,768	3,954	3,954	**138,376**
14	19.3%	3,954	20.7% 3,954	7,907	3,954		**19,768**
15					6.5% 3,954		**3,954**
Totals	**4,725,226**	**7,333,230**	**9,094,365**	**5,909,548**	**2,730,527**	**5,120,808**	**34,913,703**

Table 6-1. Table lists all lands for all ownerships across the Sonoran Desert with the number of conservation elements on the y-axis and columns for area of lands in 6 intactness classes. The colored panels indicate High, Moderate, and Low intactness classes (red, blue, and yellow, respectively) from left to right and lower and higher numbers of conservation elements (CEs) from top to bottom (lighter and darker colors, respectively). Blue numbers give the percentage of ecoregion acreage in each intactness class. Map with same color scheme (Figure 6-6) accompanies Table 6-1.

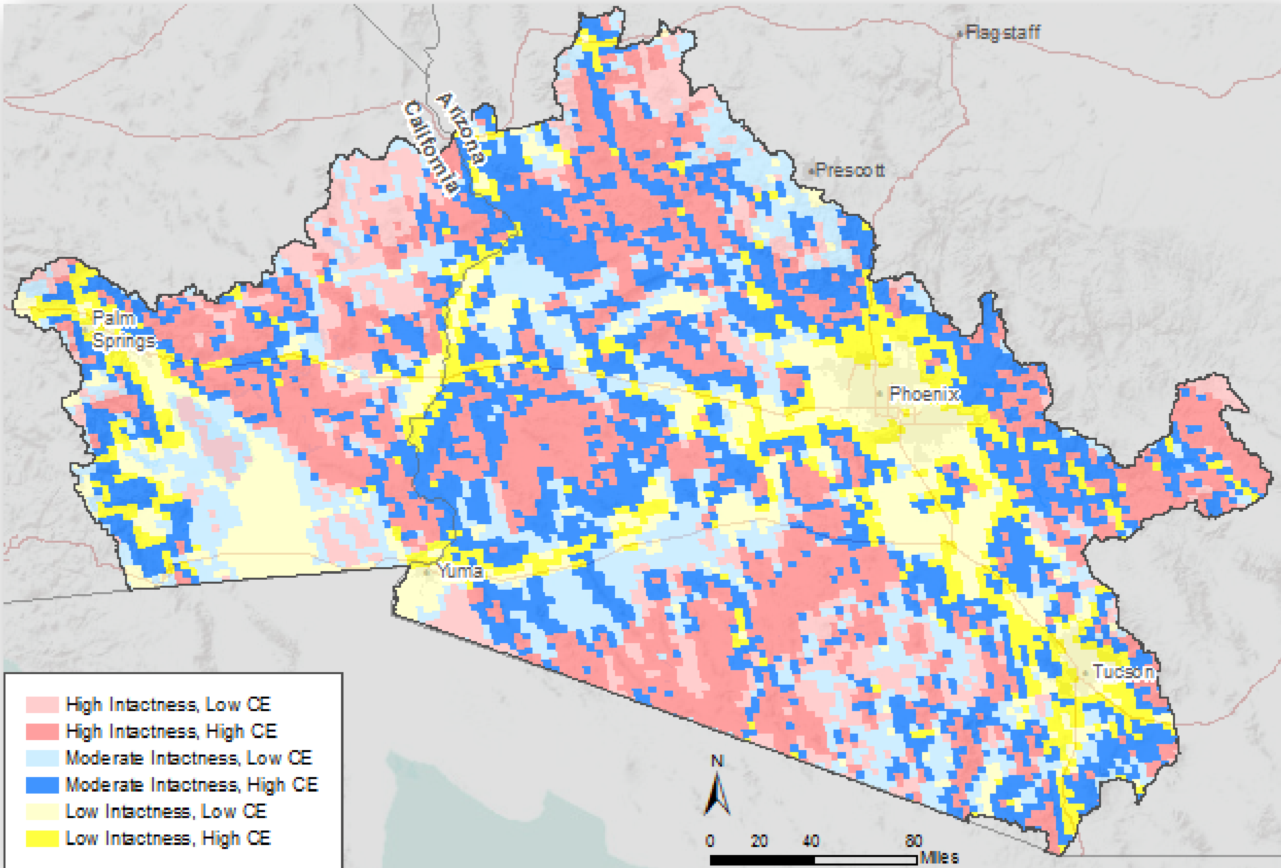


Figure 6-6. Map to accompany Table 6-1 showing 6 classes of intactness by number of CEs for all lands. Colors match color panels in Table 6-1.

Table 6-1 is just one example of how the matrix table can be organized. Depending on the circumstances and issues to be addressed, managers could organize the same data in different ways (Figure 6-7). The standard model presented here (Figure 6-7A) could be changed by increasing (Figure 6-7B) or decreasing (not shown) the threshold for conservation element concentrations. A simpler grid could be applied to the data using a 4 panel instead of a 6 panel organization (Figure 6-7C). Finally, the number of categories could be increased based on the range of conservation element concentrations or number of management options (Figure 6-7D). Managers could also take into account the rare species information by adding the heritage findings (the globally imperiled or threatened and endangered species shown in Figures 6-1B and C) into the matrix diagram. In addition to creating a useful matrix table, one could improve the approach by working at various scales (both regional and local) or within relatively homogeneous landscape areas (such as EPA level IV ecoregions), grouping species into guilds, or ranking species by sensitivity to disturbance.

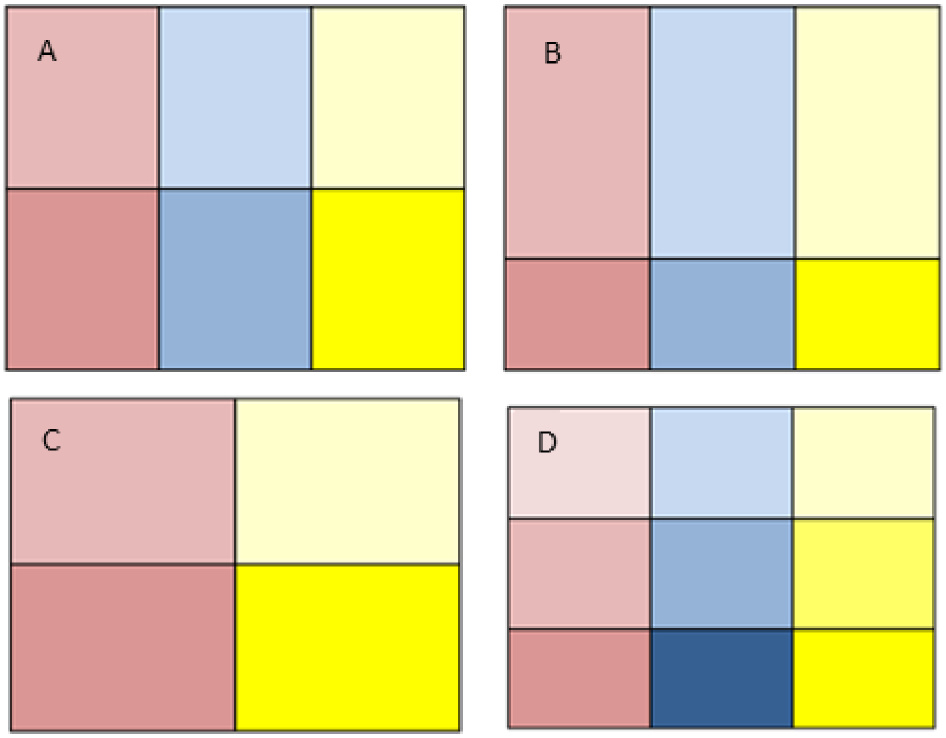


Figure 6-7. Matrix table diagrams offer different options for organizing data comparing concentration of conservation elements (y-axis) and relative landscape intactness (x-axis). Colors correspond to different categories for the combinations. These matrix tables would contain area information as presented in Table 6-1.

The analysis was rerun using the same approach that created Table 6-1, this time excluding all specially designated protected lands and all urban areas. The resulting matrix table (Table 6-2) and companion map (Figure 6-8) emphasize land areas in play across multiple ownerships and reduce the amount of land area being considered by approximately 29 percent (nearly 25,000,000 acres in Table 6-2 compared to nearly 35,000,000 acres in Table 6-1). Finally, although BLM managers will be pursuing a landscape approach to management that stresses cooperative planning across agencies and ownerships, they will also want to examine REA results for BLM lands only (Figure 6-9A, map of intactness on BLM lands and Figure 6-9B, concentrations of conservation elements on BLM lands with designated lands excluded); note maps are the same as those in Figure 6-5A and 6-5B but for BLM lands only). Table 6-3 and companion map (Figure 6-10) present the acreage information for BLM lands only outside of designated lands. The acreage total for BLM lands is almost 7,000,000 acres with over 2,000,000 acres in High or Very High intactness classes. About 785,000 acres of BLM lands, or 11% of the total, occur in the Very High intactness class. The figure is likely an overestimate of very highly intact lands because of inevitable data deficiencies.

AREA IN ACRES FOR ALL LANDS MINUS DESIGNATED SITES AND URBAN AREAS

NUMBER OF CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	14%		25.4%		17.6% 7,794	127,918	135,712
1	25,922	67,209	71,649	47,443	15,422	169,639	397,284
2	58,156	70,176	116,023	91,140	34,516	275,975	645,986
3	43,690	86,355	141,677	278,880	83,023	314,720	948,346
4	114,456	252,793	298,810	377,715	213,098	397,728	1,654,601
5	204,696	505,409	898,370	502,646	270,827	620,629	3,002,578
6	228,014	576,455	944,851	619,605	368,686	537,312	3,274,922
7	431,632	805,749	1,174,321	727,832	355,918	576,649	4,072,101
8	490,919	1,058,369	1,322,983	833,116	389,900	425,929	4,521,214
9	516,444	797,294	1,098,381	589,378	345,983	259,199	3,606,678
10	178,633	371,954	535,639	348,220	152,771	136,254	1,723,470
11	34,311	99,638	206,716	137,974	42,519	27,038	548,196
12	3,954	27,548	39,675	33,969	14,146	17,477	136,770
13		11,901	44,647	11,539	3,954	3,305	75,345
14		3,954	3,954	7,907	3,486		19,300
15	14.5%		21.1%		7.4% 3,615		3,615
Totals	2,330,827	4,734,803	6,897,695	4,607,365	2,305,656	3,889,773	24,766,119

Table 6-2. Table lists all lands minus areas of designated sites and urban lands across the Sonoran Desert with the number of conservation elements on the y-axis and six columns for area of lands in various intactness classes with acreage totals. Blue numbers give the percentage of ecoregion acreage in each intactness class.

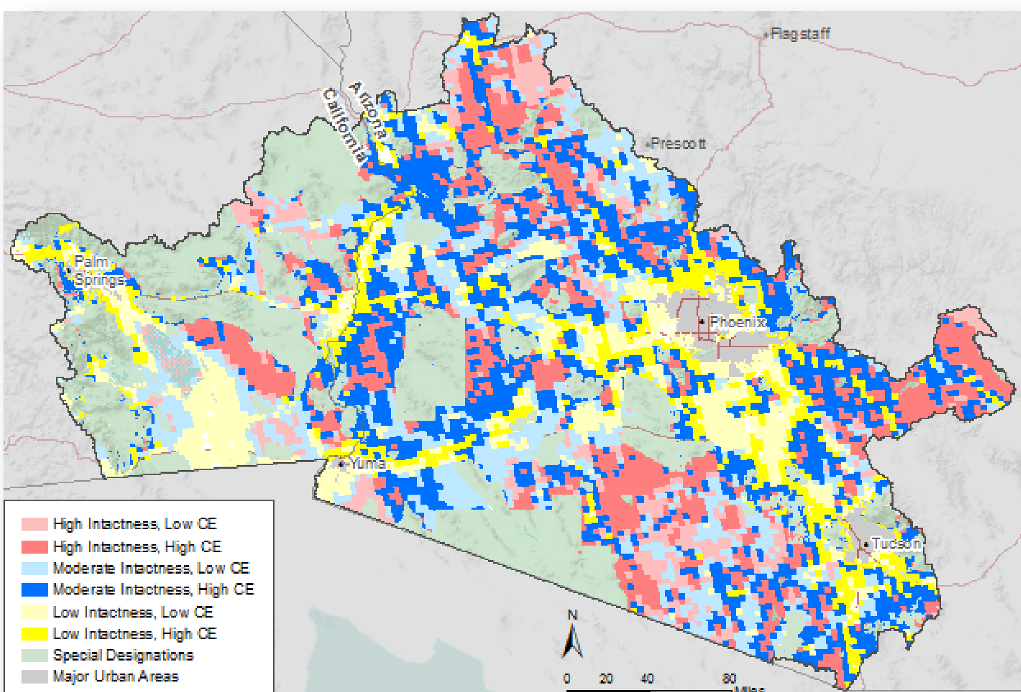
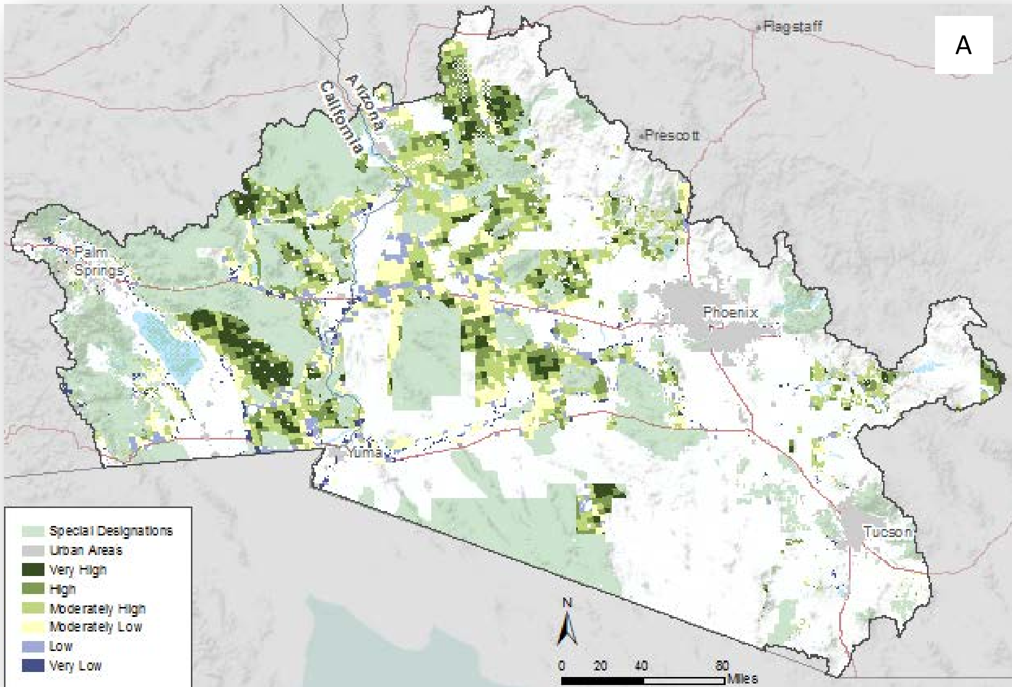


Figure 6-8. Map to accompany Table 6-2 showing 6 classes of intactness by high or low number of CEs. Colors match color panels in Table 6-2. Designated sites masked out in green.



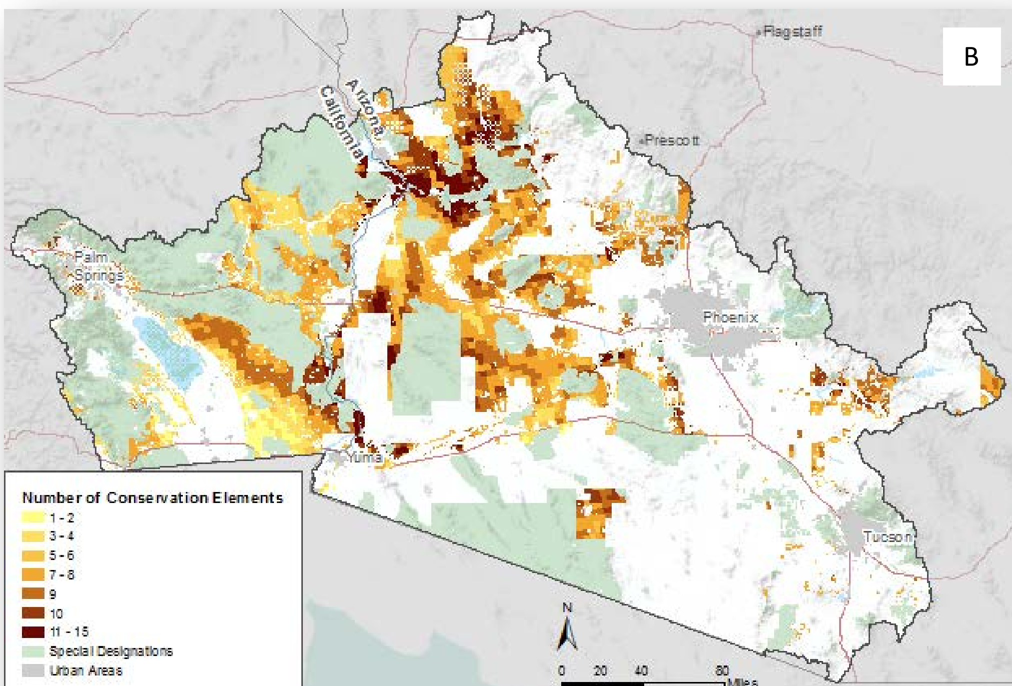


Figure 6-9. (A) Map of intactness for BLM lands outside of designated areas (light green). (B) Map of concentrations of conservation elements for BLM lands outside of designated areas (light green). These maps reproduce Figure 6-5A and 6-5B for BLM lands only.

AREA IN ACRES FOR BLM LANDS MINUS DESIGNATED AND URBAN AREAS

NUMBER OF CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	13.1%		23.6%		6.3% 6,927	566	**7,493**
1	5,358	12,315	23,610	56	4,450	606	**46,394**
2	21,124	26,091	47,428	24,352	13,572	10,948	**143,515**
3	21,283	46,327	76,995	69,558	26,908	17,172	**258,243**
4	45,760	131,043	106,372	138,038	51,879	25,811	**498,903**
5	27,404	108,711	226,608	98,623	54,082	19,326	**534,754**
6	57,880	117,337	191,184	164,093	78,288	24,160	**632,943**
7	81,971	209,360	299,964	172,001	70,280	33,170	**866,747**
8	21.9% 147,677	369,068	29.8% 481,719	264,576	5.3% 114,898	24,864	**1,402,802**
9	266,553	394,404	505,373	202,557	95,537	20,438	**1,484,861**
10	87,361	153,140	217,932	133,331	53,929	14,967	**660,660**
11	18,933	48,764	111,000	90,122	14,473	8,787	**292,079**
12	3,954	21,606	20,130	6,754	6,570	2,363	**61,377**
13		10,218	24,347	7,920	1,534	1,755	**45,774**
14		2,415	1,475	4,215	2,234		**10,340**
15					2,271		**2,271**
Totals	**785,257**	**1,650,800**	**2,334,138**	**1,376,196**	**597,832**	**204,933**	**6,949,156**

Table 6-3. Table lists all BLM lands minus areas of designated and urban lands for the Sonoran Desert with the number of conservation elements on the y-axis and six columns of area of lands in the various intactness classes with acreage totals. Blue numbers give the percentage of ecoregion acreage in each intactness class.

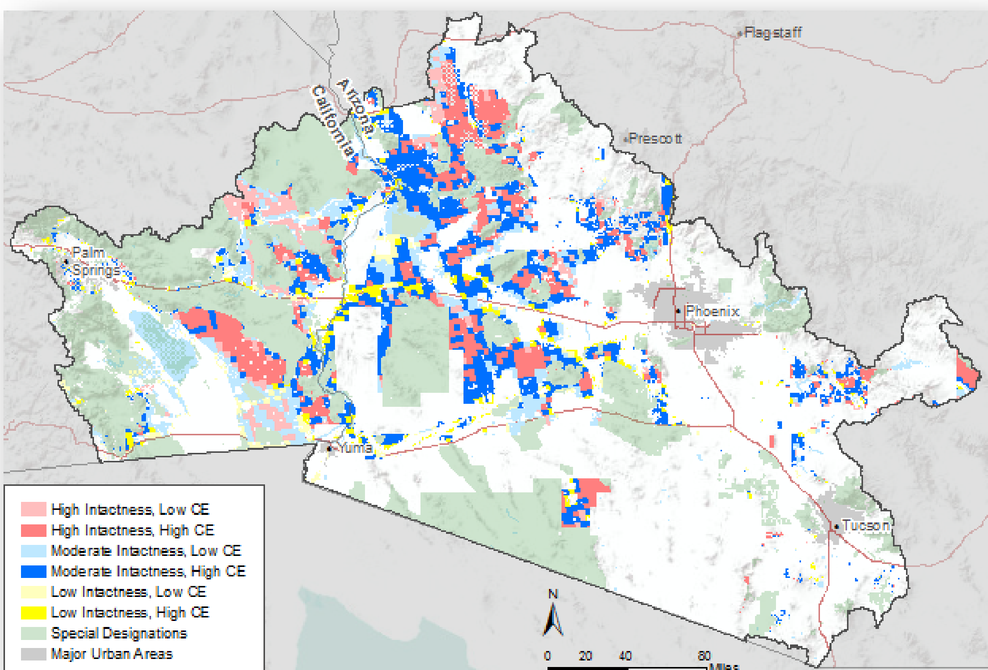


Figure 6-10. Map to accompany Table 6-3 showing 6 classes of intactness by high or low number of CEs for BLM lands minus designated and urban areas. Colors match color panels in Table 6-3.

6.2.2 Exposure of Resource Values to Change Agents

6.2.2.1 Current and Near-Term Future (2025) Development

The status of individual conservation elements relative to current and near-term future (2025) development was determined in Chapters 4 and 5. Areas where concentrations of high concentrations of conservation elements and species of concern are at risk from development pressures can be located as well (Figure 6-11A–D). Four major components of development were assessed for the ecoregion—energy, urbanization (including roads), agriculture, and recreational development—to create the *current* human development footprint (see development fuzzy logic model, Section 4.3.3). Reliable spatial data was available for all but recreation, which was difficult to acquire. Current energy development contained spatial data for both linear features (utility lines and pipelines) and point features (oil/gas wells, mines, and geothermal wells) as well as renewable energy priority projects. The urban development component of the fuzzy logic model averaged urban landcover density and road density based on the transportation data files provided by BLM. When key resource values are compared to the current development map results, the concentration of globally imperiled and threatened and endangered species in the eastern- and westernmost corners of the region and the conservation elements on either side of the Phoenix-Tucson corridor appear to be at the highest risk from development pressures (Figure 6-11A).

The *near-term future* (2025) development model was built from the logic model presented in Section 5.1, which contains the same four major development components—energy, agriculture, urbanization (including roads), and recreational development. Little predictive data were available for future projections; the model relied mainly on available data for future urban expansion and renewable energy, the two biggest development challenges to the ecoregion besides water availability, which could also limit development. The projected near-term renewable energy development included 2011 priority projects and some planned rights-of-way in California. Additional data for the California Desert Renewable Energy Conservation Plan (DRECP) was not developed in time for this assessment. The current and near-term development mapped results appear very similar, with visible changes occurring mostly in the Phoenix-Tucson corridor. Although it is difficult to see on the near-term development map (Figure 6-11B), the Very High development class grew by 1.5% and the High and Moderately High categories each gained about 0.5%., with urban expansion in the Phoenix-Tucson area and urban and renewable energy development along the western Interstate 10 corridor and in the southwestern corner of the ecoregion. In all, the development footprint increased by over 887,000 acres for the near-term (2025) development scenario. The concentrations of resource values (represented by the blue ellipses in Figure 6-11A–D) on the eastern and western ends of the ecoregion as well as those on either side of the Phoenix-Tucson corridor appear to be at greatest risk from increasing near-term future (2025) development (Figure 6-11B). The five remaining areas of resource value concentration in the north and south central portions of the ecoregion do not show visible changes from development pressure in the near term at this small scale. Much of the development pressure (urban, agricultural, and renewable energy development) occurs at lower elevations, and it affects many of the REA core conservation elements that frequent lower elevation habitats: riparian and xeroriparian areas, saltbush and creosotebush basins, and low foothills. However, although other species and habitats in somewhat higher elevations may not experience direct habitat conversion, they are subject to increasing negative effects at the development-wildland interface.

The third map, maximum potential energy development (Figure 6-11C), is more speculative—that is, not based on actual plans for development—with a longer term time frame. The maximum potential energy development results were developed from a fuzzy logic model with three major components—traditional oil and gas, wind energy, and solar energy.

Potential for oil, gas and geothermal development was created by buffering existing wells. Solar resource potential, defined as >5.5 kW/m^2, was obtained from the National Renewable Energy Laboratory (NREL) and added to solar priority projects, selected features from California BLM on verified and preliminary renewable energy rights-of-way, modified solar energy zones (SEZs), and Arizona restoration design energy project data (RDEP). NREL also provided potential wind development data defined by wind power density classes 3 and above at 50 m high. Full page maps for potential solar, wind, and maximum potential energy development across the ecoregion may be found in Chapter 5, Section 5.2, Potential Energy Development, Figures 5-3 through 5-5. Summarized in three classes at 4km resolution, the final composite map for all three energy components covered a fairly large area of the ecoregion (Figure 6-11C). For the ecoregion, over 7,000,000 acres (21%) were classified as having High Potential, almost 3,900,000 acres (11%) Moderate Potential, and almost 24,000,000 acres (68%) Low Potential. Two concentrations of resource values in the far west and central portions of the ecoregion appear to be at highest risk for change from potential energy developments.

Summary tables for future energy development (predominantly renewable energy) accompany the mapped results (Tables 6-4, 6-5, and 6-6). For the summary tables, categories of land area were assessed for the 4 km intactness surface using the intersection of the additional area of future developments and the total concentration of conservation elements per 4 km grid cell. For greater clarity in tracking development types and land areas, the acreage tables were subdivided by adding a third category to create near-term (solar and wind priority projects, Table 6-4), mid-term (near-term projects plus modified SEZs and RDEP, Table 6-5), and maximum potential (or long-term = near-term and mid-term plus NREL wind and solar potential) energy development (Table 6-6).

AREA IN ACRES OF LAND SURFACE AFFECTED BY NEAR-TERM (2025) ENERGY DEVELOPMENT BY NUMBER OF CONSERVATION ELEMENTS AND INTACTNESS CLASS

# of CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	4.9%		46.2%		18.7%		
1							
2							
3				7,556	10,225		17,781
4		1,333	3,731	10,747	2,537	853	19,201
5		2,734	767	4,944	3,726	534	12,705
6		1,230	12,190	10,222	1,886	515	26,043
7	2.2% 26	1,345	15.5% 739	3,744	12.5% 3,772	330	9,956
8		837	1,790	4,013	9,414		16,054
9		182	5,994	300			6,476
10				265			265
11							
12							
13							
Totals	**26**	**7,661**	**25,212**	**41,792**	**31,559**	**2,232**	**108,480**

Table 6-4. Table shows area in acres of land surface in various intactness classes and number of conservation elements affected by near-term (2025) energy development. Near-term energy development is defined by a number of identified 2011 renewable energy priority projects in California and Arizona that are in the approval process.

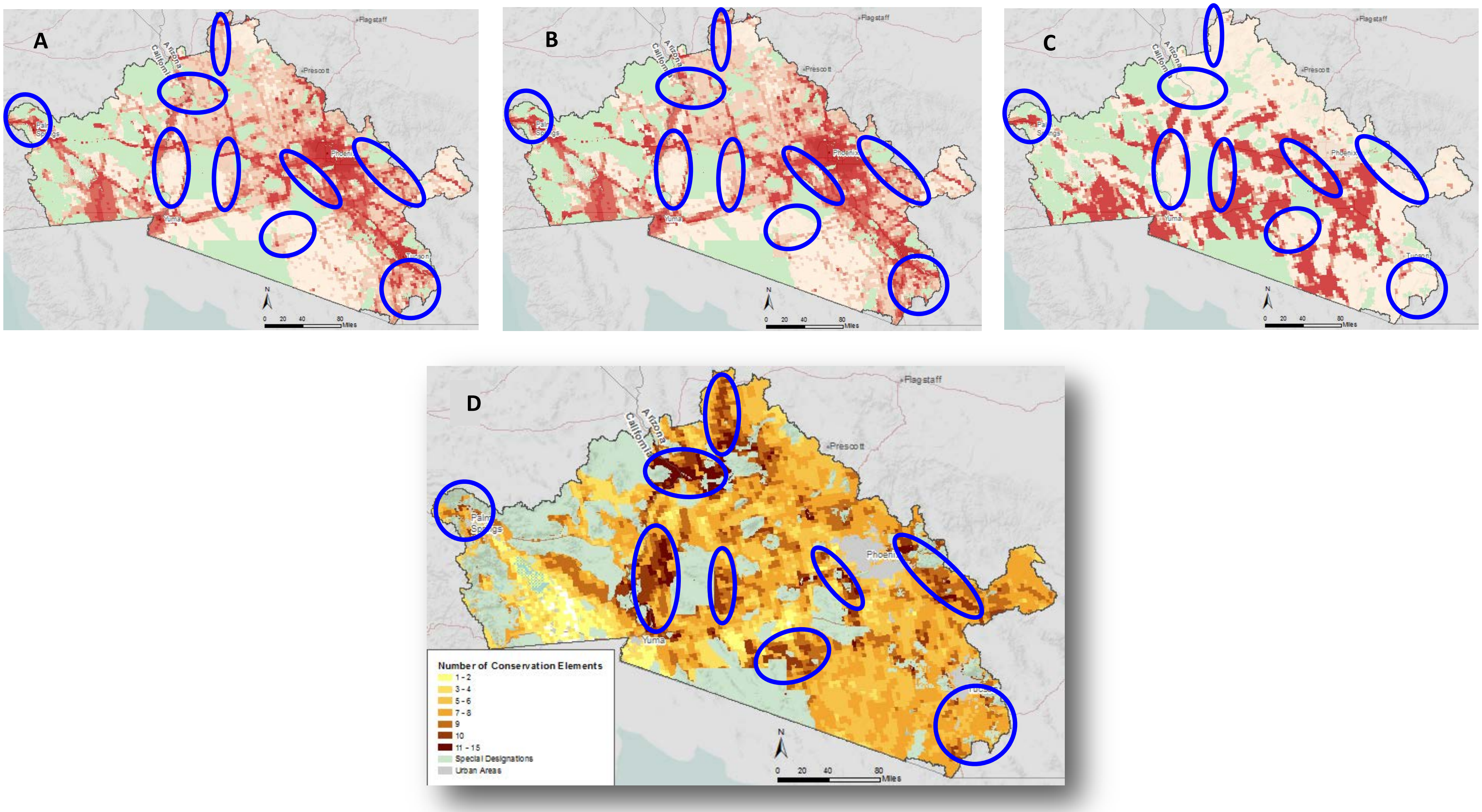


Figure 6-11. Maps indicate (A) current development footprint, (B) near-term future development (2025), (C) future maximum (long term) potential renewable energy development (priority projects, NREL solar energy zones, solar and wind potential), and (D) concentrations of conservation elements and species of concern. On all maps, blue ellipses identify corresponding areas with high concentrations of conservation elements and species of concern. Protected areas masked out in light green.

AREA IN ACRES OF LAND SURFACE AFFECTED BY MID-TERM RENEWABLE ENERGY DEVELOPMENT BY NUMBER OF CONSERVATION ELEMENTS AND INTACTNESS CLASS

# of CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	7.2%		22.2%		30.6%	4	**4**
1		78	1,793		509	6,522	**8,901**
2	3,266	2,476	3,470	9,980	1,347	15,766	**36,303**
3	7	3,954	5,317	17,475	12,581	22,747	**62,080**
4	5,311	33,081	33,489	57,667	34,632	78,044	**242,225**
5	9,774	28,195	36,774	61,400	44,138	103,959	**284,240**
6	4,854	18,102	50,092	60,574	49,573	96,485	**279,681**
7	4.9% 6,980	34,117	18.5% 63,719	66,127	16.6% 37,919	89,370	**298,232**
8	4,943	21,236	36,051	47,653	31,143	33,761	**174,788**
9	392	2,526	33,306	24,563	26,948	14,110	**101,845**
10	1,191	2,968	3,693	6,334	4,871	15,469	**34,526**
11				886			**886**
12							**0**
13				15		32	**46**
Totals	**36,719**	**146,732**	**267,703**	**352,675**	**243,661**	**476,268**	**1,523,758**

Table 6-5. Table shows area in acres of land surface in various intactness classes and number of conservation elements affected by mid-term renewable energy development. Mid-term renewable energy is defined by recent priority projects, modified solar energy zones (SEZs), restoration design energy projects (RDEP), and some planned rights-of-way in California.

AREA IN ACRES OF LAND SURFACE AFFECTED BY POTENTIAL RENEWABLE ENERGY DEVELOPMENT BY NUMBER OF CONSERVATION ELEMENTS AND INTACTNESS CLASS

# of CONSERVATION ELEMENTS	Very High	High	Moderately High	Moderately Low	Low	Very Low	Totals
0	11.1%		25.2%		30.3% 6,968	125,247	**132,216**
1	21,683	20,270	48,953	47,185	14,471	167,332	**319,894**
2	59,588	50,802	88,008	69,626	21,663	239,516	**529,203**
3	28,430	53,331	88,758	210,172	51,778	255,693	**688,162**
4	44,003	120,376	141,576	242,539	110,792	307,759	**967,044**
5	55,331	167,562	258,179	207,745	114,796	524,463	**1,328,076**
6	44,428	240,964	406,506	249,621	152,740	379,724	**1,473,981**
7	4.9% 38,830	128,949	15.5% 234,026	291,981	12.8% 126,522	361,659	**1,181,969**
8	36,223	144,897	171,628	168,455	98,001	186,821	**806,025**
9		22,197	135,621	109,946	78,931	95,343	**455,207**
10		21,779	54,745	55,629	23,143	55,620	**227,037**
11		3,063	17,625	19,013	2,077	6,180	**47,958**
12			461	471	789	5,607	**7,328**
13			459	2,934		660	**4,053**
Totals	**328,518**	**974,191**	**1,646,544**	**1,675,317**	**802,671**	**2,711,625**	**8,168,154**

Table 6-6. Land area in various intactness classes and number of conservation elements affected by maximum potential renewable energy development. Maximum potential renewable energy development subsumes near-term priority projects, mid-term projects described in Table 6-5, plus NREL wind and solar potential areas over an indeterminate, longer-term time frame.

6.2.2.2 Current and Future Risk from the Spread of Invasive Species

Urban area and invasive projections (see logic model Section 5.3) were updated for the near-term future (2025) terrestrial landscape intactness model. The change in urban area and in areas affected by renewable energy development relative to concentrations of conservation elements was covered in the previous future development section (6.1.2.1). The only other future projection data available was that for the spread of invasive species, based on the potential expansion of Sahara mustard as predicted by a MaxEnt model using future climate inputs. The near-term future distribution of Sahara mustard was estimated by projecting the existing model against near-term climate (RegCM3 based on ECHAM5 boundary conditions for 2015–2030). The small amount of increase in invasives shown in the near-term future (Map 6-12A) may indicate that the original MaxEnt model depicting current condition was generous in predicting potential area based on physical and climatic factors, leaving only a small area of increase based on future climate changes. The near-term (2025) change attributed to the spread of invasives shows the highest impacts in the Interstate corridors and areas surrounding Phoenix and Tucson (Figure 6-12). Concentrations of resource values located in the west-central portion of the ecoregion (that were not as affected by development pressures as were others in highlighted areas closer to urban centers, Figure 6-11B) are most highly exposed to the spread of invasive species.

6.2.2.3 Future Risk from Climate Change

The MAPSS climate results were used to predict changes in temperature, precipitation, potential evapotranspiration, and runoff; a number of the key findings from these analyses were selected to assemble into an overall relative climate change map that can be used to assess the relative exposure of the specific conservation elements to climate change effects (Chapter 5, Section 5.4). The fuzzy model inputs included potential for summer temperature change and potential for winter temperature change averaged into a single factor, potential for runoff change from MAPSS modeling, potential for precipitation change, and potential for vegetation change again from MAPSS modeling. Direction of the change is not important—only degree of departure from historic measures. Areas most likely to show the most serious changes are those that either are predicted to change in their vegetation type or as a combination of all the other factors (temperature, precipitation, and runoff). Results were mapped in five separate classes: Very High, High, Moderate, Moderately Low and Low potential for an area to be affected by climate change (Figure 6-13A). Individual species and vegetation communities' response to climate change were presented in Section 5.4. Of the vegetation communities, the lower elevation shrublands in the western portion of the Sonoran Desert show the highest exposure to climate change. Higher elevation areas show less potential for change as expected and may serve as potential refugia. Another area in the northeastern portion of the region shows Very High to Moderately High potential for change. When the climate change map (with designated areas removed, Figure 6-13B) is compared to the map of concentrations of conservation elements and species of concern (Figure 6-13C), most of the species hotspots (outlined in royal blue) are in the Moderate to Moderately Low potential exposure categories. The areas east of Phoenix, in the northern portion, and the west central portion of the ecoregion are in the higher exposure categories. The concentration of threatened and endangered species in the northwest near Palm Springs may be somewhat buffered by proximity to the coast range and somewhat higher elevation 134 m (440 ft.) relative to the Salton Sea basin that is below sea level (therefore hotter) and in full rain shadow (drier).

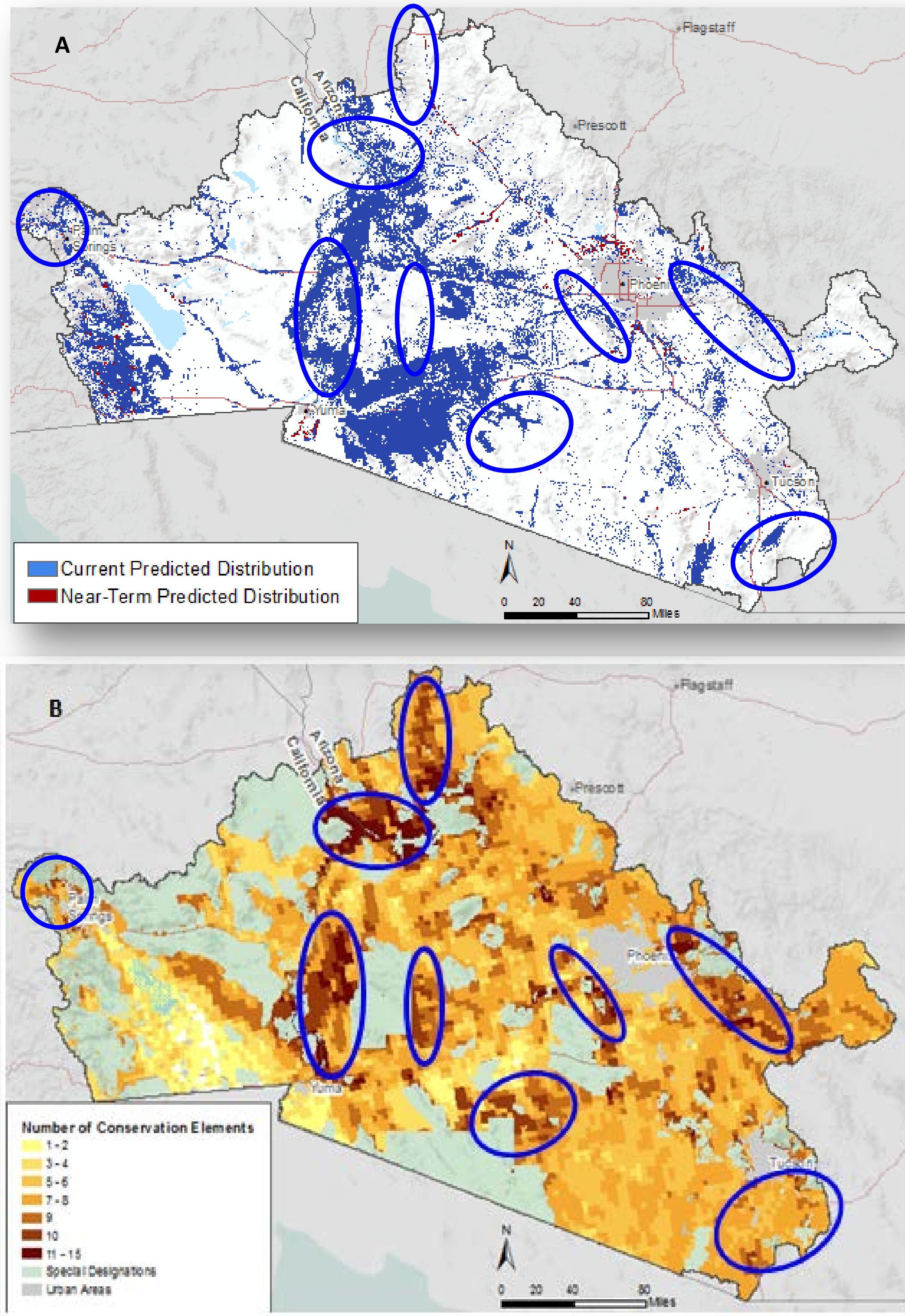


Figure 6-12. Maps show (A) current (in blue) and near-term future (2025, in red) distribution of invasive species compared to (B) concentrations of resource values with designated sites shown in green.

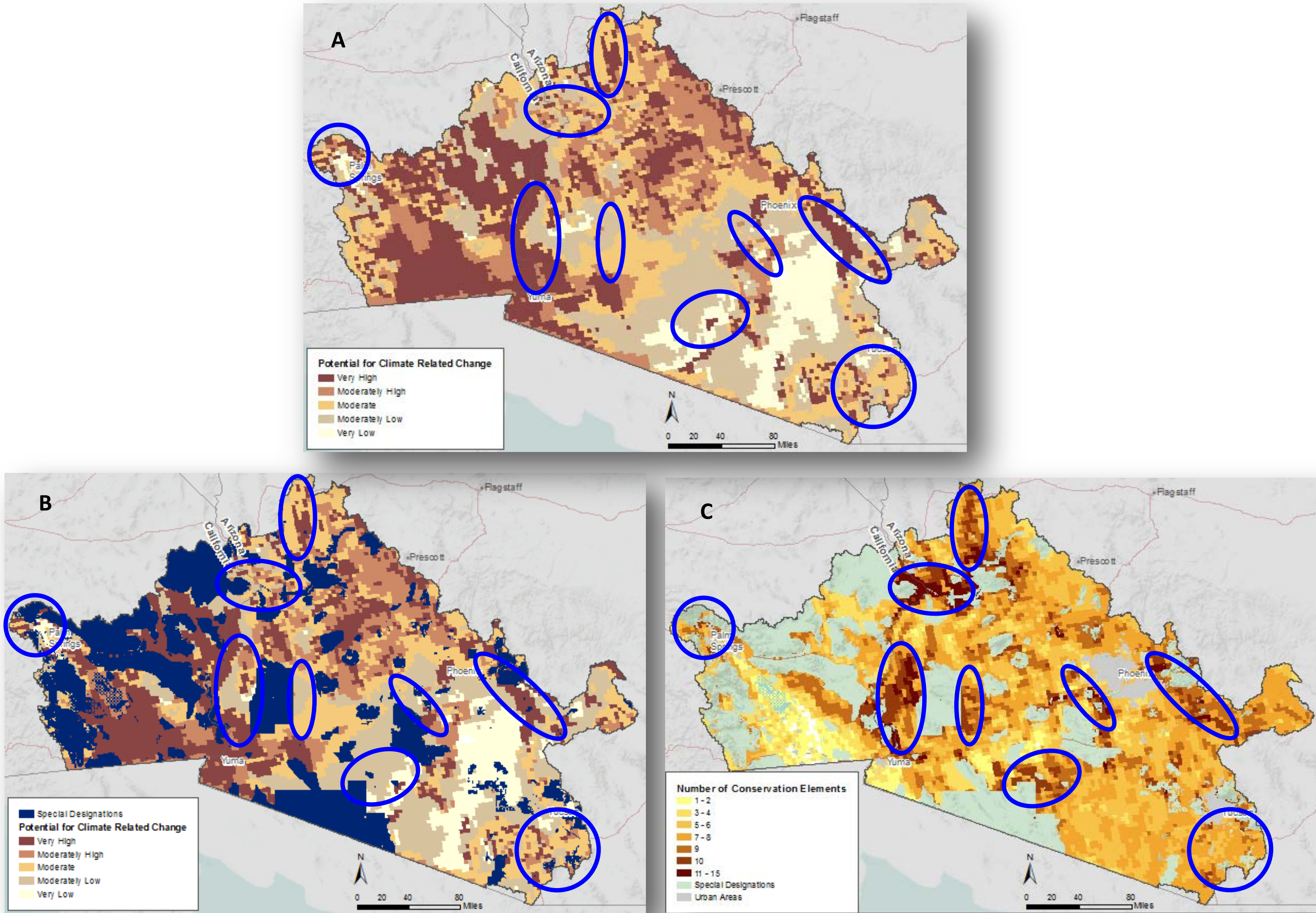


Figure 6-13. Maps of (A) climate change potential (2060), (B) climate change map with designated areas masked in blue, and (C) concentrations of conservation elements. Blue ellipses identify highest concentrations of resource values and allow comparison among the maps.

6.2.3 Connectivity

One of the REA management questions asked, Where are potential areas to restore connectivity? Managers can use the intactness results and the concentrations of resource values presented in this chapter to examine connectivity at various scales across the region.

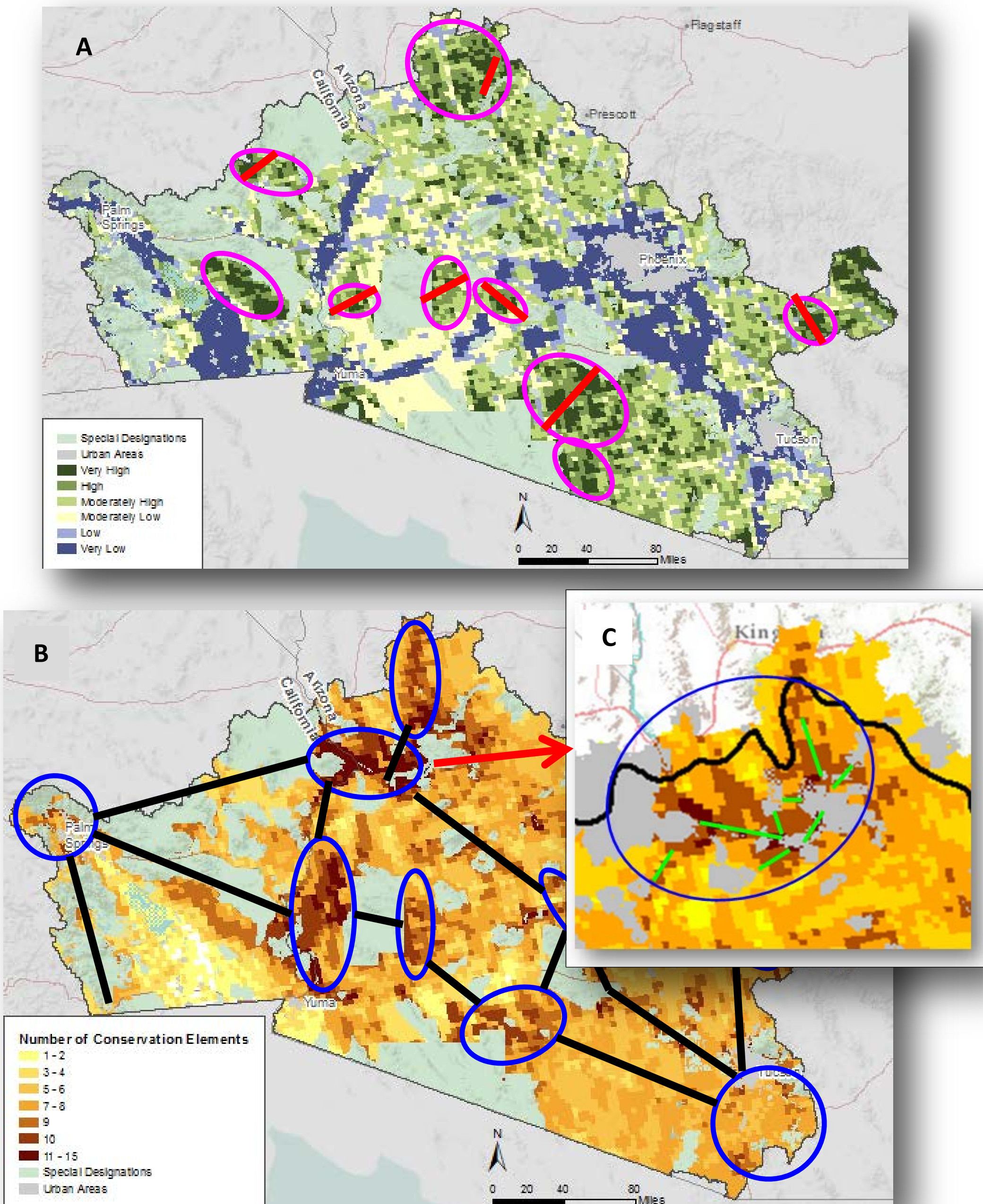


Figure 6-14. Various ways to approach connectivity: at a broad scale (A) between protected areas through corridors of higher landscape intactness, (B) among concentrations of resource values across protected areas as stepping stones, and (C) at a finer scale among protected areas to capture concentrations of resource values.

In Chapter 4, Section 4.2.3.2, a map of a least-cost path analysis was presented for Natural Landscape Blocks for California (Spencer et al. 2010) and general corridor mapping in Arizona (AZDOT 2006) and combined as one scenario of connectivity in the ecoregion. Although a least-cost path analysis should be done at a finer grain than these 4 km grid results, there is value in a regional overview to ponder and assimilate patterns of resource values and the distribution of existing protected areas. Options include searching for corridors and habitat blocks between existing protected areas through patches of higher landscape intactness or among concentrations of resource values across the stepping stones of existing protected areas (Figure 6-14A and B). Once areas of interest are located at a broad scale, evaluations can continue at a finer scale to buffer or connect existing protected areas within an area of interest (Figure 6-14C). In the inset example, connectivity pathways connect a network of wilderness areas, wilderness study areas, and ACECs to the Colorado River to the west and to the adjoining uplands to the east.

6.3 Conclusion

The examples presented in this chapter and Chapter 5 offer a few of the many ways this wealth of REA data and maps may be examined depending on project objectives, area of interest, species of concern, and present or future time frames. All that is required of the user is an understanding of the relatively coarse resolution of the results and an ability to translate the results between scales, from regional to local. Application of the results of the current and near-term future intactness models and conservation element status determinations also depend on an understanding of the limitations of a rapid ecoregional assessment of this kind. The effort is fundamentally limited by available spatial data and ecological thresholds so important to tailoring the logic models. These aspects are only likely to improve in the future as the geospatial technology and science evolve.

This REA will serve as a baseline for future efforts in the Sonoran Desert ecoregion. This REA effort provided the opportunity to inventory available information, to collect and archive an atlas of useful spatial data, and to produce hundreds of mapped products. Users may find information about access to the data at http://www.blm.gov/wo/st/en/prog/more/climatechange.html. The models are well documented and are flexible enough to be modified and improved with the addition of new data. Using the baseline current scenario, the REA components are designed for periodic updating to track the ecological status of Sonoran Desert conservation elements as they respond to landscape change and adaptive management in the coming years.

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Photo: Cholla cactus flowers, Saguaro National Park, National Park Service.

Glossary and Acronym List

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

ArcGRID: A raster GIS file format developed by Esri**.** The grid defines geographic space as an array of equally-sized square grid points arranged in rows and columns. Each grid point stores a numeric value that represents a geographic attribute for that unit of space. Each grid cell is referenced by its xy coordinate location.

Areas of Critical Environmental Concern (ACEC): Areas within the public lands where special management attention is required to protect and prevent irreparable damage to important historic, cultural, or scenic values, fish and wildlife resources or other natural systems or processes.

Assessment Management Team (AMT): A group of BLM managers that provides overall direction and guidance to the REA and makes decisions regarding ecoregional goals, resources of concern, conservation elements, change agents, management questions, tools, methodologies, models, and output work products.

C_3: Cool-season plants in which carbon dioxide is first fixed into a compound containing three carbon atoms before completing the photosynthesis cycle.

C_4: Warm-season plants in which carbon dioxide is first fixed into a compound containing four carbon atoms before entering the photosynthesis cycle.

C**hange Agent:** An environmental phenomenon or human activity that can alter or influence the future status of resource condition. Some change agents (e.g., roads) are the result of direct human actions or influence. Others (e.g., climate change, wildland fire, and invasive species) may involve natural phenomena or be partially or indirectly related to human activities.

Coarse Filter: A focus of ecoregional analysis that is based upon conserving resource elements that occur at coarse scales, such as ecosystems, rather than upon finer scale elements, such as specific species. The concept behind a coarse filter approach is that preserving coarse-scale conservation elements will also preserve elements occurring at finer spatial scales.

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. Conceptual models are also supported and referenced by scientific literature.

Conservation Element: A renewable resource object of high conservation interest.

Development: A type of change (change agent) resulting from urbanization, industrialization, transportation, mineral extraction, water development, or other human activities that occupy or fragment the landscape or that develop renewable or non-renewable resources.

Ecological Integrity: The ability of an ecological system to support and maintain a community of organisms that have the species composition, diversity, and functional organization comparable to those of natural habitats within the ecoregion.

Ecoregion: An ecological region or ecoregion is defined as an area with relative homogeneity in ecosystems. Ecoregions depict areas within which the mosaic of ecosystem components (biotic and abiotic as well as terrestrial and aquatic) differs from those of adjacent regions.

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

Fine Filter: A focus of ecoregional analysis that is based upon conserving resource elements that occur at a fine scale, such as specific species. A fine-filter approach is often used in conjunction with a coarse-filter approach (i.e., a coarse filter/fine-filter framework) because coarse filters do not capture every management concerns, such as management of endemic species.

Geographic Information System (GIS): A computer system designed to collect, manage, manipulate, analyze, and display spatially referenced data and associated attributes.

Habitat: A place where an animal or plant normally lives for a substantial part of its life, often characterized by dominant plant forms and/or physical characteristics.

Hydrologic Unit: An identified area of surface drainage within the U.S. system for cataloging drainage areas. The drainage areas are delineated to nest in a multilevel, hierarchical arrangement.

Intactness: Intactness may be mapped as 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.

Invasive Species: Species that are not part of (if exotic non-natives) or are a minor component of (if native), an original community that have the potential to become a dominant or co-dominant species if their future establishment and growth are not actively controlled by management interventions, or that are classified as exotic or noxious under state or federal law.

Landscape Species: Landscape species use large, ecologically diverse areas. The species often have significant impacts on the structure and function of natural ecosystems.

Logic Model: A logic model is a cognitive map that presents spatial data components and their logical relationships to explain the process used to evaluate a complex topic. Logic models are constructed in a hierarchical fashion relying on symbols, colors, labels, and the physical arrangement of components to communicate how a series of spatial datasets are assembled and analyzed to answer a particular question.

Management Questions: Questions from decision-makers that usually identify problems and request how to fix or solve those problems.

Model: Any representation, whether verbal, diagrammatic, or mathematical, of an object or phenomenon. Natural resource models typically characterize resource systems in terms of their status and change through time.

Native Species: Species that historically occurred or currently occur in a particular ecosystem that were not introduced.

Population: Individuals of the same species that live, interact, and migrate through the same niche and habitat.

Process Models: Process models are diagrams that map out data sources, GIS analyses, and workflow. Process models present the spatial analysis details and allow for repeatability of the same or similar model in the future

Rapid Ecoregional Assessment (REA): The methodology used by the BLM to assemble and synthesize regional-scale resource information, which provides the fundamental knowledge base for devising regional resource goals and priorities on a relatively short time frame (less than 2 years).

Resource Values: As presented in the applications of results in Chapter 6, *resource values* was a phrase used to describe the collection of REA conservation elements plus additional species of concern—NatureServe G1–G3 species and USFWS threatened and endangered species that were used in applications map comparisons.

Status: The condition of a criterion (biological or socio-economic resource values or conditions) within a geographic area (e.g., watershed, grid). A rating (e.g., low, medium, or high) or ranking (numeric) is assigned to specific criteria to describe status.

Step-Down: A step-down is any action related to regionally-defined goals and priorities discussed in the REA that are acted upon through actions by specific State and/or Field Offices. These step-down actions can be additional inventory, a finer-grained analysis, or a specific management activity.

Acronyms

AM	Arbuscular Mycorrhizal
AMT	Assessment Management Team
AUC	Area Under the Curve
ArcGIS	Arc Geographic Information System
BpS	Biophysical Setting
BLM	Bureau of Land Management
CO_2	Carbon Dioxide
CE	Conservation Element
CCVI	Climate Change Vulnerability Index
DEM	Digital Elevation Model
ECHAM5	European Centre Hamburg, Version 5
EMDS	Ecosystem Management Decision Support
EPA	Environmental Protection Agency
ENSO	El Nino Southern Oscillation
EVT	Existing Vegetation Type (LANDFIRE)
FGDC	Federal Geographic Data Committee
FRAGSTATS	Fragmentation Statistics software
FRCC	Fire Regime Condition Classification

G-1, G-3	Globally Imperiled-Globally Vulnerable
GCM	Global Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GENMOM	GENesis-Modular Ocean Model
GIS	Geographical Information System
HMAs	Herd Management Areas
HUC	Hydrologic Unit Classification
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
LAI	Leaf Area Index
LANDFIRE	LANDscape FIRE and Resource Management Planning Tools Project
MAPSS	Mapped Atmosphere Plant Soil System
MaxEnt	Maximum Entropy model
MQ	Management Question
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NetCDF	Network Common Data Form
NHD	National Hydrography Dataset
NREL	National Renewable Energy Laboratory
OHV	Off-Highway Vehicles
PET	Potential Evapotranspiration
PFT	Plant Functional Type
PRISM	Parameter-elevation Regressions on Independent Slopes Model
REA	Rapid Ecoregional Assessment
RegCM3	Regional Climate Model Version 3
RMP	Resource Management Plan
SSURGO	Soil Survey Geographic database
STATSGO	State Soil Geographic
SOW	Statement of Work
SW ReGAP	Southwest Regional Gap Analysis Project
TNC	The Nature Conservancy
URTD	Upper Respiratory Tract Disease
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey