MADREAN ARCHIPELAGO
RAPID ECOREGIONAL ASSESSMENT

EXECUTIVE SUMMARY

Executive Summary of Final Report for

U.S. Department of the Interior
Bureau of Land Management
Rapid Ecoregional Assessments

December 23, 2014

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

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COVER PHOTO

Near Elgin and Audubon Research Ranch
Tahnee Robertson, Southwest Decision Resources

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U.S. Department of the Interior Bureau of Land Management Rapid Ecoregional Assessments

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1 Executive Summary

This executive summary describes the breadth of the entire Madrean Archipelago (MAR) Rapid Ecoregional Assessment (REA) and illustrates examples from all of the products. It does not summarize methods but instead focuses on products, key findings, and limitations. Because of the breadth and number of assessments, this summary is necessarily longer than a typical executive summary and is intended to give a brief but fairly complete picture of the MAR REA results.

1.1 Rapid Ecoregional Assessments: Purpose and Scope

Working with agency partners, the BLM is conducting rapid ecoregional assessments (REAs) covering approximately 800 million acres of public and non-public lands in 14 ecoregions and combinations of ecoregions in the American West. The goal of the REAs is to characterize the status of ecological resources and their potential to change from a landscape viewpoint. REAs are intended to serve BLM's developing Ecoregional Direction that links REAs and the BLM's Resource Management Plans and other on-the-ground decision-making processes. Ecoregional Direction establishes a regional roadmap for reviewing and updating Resource Management Plans; developing multi-year work for identified priority conservation, restoration, and development areas; establishing Best Management Practices for authorized use; designing regional adaptation and mitigation strategies; and developing conservation land acquisitions. While REAs produce information designed to be integrated into specific management processes, they are not decision documents and stop short of integrating the findings into management actions.

1.2 Organization of the MAR REA Final Report

This report for the Madrean Archipelago Rapid Ecoregional Assessment (MAR REA) conveys the objectives, methods, and results of the MAR REA. The report is arranged as the main report and a series of nine appendices:

A. Methods for Selecting and Evaluating Feasibility for Conservation Elements, Change Agents, and Assessments
B. Assessment Methods: Approaches and Rationales
C. Technical Methods: GIS Documentation
D. Terrestrial Ecological Systems: Conceptual Models and Ecological Status
E. Aquatic Ecological Systems: Conceptual Models and Ecological Status
F. Species: Conceptual Models and Ecological Status
G. Ecoregional Conceptual Model and Ecological Integrity Assessment
H. Mesquite Scrub Expansion: Restoration Opportunities
I. Climate Change: Assessment Methodology and Results

1.2.1 Common Terminology

Following are key terms and abbreviations used throughout the report; a complete listing of terms and abbreviations is found in the glossary and acronym list in Appendix E.

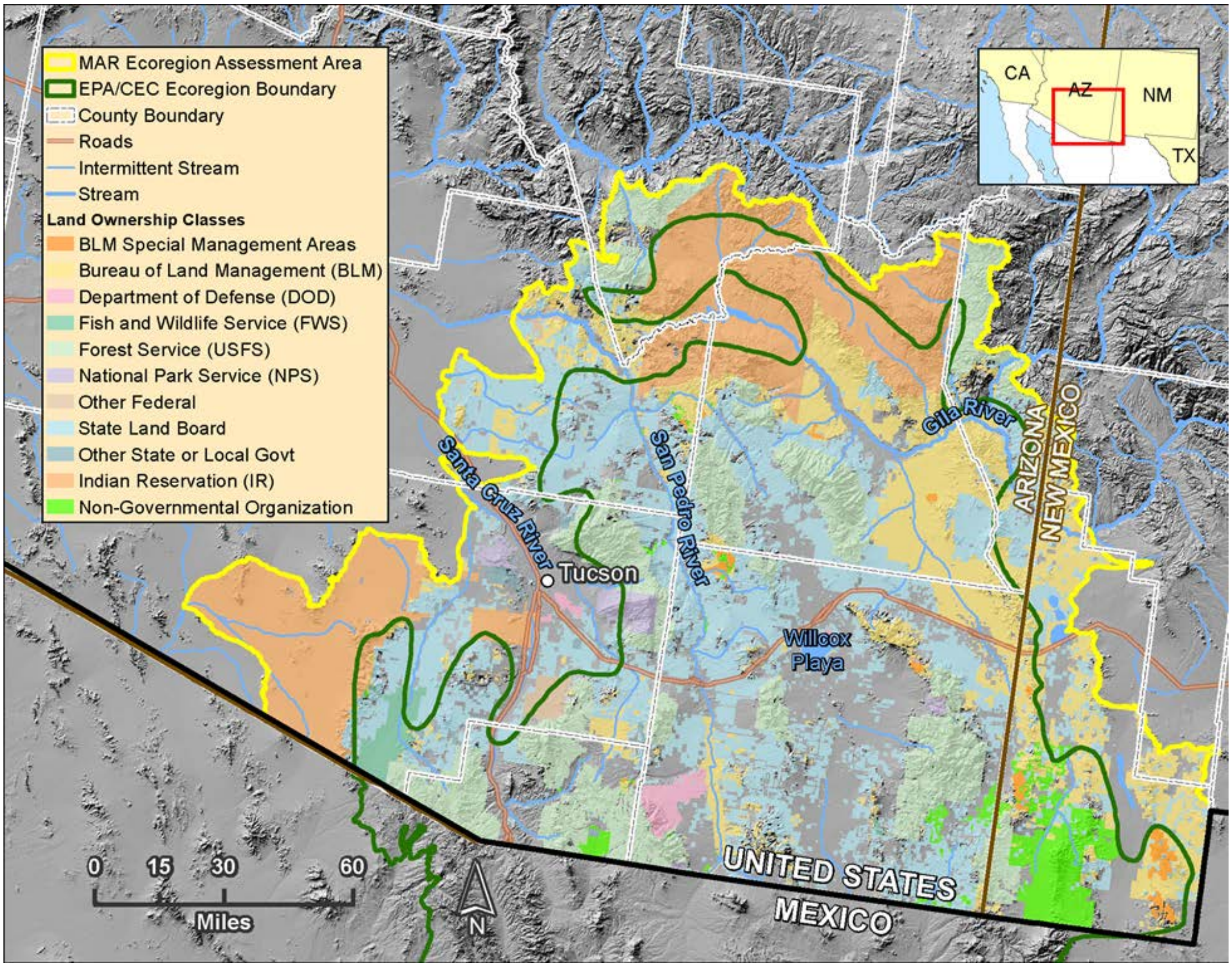
- **AMT**: **Assessment Management Team**. This is the team of BLM staff and participating partners in the region that provided review and guidance for the contractor throughout the REA.

- **CA**: **Change Agent**. These are the features or processes that can negatively impact **conservation elements** (and in some cases can have neutral or beneficial effects on certain CEs). Development, invasive species, fire, and climate change effects are the four primary change agents addressed in this REA.
- **CE**: **Conservation Element**. These are the natural resource features assessed in the REA and include terrestrial and aquatic ecological systems, species, and species assemblages.
- **CE conceptual model**: Conceptual models are the descriptive text and accompanying graphics that characterize the ecology and biology of the CEs, including descriptions of how change agents are expected to affect the **ecological status** or **condition** of CEs.
- **CE response model:** The set of numeric values that characterize the way a CE responds to direct exposure to a **CA** (site intensity value) and (optionally) within a specified distance from the CA.
- **Condition**: used interchangeably with **Status** (see below)
- **Ecological status (**or **Status):** formal term in BLM **REA**s to describe the **condition** or integrity of areas of distribution of a **CE** based on presumed effects of change agents on the CE.
- **EIA**: ecological integrity assessment used to indicate the overall integrity or condition of the ecoregion as a whole.
- **Indicator**: Biophysical attributes that are used either directly or indirectly to measure the status of the **KEA**s, and therefore of the CEs.
- **KEA**: **Key Ecological Attribute**. A KEA is a characteristic of a species' or ecosystem's biology, ecology, or physical environment that is critical to the resource's persistence in the face of both natural and human-caused disturbance. The combined **status** or **condition** of KEAs for a CE together determine the overall **ecological status** of the CE.
- **KEA indicator scenario (**or **Scenario)**: The aggregation of **CA** distribution maps used to assess the **indicators** associated with each of the **KEAs** for each of the CEs. The scenarios are input into the **LCM**.
- **Landscape Condition Model** (**LCM**): the geospatial modeling tool used to calculate the **ecological status** of CEs and conduct other related assessments (e.g., ecological integrity of the ecoregion). The **CE response models**, **KEA indicator scenarios**, and **CE** distribution maps are the key inputs that are run through the **LCM**.
- **MAR**: **Madrean Archipelago Ecoregion**, specifically referring to the U.S. portion assessed in this REA.
- **MQ**: **Management Question**. These are questions developed by BLM and gathered during the REA that are important for guiding natural resource management and land use decisions. The **ecological status** assessments of CEs and other assessments conducted in the REA provide information and analysis results to help address the management questions.
- **REA**: **Rapid Ecoregional Assessment**
- **Status:** See **Ecological Status** above.

1.3 The Assessment Region

The U.S. portion of the Madrean Archipelago ecoregion, including its intersecting 5th-level watersheds, was assessed in this REA. The REA assessment area encompasses approximately 6.4 million hectares (15.7 million acres). Within the assessment region, total BLM ownership is 1,009,375 ha (2,494,222 ac) or about 16% of the area and 38,382 ha (94,846 ac) is in BLM special management or 0.6% of the MAR.

Figure 1-1. Map of the Madrean Archipelago REA assessment area. The area assessed for this REA is the U.S. portion of the Madrean Archipelago plus its intersecting 5th-level watersheds, shown in the yellow outline and by the border between the U.S. and Mexico. The Madrean Archipelago ecoregion is shown by the solid green line and extends into Mexico beyond the map extent.



1.4 Management Questions

In this REA, natural resources management questions (MQs) and issues were identified by various agencies participating in the REA process. These MQs were iteratively reviewed and distilled into a discrete set of potential assessments and evaluated for appropriatness for an REA and feasibility. Relevant available datasets needed to answer the MQs were identified and evaluated, and proposed analytical steps were summarized for conducting the identified assessments. Based on management needs, data availability and suitability, and technical feasibility of the proposed analyses, the pool of potential assessments was narrowed to the following:

- Ecological Status of CEs (current)
- Ecoregional Ecological Integrity (current)
- Climate Space Trends (recent)
- Climate Space Trends (future)
- CE Distributions Intersected with Future Climate

- Bioclimate Envelope Models
- 2025 Risk Assessment (for three case study CEs)
- Mesquite Scrub Expansion: Restoration Opportunities
- Soil Erosion Potential

1.5 Conservation Elements

Conservation elements (CEs) are one of the core components of the REA. They are the natural resources – ecosystems and species (inclusive of species assemblages) -- that are the focus of the assessment. Ecological system and species CEs were selected through an iterative review process based on the following criteria and considerations:

- Regional significance
    - Relevant to more than one BLM field office or other agency's local management jurisdiction (ecosystems and species)
    - Dominant in the ecoregion (ecosystems)
    - Broadly represent a cross-section of the region's diversity (ecosystems and species)
    - Endemism (ecosystems and species)
- Nexus with identified management issues (ecosystems and species)
- Representation by associated ecological system CE (i.e., species that would add to, rather than being duplicative of, ecosystem CEs)

This resulted in the identification of 18 CEs that were the focus of the assessments in this REA (see Table 1-1 and Table 1-2). In addition, a significant portion of the ecoregion (~19%) is occupied by Apacharian-Chihuahuan Mesquite Upland Scrub, an ecological system that has greatly expanded primarily through mesquite expansion into grassland areas. This system is treated separately from the other 18 conservation elements (via the Mesquite Scrub Expansion assessment listed above) because managers desired information about restoration opportunities rather than a generalized status assessment of this ecosystem type.

Table 1-1. Ecological system conservation elements (CEs) selected for the Madrean Archipelago REA. The ecological systems are organized in this table according to the four major system divisions or groupings (valley upland system, montane upland system, connected stream and wetland, and isolated wetland) from the ecoregion conceptual model. Apacharian-Chihuahuan Mesquite Upland Scrub is a non-natural ecological system that has greatly expanded primarily through mesquite expansion into grassland areas.

Ecological System Name	Approx. % Ecoregion
Valley Upland System Division	**56.0%**
Apacherian-Chihuahuan Mesquite Upland Scrub	19.5%
Chihuahuan Creosotebush Desert Scrub	13.2%
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	18.2%
Madrean Encinal	5.1%
Montane Upland System Division	**13.4%**
Madrean Pinyon-Juniper Woodland	5.8%
Montane Conifer-Oak Forest and Woodland	2.8%

Ecological System Name	Approx. % Ecoregion
Mogollon Chaparral	4.8%
Isolated Wetland System Division	**<1%**
North American Warm Desert Playa and Ephemeral Lake	<1%
Connected Stream and Wetland System Division	**4.3%**
North American Warm Desert Riparian Woodland and Shrubland, Mesquite Bosque and Stream	3.3%
North American Arid West Emergent Marsh/Ciénega and Pond	1.0%
North American Warm Desert Lower Montane Riparian Woodland and Shrubland and Stream	<1%

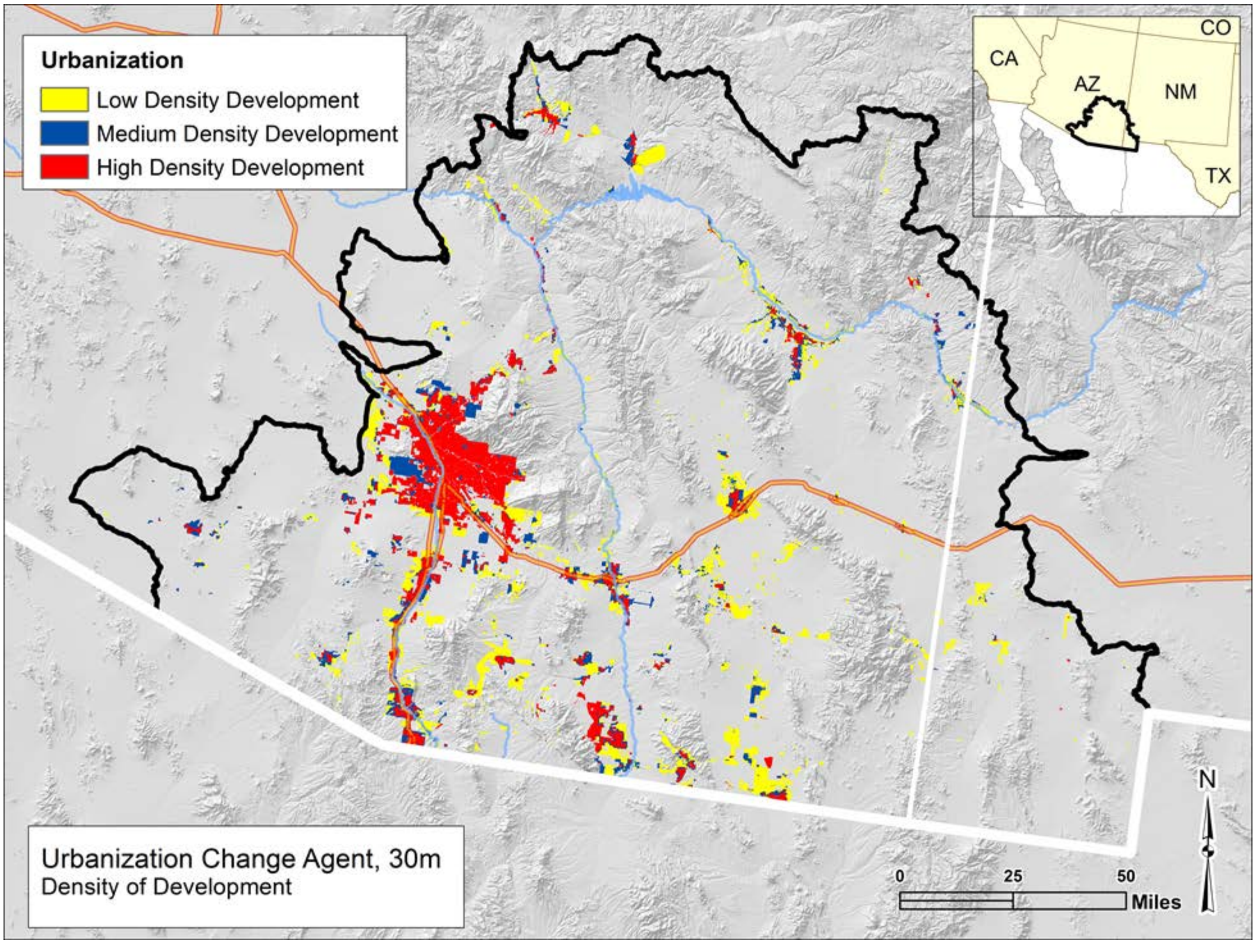
Table 1-2. Species conservation elements (CEs) selected for the Madrean Archipelago REA. Includes current state or federal endangered listing status.

Category	Species Name	Listing Status (State or Federal)
Mammal	Pronghorn (*Antilocapra americana*)	None
Mammal	Coues white-tailed deer (*Odocoileus virginianus couesi*)	None
Mammal	Desert bighorn sheep, all subspecies (*Ovis canadensis*)	None
Mammal	Nectar-feeding bats	See conceptual model
Mammal	Black-tailed prairie dog (*Cynomys ludovicianus*)	None
Bird	Grassland bird assemblage	See conceptual model
Reptile	Ornate box turtle (*Terrapene ornata luteola*)	None
Amphibian	Chiricahua leopard frog (*Lithobates chiricahuensis*)	Federally Threatened, Arizona Threatened

1.6 Change Agents

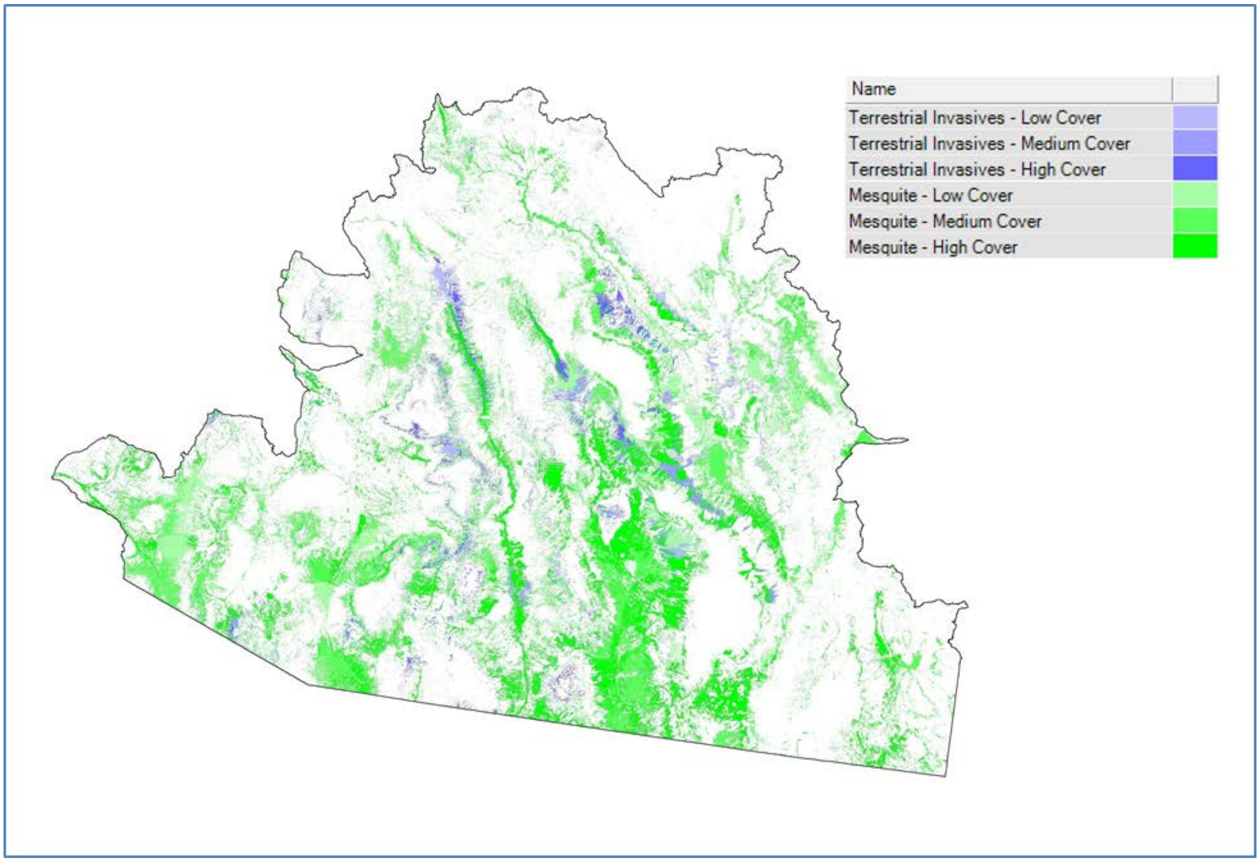
Change agents (CAs) are those anthropogenically-driven or -influenced land uses, activities, or phenomena that can affect the ecological status or condition of conservation elements. They are drawn from the standard REA change agent categories of development, climate change (described in greater detail below), invasive species, and wildland fire (fire). Development is a particularly broad category that includes any direct human use, activity, or infrastructure on the landscape, such as agriculture, border patrol activities, roads, urban development, or energy development, among many others. The invasive species CA includes invasive non-native species, managed non-native species (e.g., sport fish, game animals), and native woody increasers (such as mesquite). Figure 1-2 provides an example of a development CA; all individual CA maps can be viewed on the BLM REA GIS portal.

Figure 1-2. Example of a development change agent. The urbanization change agent comes from a model of urban density ICLUS SERGoM generated by EPA.



There were no direct assessments made of change agents in isolation (i.e., without interactions with CEs, other than climate change trends). Instead, change agents were incorporated into a series of "KEA indicator scenarios" (scenarios) that represent indicators of conservation element Key Ecological Attributes (see example Figure 1-3). These scenarios were used to model the current status of the conservation elements, the 2025 future landscape condition (development-caused) status of three case study conservation elements, and model the current ecological integrity of the ecoregion as a whole (see sections below). Additionally, more speculative modeled urban development for the 2025 timeframe is graphically overlaid on the case study conservation elements and solar potential maps are presented alone to indicate where future risks to conservation elements may occur (see section 1.7.3).

Figure 1-3. Example of a KEA indicator scenario. The invasive species indicator scenario is comprised of invasive species change agents represented at different levels of density that could be associated to different levels of impact to the KEA indicator.



The climate change assessment addresses climate exposure across the MAR by analyzing recent and future climate trends and their estimated influence on conservation elements (CEs). The recent and future climate trend analysis examines spatial and temporal patterns of change in a range of climate variables. Multiple trend detection statistics were employed to quantify the distribution and magnitude of recent climate change, as well as future changes projected by a suite of six global climate models run under the A2 greenhouse gas emissions scenario. Additionally, bioclimatic envelope modeling explores how projected future climate change may affect the distribution of suitable climate conditions for several ecological communities of the MAR. This approach estimates suitable climate conditions for a given CE and projects where those suitable conditions are likely to occur in the mid-century future.

1.7 REA Products and Results

1.7.1 Conservation Elements: Current Status

Current ecological status was assessed for five terrestrial upland CEs, four aquatic CEs, five species and two species assemblage CEs. Each indicator for each key ecological attribute was assessed individually for each CE; the indicators were then combined to calculate the overall ecological status for each CE. The individual indicators and overall ecological status were assessed at 30 m resolution and then the overall status was averaged across reporting units to show broader patterns of overall ecological status for each CE (see example of both resolution products for the nectivorous bat assemblage CE, Figure 1-4). Additionally, a frequency graph of status by reporting unit is provided for each CE that illustrates the proportion of the CE area in which range of status values (e.g., in Figure 1-5, the bulk of the CE's distribution is in relatively low status).

Generally across the three groups of CEs, similar patterns were observed in the assessment results. First, while development activities can have major, local-scale impacts; most development occurs in, and hence has impacts upon, lower elevation areas including valleys, floodplains, or in the foothill zones. Therefore, it is generally a minor driver of the status results for the CEs found at higher elevations. Effects of development on CE distributions close to heavily populated or developed areas are evident in the ecoregion-wide maps. Effects of the many small roads and highways, which are pervasive throughout the area, are difficult to visually discern in the maps. Their impacts on status locally are evident when zoomed into specific areas and these smaller, pervasive impacts do contribute to ecoregional status results.

Secondly, altered fire regimes are affecting most areas of the ecoregion. All of the terrestrial upland ecosystems have significant portions of their distribution in either moderate or severe departure categories from historical fire regimes. Most of the species also have poor ecological status across much of their distribution due to the fire regime indicator.

Third, invasive species, both in the upland and aquatic realms, are a significant problem at middle to lower elevations of the ecoregion. The data for the invasives indicators was generally of poor to moderate quality, but the patterns are similar across all three groups of CEs. Lower elevations (i.e. not in the mountain ranges) are impacted by invasives, while the higher montane elevations are much less affected. These results are not unanticipated; invasion by mesquite (*Prosopis* spp.), exotic grasses and forbs, tamarisk (*Tamarix* spp.) or Russian olive (*Elaeagnus angustifolia*) and exotic aquatic animal species, is well documented for this ecoregion and known to be a growing issue.

Lastly, water use is one of the greatest stressors affecting aquatic CEs in the Madrean Archipelago ecoregion, especially at lower elevations. While the water use data used in this assessment are spatially coarse, the effects of high water usage can be severe and cause stress to the plants and animals dependent upon aquatic ecosystems and their associated riparian or wetland vegetation. The abbreviation "AMA" designates a basin identified as an "Active Management Area" for groundwater resources under Arizona water law. The areas of high rates of water use are all basins in Arizona with either dense municipal development (Tucson "AMA") or large areas of intensive irrigation (Pinal "AMA," Douglas and Willcox basins). Figure 1-5 illustrates the 30 m overall ecological status for one of the aquatic CEs, as well as its ecological status averaged across the watershed reporting units.

Figure 1-4. Current overall ecological status scores for the nectivorous bat assemblage for each 30m pixel (top) and 4km grid cells (reporting units, bottom). LCM = landscape condition model. Yellow scores (equivalent to 0) indicate high impacts from the CAs and correspondingly lower ecological status, dark blue (equivalent to 1) indicate little to no impact from the CAs and correspondingly higher ecological status. In the second map, the score for each 4km cell is an average of the overall ecological status scores of the 30m pixels within the 4km cell that were were scored for the CE.

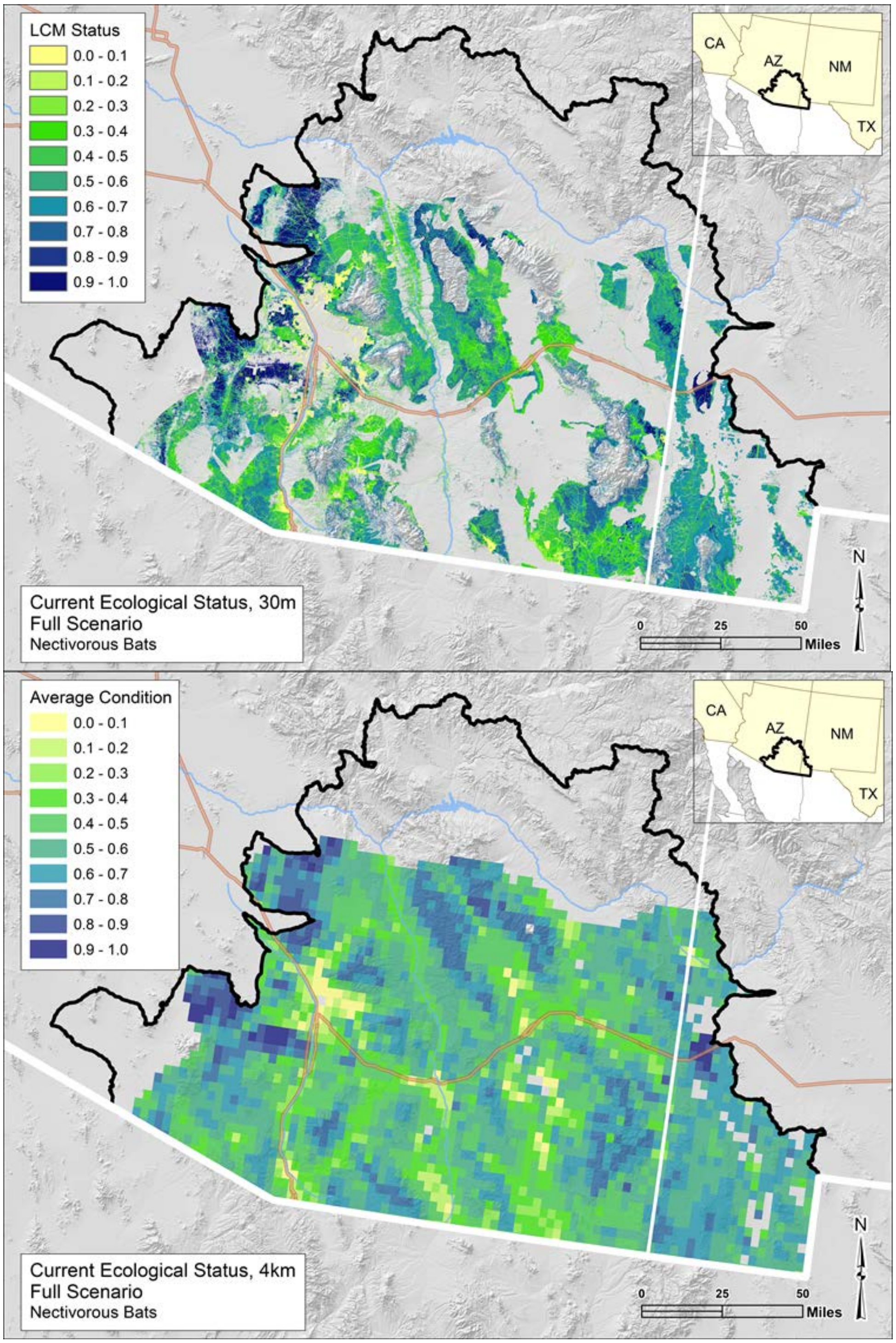
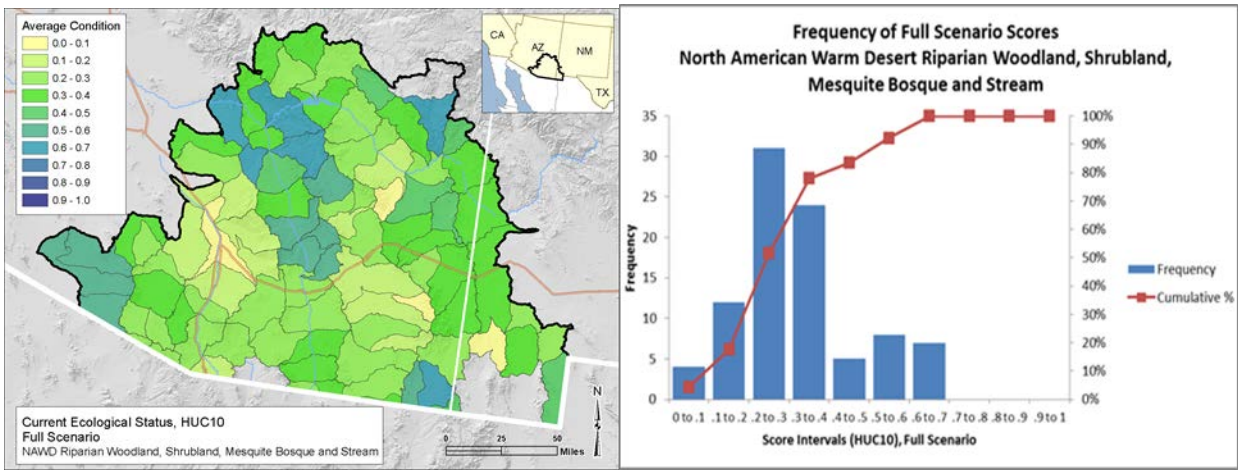


Figure 1-5. Overall ecological status scores for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE (left) and graphs of frequency distribution (right). Ecological status scores were averaged across 5th-level watersheds for the CE. A companion graph indicates the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of watersheds in each interval (left) and the cumulative percentage of the grid cells for each interval (right).

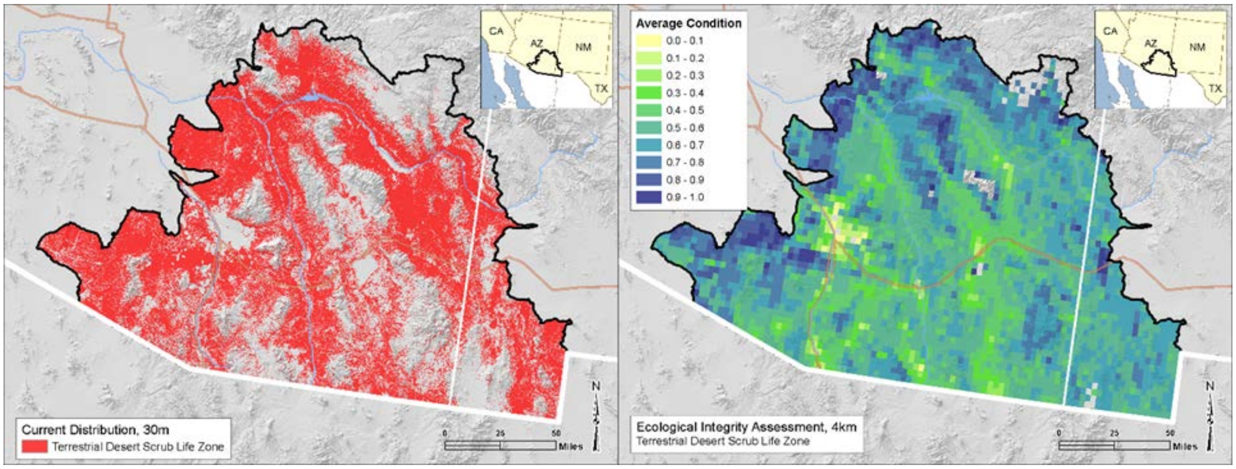


1.7.2 Current Ecological Integrity of the Ecoregion

Ecological integrity assessment characterizes the overall status or condition of the ecoregion. For the MAR, integrity was assessed for five life zones that incorporated the CEs but provided ecoregion-wide coverage: two for the aquatic realm (montane and lowland) and three for the uplands (montane, valley and desert). An additional analysis calculated the change in extent of distribution for upland ecological systems from historical distribution to current.

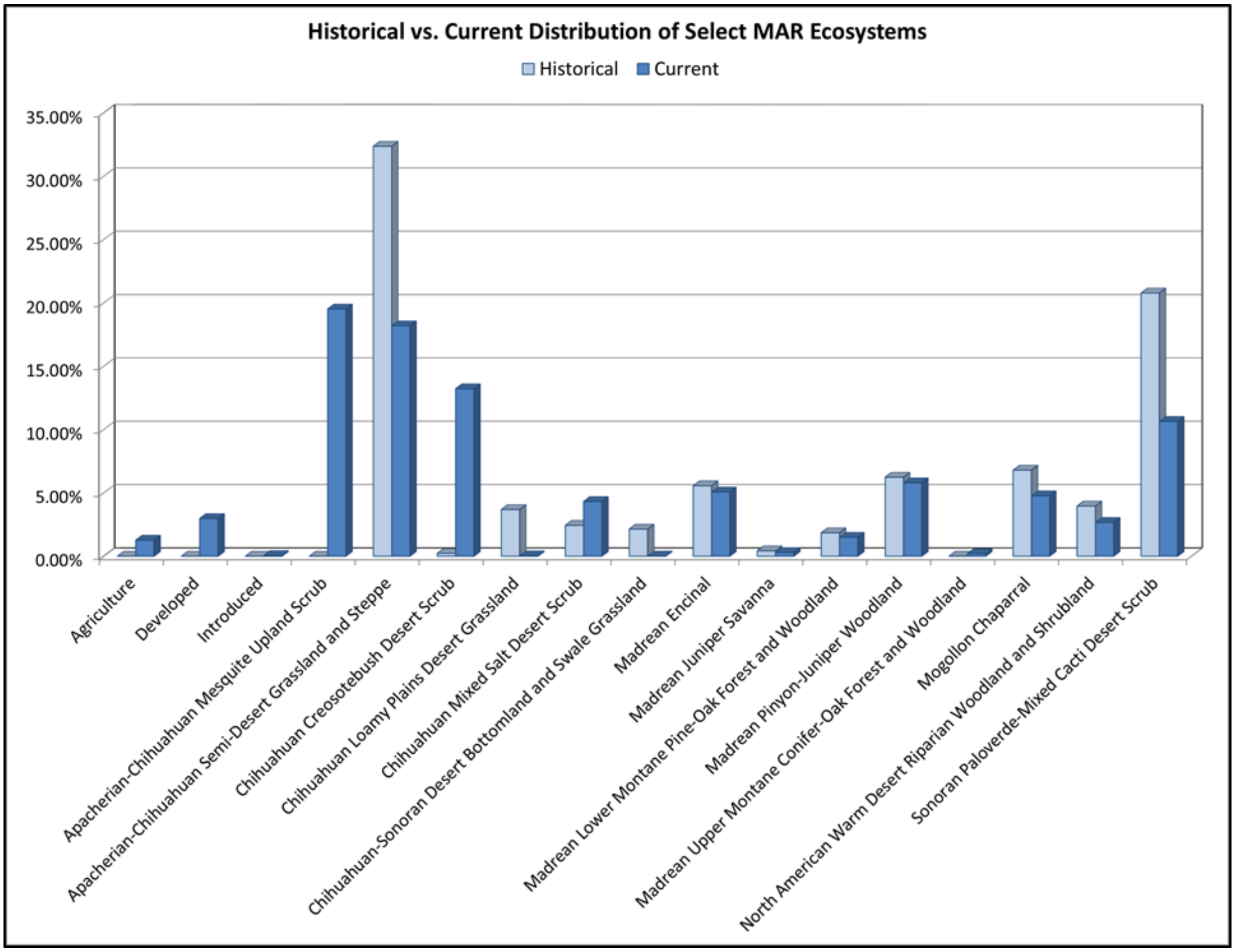
For the five life zones, the results for the ecological integrity assessment of the ecoregion show similar patterns to those for the CEs. In general, the higher elevation regions have better ecological integrity, a result of less development and fewer invasive species, although fire regime departure is significant in all of the upland life zones. The Desert Scrub life zone has poor to moderate ecological integrity for much of its distribution, a result of fire regime alterations and proximity to heavily developed areas (Figure 1-6). In contrast, much of the Montane Forest life zone has moderate to good ecological integrity (less development or invasives species). However, altered fire regimes are a real issue throughout much of the montane zone. The Valley Grassland life zone has low ecological integrity across much of its distribution. This life zone suffers from effects of all three indicators- extensive development impacts, invasive species including mesquite, and moderately to severely altered fire regimes. Only a few areas in the northern portions of the ecoregion have good integrity.

Figure 1-6. Distribution (left) and integrity assessment results (right) of the Terrestrial Desert Scrub life zone in the Madrean Archipelago ecoregional assessment area. The map on the left shows the combined distributions of 13 terrestrial ecological systems which comprise the distribution of this life zone. The map on the right illustrates integrity results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each 4km^2 grid cell. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.



The results of the change in extent analysis from historical to current area of terrestrial ecological systems show major compositional changes have occurred that have resulted in type conversion (i.e. from one ecosystem to another) and resultant changes in extent (Figure 1-7). Mesquite Upland Scrub has expanded substantially (0% to 20%), as has Chihuahuan Creosotebush Desert Scrub (0.5% to 13%) with subsequent large declines in all of the grassland ecological systems (Apacherian-Chihuahuan Semi-desert Grassland and Steppe (32% to 18%), Chihuahuan Loamy Plains Desert Grassland (4% to nearly 0%), Chihuahuan Bottomland and Swale Grassland (2% to nearly 0%). In addition there has been a large decline in the extent of Sonoran Paloverde-Mixed Cacti Desert Scrub (21% to 11%), largely due to urban expansion from Tucson and surrounding areas and conversion to other desert scrub systems. There are only modest amounts of conversion from natural vegetation due to increases in post-European settlement (as a proportion of the ecoregion area) such as agriculture (to 1.3%) and development (to 3%).

Figure 1-7. Historical vs. current area of select terrestrial ecological systems for the entire MAR ecoregion. The y-axis presents the percent of the MAR study area of the mapped historical (light shade) or current (dark shade) extent of each ecological system or land cover type. Historical distribution was derived from the Landfire biophysical settings map and current distribution from the NatureServe terrestrial ecological systems map, which is based upon the land cover mapping of SW ReGAP.



The Aquatic Lowland life zone has reduced ecological integrity primarily because of water use and development whereas the Aquatic Montane life zone has much better integrity. For the Lowland life zone, areas surrounding, and waters within, the Gila River downstream from the San Simon River confluence, most of the San Pedro River, and most of the Santa Cruz River south of Tucson show high levels of impact from development, water use, and invasive species. The most altered watersheds are located in the areas of Safford, Willcox, and the Tucson metropolis, AZ. The least altered watersheds occur in the far west-southwestern corner of the ecoregion assessment area west and south of Sells, AZ (in the buffer area of the ecoregion); in the northern third of the lower San Pedro River basin; in the lower San Francisco River basin; and surrounding San Bernardino National Wildlife Refuge. Watersheds in the Aquatic Montane life zone occur in areas that are generally not impacted by significant groundwater withdrawal and surface water diversions, nor are they as heavily exposed to development.

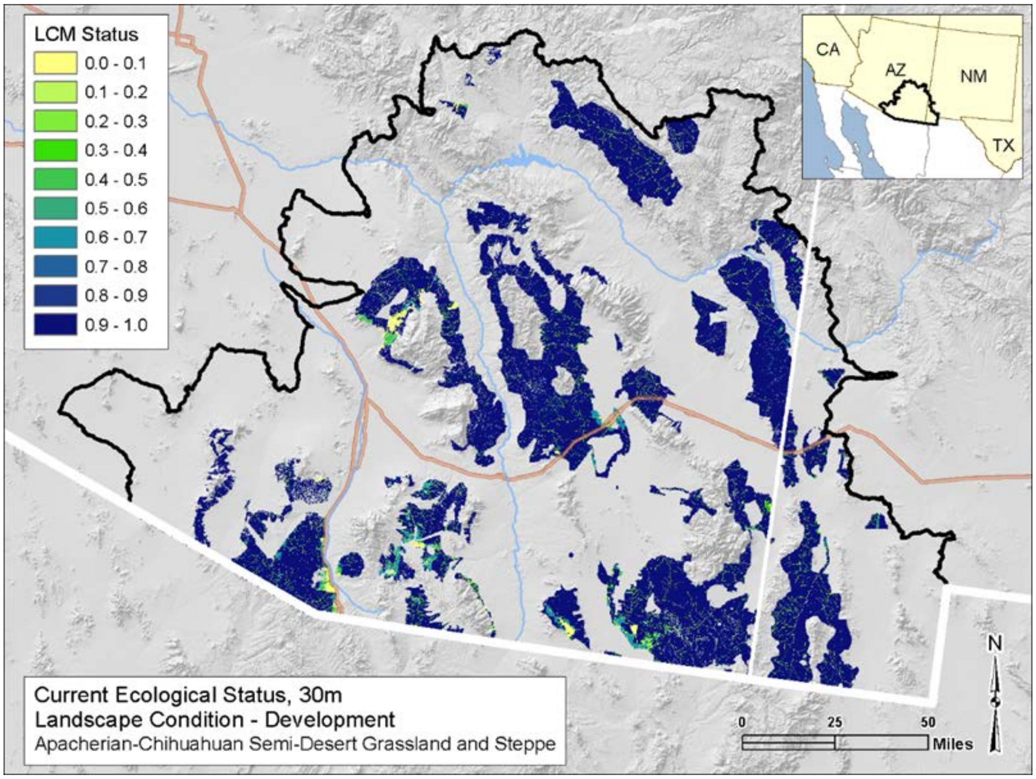
1.7.3 Conservation Elements Future Risk

Inadequate data were available to conduct complete status assessments of the CEs for the 2025 timeframe equivalent to those done for the current (2014) assessments. However, a variety of data representing potential areas of development change agents for near future timeframes were available. Therefore, only the development indicator was assessed for the 2025 timeframe for each of the three case study CEs (see example Figure 1-8) to provide a limited picture of potential ecological status in 2025. In addition, the case study CE distribution maps were overlaid with a "risk map" of potential urban expansion areas to further inform areas and CEs at risk. Solar energy potential maps are provided but not overlaid on the CE distributions because of their broad distribution, but they can be overlaid with any CE via BLM's GIS portal found at http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/dataportal.html.

Comparing the development indicator scores for the current timeframe to the 2025 development-based ecological status scores, the observable differences are subtle at the ecoregion scale and are primarily driven by urban expansion in the central and southwest portions of the ecoregional assessment area and around Tucson and the SunZia and Southline planned transmission corridors. For the aquatic ecosystem assessed, the impacts from proposed development appear negligible.

The extent of future development currently planned, modeled, or with fairly high potential for action by 2025 is relatively small compared to the ecoregion extent. Therefore, separate assessments would need to be conducted to characterize localized effects of individual projects. The SunZia and Southline electrical transmission corridors bisect the entire ecoregion and numerous occurrences for several CEs. No Solar Emphasis Zones were designated in the BLM Solar PEIS in the Madrean Archipelago Ecoregion, but there is some solar development on non-federal lands. There are extensive areas of federal lands delineated as variance areas where, through careful planning, facilities could be located on certain federal lands.

Figure 1-8. Future ecological status scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe. Current status is provided first for comparison. Status is generated for the landscape condition (development) indicator for each 30m pixel.

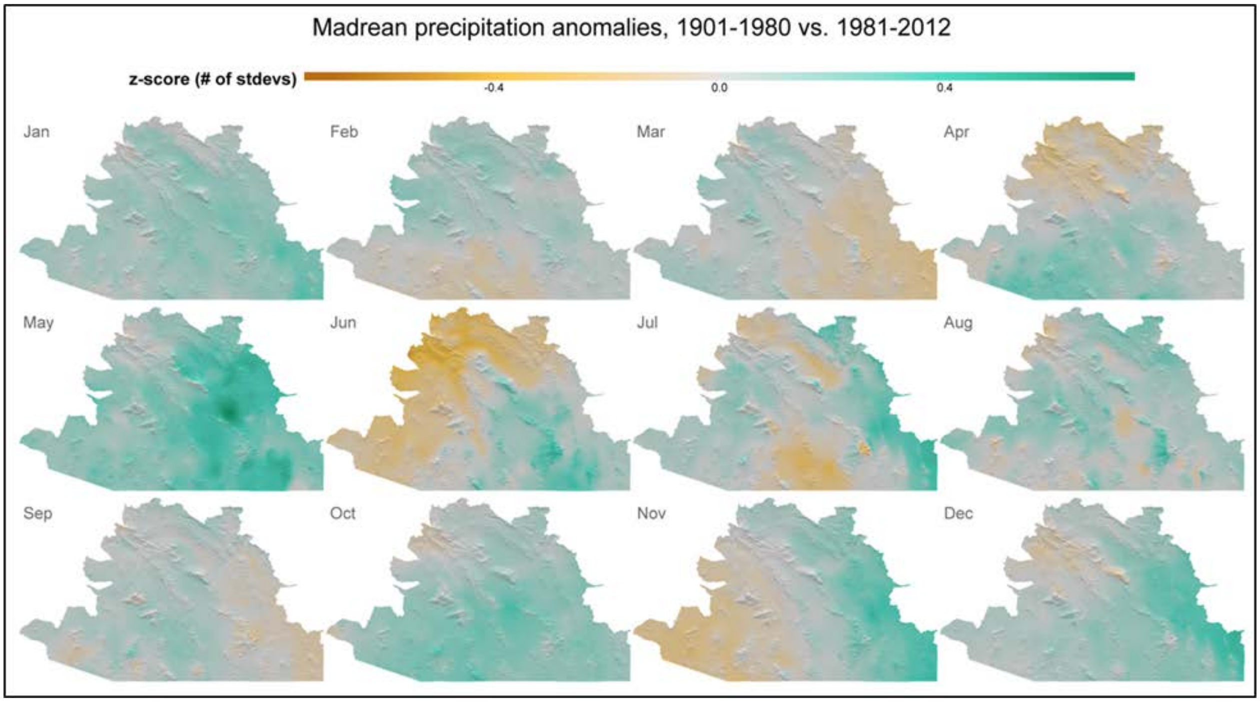


1.7.4 Recent and Future Climate Trends

Climate trends assessment includes differences between two time periods (recent vs baseline and future vs. baseline) for monthly climate variables. These differences are expressed in actual units of climate (degrees Celsius or mm of precipitation) as well as in relation to historical variability (units of standard deviation from the baseline mean). For recent trends only, additional analysis explores statistically significant trends within the recent period (as opposed to comparing it to a baseline climate). Finally, some of these change metrics were aggregated to create an index of overall climate exposure across the ecoregion.

Generally these trends highlight the relative stability of high elevations and mountainous areas compared to low-lying areas across the MAR. Both recent and future changes in minimum temperature show the most pronounced change in actual climate values, as well as in relation to natural variability. Recent precipitation changes are lesser in magnitude than temperature changes in comparison to the baseline, changes across months fall within one standard deviation of the baseline mean (Figure 1-9). Precipitation changes do not exhibit a clear spatial pattern and are generally not statistically significant. However, future projections of precipitation (as well as moisture stress indices such as climatic moisture deficit) show a general drying trend, particularly in spring. Inconsistencies in the trends between current precipitation patterns and modeled future projections make conclusions about shifts in precipitation patterns difficult to identify with confidence. Additional indices for characterizing future climate show that the average length of the frost free period (warm season) is projected to become substantially longer which may benefit some species while stressing others.

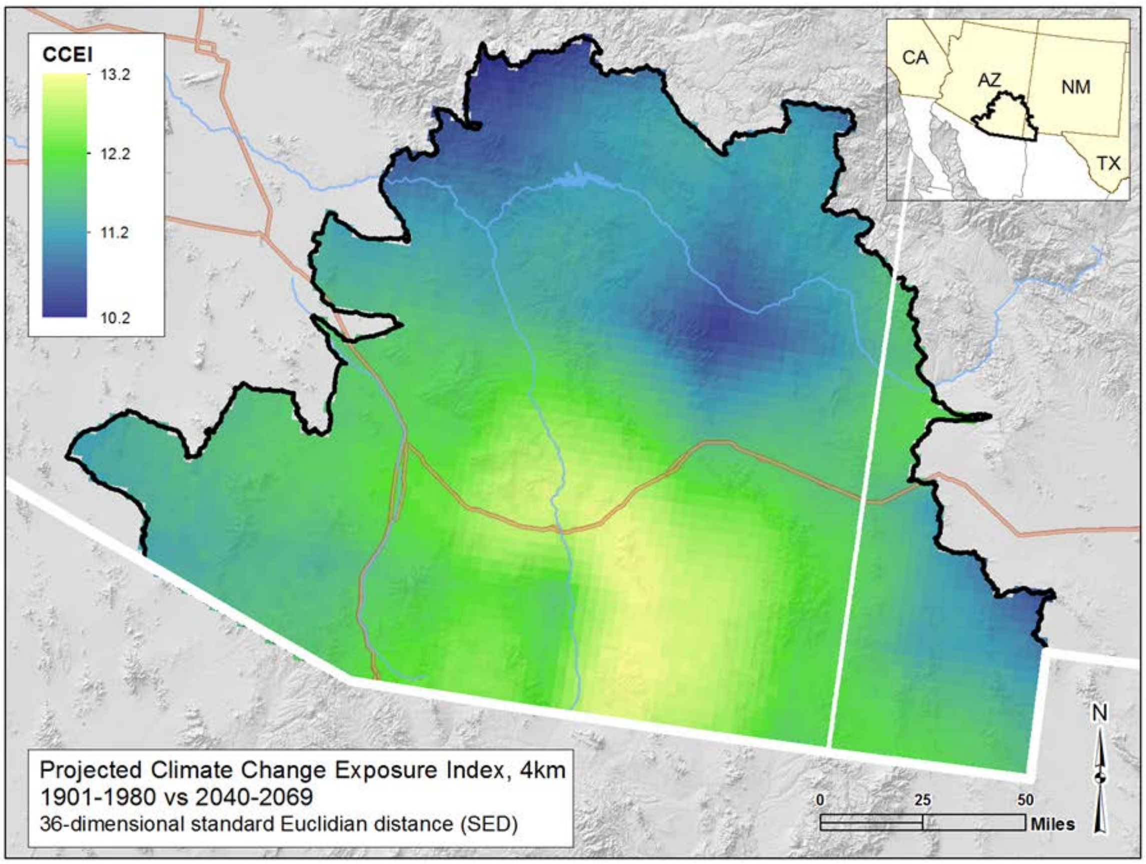
Figure 1-9. Recent monthly trends in precipitation over last 30 years, compared to 20th century baseline. Scale represents number of standard deviations from baseline. In this comparison, the entire scale falls within 1 SD, indicating all recent precipitation shifts fall well within the values of normal precipitation variability.



1.7.4.1 Overall Climate Trends and Evaluation of Conservation Elements

To characterize overall climate trends, a future climate change exposure index was created to summarize overall departure for all climate variables (minimum temperature, maximum temperature, and precipitation) for all months. The index is a quantification of relative overall departure of future climate conditions from the baseline conditions (Figure 1-10). Conservation element (CE) distributions were overlaid onto the climate exposure index map to identify areas where CEs might experience significant climate change in the future.

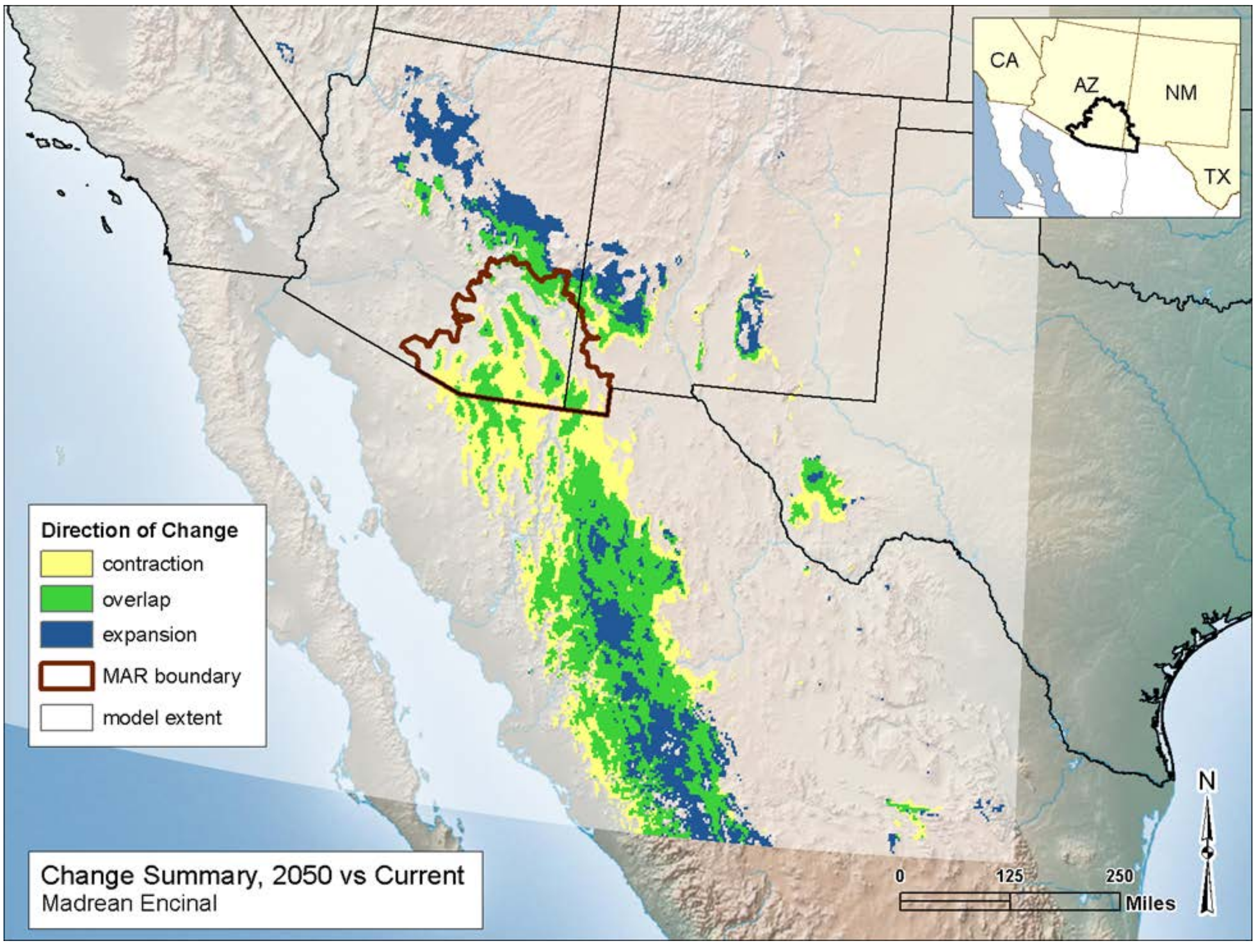
Figure 1-10. Climate Change Exposure Index (CCEI), observed values. This index is in units of standard deviation from the baseline mean. While possible values range from 0-13.2, all values for the future CCEI are greater than 10.2, representing significant changes across the entire ecoregion. In this map, only these observed values are shown, allowing for better visualization of differences across the ecoregion.



1.7.4.2 Bioclimatic Envelope Modeling

Bioclimatic envelope modeling was used to help understand projected geographic shifts in the distribution of suitable climate conditions for a subset of CEs. Models were generated for four terrestrial ecosystems, producing three derived data products for each: 1) the modeled current suitable bioclimate; 2) the modeled future suitable bioclimate with degree of model agreement in suitability across six independent future climate model projections; and 3) a change summary layer comparing the current bioclimate and projected future bioclimate and depicting areas of potential future stability, contraction, and expansion resulting from this modeling approach (Figure 1-11). These products can be useful in management prioritization by suggesting which portions of the current CE range may experience the greatest and least climate stress in future decades.

Figure 1-11. Summary of modeled expansion, contraction, and stability for the geographic distribution of suitable climate conditions for Madrean Encinal. Contraction areas are where suitable climate for the conservation element currently exists but may not in the future, overlap is where current and future climate are suitable (indicating potential stability), and expansion is where current climate is not suitable but may be in the future.



1.8 Limitations and Applications

A rapid assessment is, by nature, going to be limited to the use of available data, a short project timeframe, and resource limitations. Some key limitations and data gaps for the MAR REA are discussed below. One of the major data gaps and limitations is that the Mexico portion of the ecoregion was not included in any of the data discovery steps or spatial analyses.

1.8.1 Conservation Element Distributions

Most ecosystem CE distributions data originated in imagery from 2001 or older and, therefore, does not reflect vegetation changes since that time. Because the TNC data used for grasslands is spatially represented as large polygons, there are most likely areas of woodlands, shrublands, bare ground, or even human development within those polygons. The hydrographic data does not capture the entire range of variability due to variation in weather and human water use. Because many ciénega locations are on private land, this assessment represented ciénega distribution by 6th level (HUC 12) watersheds. The distributions for the species conservation elements were derived from a variety of sources which in turn were developed with a variety of methods, from actual known herd locations for the ungulates, a predicted habitat distribution model for the desert box turtle, and utilizing mapped area of ecological systems for both of the assemblages. The Chiricahua leopard frog distribution is represented by small-scale watersheds (6th level HUC 12s) within which it may or may not occur. These data limitations can result in mapping CEs where they do not occur (commission errors) or not representing them where they do occur (omission errors). Consequently status assessments will reflect such errors as well as indicating (e.g., with the grasslands) areas of low status that no longer contain the CEs.

1.8.2 Change Agent Distributions

1.8.2.1 Development, Invasive Species, and Fire

The CA data used in the model are of varying spatial resolutions and file format types (i.e. point, line, polygon and raster), and some of the CA datasets are modeled data (e.g. fire, mining footprints, etc.). A key data gap, as in other REAs is the absence of grazing data and thus this CA was not included in the assessment. In addition, modeling results may be limited because some CA data may not include complete distributions (e.g. trails, mines, etc.) or were data gaps and not included in the assessment (e.g. pipelines, border roads/infrastructure, etc.). No systematic, ecoregion-wide survey for aquatic invasive species has been conducted. Data sets used for this assessment include intensive surveys, casual observations, and plot based data. While these data are highly accurate, they are sparsely located and by no means systematic across the entire ecoregion. Invasive plant species and mesquite expansion data are modeled “predicted” distributions derived from the Integrated Landscape Assessment Project (ILAP), not actual mapped distribution and have not been field-verified. Outside of the ILAP data, there is a lack of comprehensive (MAR-wide) current distribution or risk of occurrence data for exotic invasive plants. Fire regimes are complex, and while a substantial body of work exists documenting current and past fire regimes across the southwest, many of these studies are local in nature. The LANDFIRE Vegetation Condition Class (VCC) dataset, used to understand risk from potential changes to fire regime, is not a direct measure of fire risk or fire regime departure from expected historical range of variability. Water use is one of the greatest stressors affecting aquatic CEs in the Madrean Archipelago ecoregion. However, estimates of water use for the ecoregion are spatially very coarse, and so do not support any discrimination of impacts at the scale of individual CE occurrences. Precise surface-groundwater models do exist for portions of the Madrean Archipelago ecoregion, but only for small portions of the ecoregion (e.g., the San Pedro River and Cienega Creek valleys). The BLM has collected extensive, standardized data on riparian-stream habitat condition using its Proper Functioning Condition protocol, however, these data were not readily available in digital format for the entire ecoregion. The assessment also faced a large gap in knowledge of biotic conditions in the playas within the ecoregion, which have not been systematically surveyed. Coarse or modeled data introduce uncertainties and may falsely indicate or fail to indicate impacts on CE status.

Change agent data to represent the expected 2025 conditions were lacking. Adequate data were obtained to represent the development change agents but much of that is secure data that could be used in the assessment but not shared. Data gaps exist for invasive species and fire for 2025 that prevented the generation of a complete 2025 CE status assessment or ecoregion ecological integrity assessment.

1.8.2.2 Climate Change Data

Interpolation

Interpolated climate data, an analysis process to create values where no direct observations exist, introduces an inherent degree of uncertainty about those interpolated values. Results of spatial and temporal precipitation analyses from interopolated climate data are less certain than those for temperature, particularly over mountainous terrain. Uncertainty of current climate surfaces also influences the degree of confidence for future interopolated climate surfaces, because interpolated 20th century observations are used as the baseline in the downscaling method that produced the Climate Western North America dataset (CWNA).

Global Circulation Model Uncertainty

Any effort to understand the impacts of future climate change on biodiversity requires outputs from global circulation models (GCMs). GCMs attempt to capture the patterns, forcings, and feedbacks of the entire global climate system from the recent past into the future, and therefore introduce some unavoidable uncertainty when applied to regional scale questions (also see downscaling limitations below). GCMs often disagree in the magnitude of projected change in climate, and can even disagree in the direction of change for future precipitation trends. One approach to address this kind of uncertainty, supported by the climate modeling community, is to use multi-model ensembles in ecological forecasting analysis (Tebaldi and Knutti 2007). For the MAR climate trend analysis, an ensemble of six GCMs was used, which is every GCM available for the A2 scenario in the CWNA dataset and represents a reasonable sample of future projections. For the bioclimatic envelope modeling, each of the six projections is modeled independently, and the degree of model agreement is assessed for each bioclimatic envelope result. This is a robust approach to addressing uncertainty in alternative climate model projections. The REAs have selected to work with only a single greenhouse gas emissions scenario, representing only one possible future trajectory for emissions, which limits the range of possible future climate conditions that were assessed for the MAR. However, the variation between emission scenarios is less for mid-century projections than for end of century projections.

Climate Model Downscaling

The process of climate model downscaling supports the use of GCM outputs at much finer spatial resolution than the coarse scale native to climate model outputs. The use of downscaled climate models is essential to any assessment of climate change impacts on conservation elements, which interact with climate conditions at relatively fine spatial scales. However, the downscaling process introduces a source of uncertainty. For the analysis of future trends undertaken here, the downscaled global climate dataset was produced using the delta, or change-factor approach. This widely used approach is based on calculating changes in the values of climate variables between the future and the present, and interpolating those changes (deltas) to a finer resolution baseline spatial climate dataset (such as PRISM). One limitation of this approach is that it assumes a static relationship between climate and topography at local scales (i.e. temperature inversions, cold-air pooling), even though these interactions may change over time with a changing climate.

1.8.3 Modeling Methods

1.8.3.1 Conservation Element Status and Ecological Integrity Assessments

The primary limitation in the modeling methods for these assessments is the ability to link the effects of remotely mapped (for the most part) CAs on individual CEs. Geospatial modeling always introduces assumptions and abstractions of actual ecosystem processes and CA effects. The many factors that can be observed and measured in the field cannot be fully captured with existing data and geospatial modeling.

1.8.3.2 Climate Change: Bioclimatic Envelope Modeling

Niche models make several simplifying assumptions: they do not account for the varying dispersal ability of different taxa, they do not consider genetic or evolutionary adaptive potential across individuals or populations, and they do not account for the influence of biotic interactions. Results of bioclimatic envelope modeling should not be interpreted as shifts in vegetation assemblages because individual species componenets are likely to respond differently to climate change. Rather, the results show which portions of the vegetation assemblage are projected to experience the greatest and least climate stress in the future.

1.9 Potential Applications and Decision Support

The extensive source data and analytical results created in this REA can support innumerable applications in assessment and planning; the BLM GIS portal (http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/dataportal.html) provides an opportunity to explore the actual map data through panning, zooming, querying, and overlays with other data sets. Scale of application and appropriateness of the data to specific management questions must be handled with care. In general, the results of the analyses are intended to be applied to landscape/watershed-scale questions where the status of conservation elements and general patterns are informative. Questions that seek to establish firm boundaries on the ground or apply management actions will often require the use of supplemental, local data and on-site assessment and confirmation prior to completing decisions. Further, like all REAs, this REA did not systematically treat all biodiversity. In particular, many rare, imperiled, or legally protected species are considered “local species” that are not typically treated in REAs so the MAR REA results should not be used to screen projects for potential conflicts with such species.

The asssessments were largely conducted using the NatureServe Vista ArcGIS extension for ArcMap. The decision support project (.mxd and all associated data, database, and parameters) were delivered to BLM to facilitate a number of applications such as:

- Easily refreshing analyses with updated inputs (data or model parameters)
- Running analyses with different inputs or assumptions such as different reporting units or different parameters for the landscape condition model that computes CE status
- Incorporating other data to expand the analyses (e.g., other CEs, other scenario inputs or different scenarios)
- Assessing proposals for projects or actions such as large infrastructure or resource extraction projects, land management actions such as invasive species control, etc.
- Assisting development of Resource Management Plans or other landscape plans such as county comprehensive plans by assessing the current condition and developing and assessing various alternatives.

Currently, NatureServe Vista can be downloaded for free from www.natureserve.org/vista; contact BLM for access to the MAR Vista project.

MADREAN ARCHIPELAGO
RAPID ECOREGIONAL ASSESSMENT

FINAL REPORT

Final Report for

U.S. Department of the Interior
Bureau of Land Management
Rapid Ecoregional Assessments

December 23, 2014

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

SUBMITTED TO

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Final Report for

U.S. Department of the Interior Bureau of Land Management Rapid Ecoregional Assessments

December 23, 2014

COVER PHOTO

Near Elgin and Audubon Research Ranch
Tahnee Robertson, Southwest Decision Resources

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1 Executive Summary

Please see the separate document "MAR REA Final Report Exec Sum FINAL."

2 Introduction

2.1 Rapid Ecoregional Assessments: Overview

2.1.1 REA Purpose

Working with agency partners, the Bureau of Land Management began conducting rapid ecoregional assessments[1] (REAs) in 2010 covering approximately 800 million acres of public and non-public lands of the American West. The goal of the REAs is to characterize the status of ecological resources and their potential for change across the landscape, so that the relative value of and risk facing natural resources can be used to identify potential priority areas for conservation, restoration, and development. REAs are intended to serve BLM's developing "Ecoregional Direction" that links REAs and the BLM's Resource Management Plans and other on-the-ground decision-making processes. Ecoregional Direction establishes a regional roadmap for reviewing and potentially updating Resource Management Plans, developing multi-year work for identified priority conservation, restoration and development areas, designing regional adaptation and mitigation strategies, and developing conservation land acquisitions. While REAs produce information designed to inform specific management processes, they are not decision documents and stop short of recommending particular management actions.

2.1.2 REA Key Components

REAs are designed around ***management questions (MQs)*** that specify the key information needs of managers as expressed by the Assessment Management Team (AMT). REAs describe and map ***conservation elements (CEs)***, which are generally ecosystems, species, or other natural features of high ecological value or sensitivity. REAs look across all lands in an ecoregion to identify regionally important habitats for fish, wildlife, species of concern, and other features of management interest. REAs then evaluate the potential impacts on CEs from four overarching categories of environmental ***change agents (CAs):*** development (such as land use, energy development, infrastructure, or hydrologic alterations), invasive species, climate change, and fire.

Because REAs address all lands within the ecoregion of interest, regardless of ownership, BLM engages with partners and stakeholders within the ecoregion to obtain input and to provide a set of products that can be used by any interested agency or organization. REAs are conducted by contractors, with guidance and input from BLM and partners within the ecoregion; BLM provides oversight for the project. The Assessment Management Team (AMT) and the Technical Team, which are composed of decision makers and technical experts from state and federal agencies, provide guidance and input throughout the REA process. For more information on the structure of the various BLM- and contractor-led teams that conducted this REA, the reader is referenced to the pre-assessment work plan (Crist et al. 2013b) for this REA, available at http://www.blm.gov/pgdata/etc/medialib/blm/wo/Communications_Directorate/public_affairs/landscape_approach/documents1.Par.26493.File.dat/MAR-1_Pre-assessment_Work_Plan.pdf)

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[1] Also see BLM's REA website at www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html.

2.1.3 MAR REA Process

The MAR REA process was organized as a series of tasks in two major phases: Phase 1, the pre-assessment phase, and Phase 2, the assessment phase. The overall goal of the pre-assessment phase was to lay the foundation for the assessment phase of the REA. The Pre-Assessment Report (Harkness et al. 2013) is the culmination of the first phase of the REA; its primary purpose is to serve as a stand-alone document that characterizes the ecoregion as a whole, the management information needs, the conservation elements (species and ecological systems), the change agents, and the interactions and relationships among these within the Madrean Archipelago ecoregion. Based on current scientific understanding derived from literature review and scoping workshops, the interactions among CEs, CAs, and other components of the environment are described and illustrated through conceptual models for the ecoregion as a whole, and for the selected CEs (provided in the Appendices to the MAR REA final report). The MQs, CEs, and CAs were assessed in Phase 2, the assessment phase. Table 2-1 provides a simple summary of the two phases and the major tasks comprising this REA. A work flow diagram (Figure 3-2) is provided later in section 3.1 to illustrate the flow of activities, information, and interactions among the tasks of Phase 2.

Table 2-1. Overview of Phases and Tasks in the REA process.

Phase	Task #	Task
Phase 1: Pre-Assessment	**Task 1**	**Initiate REA Project**: • Engage Teams and Develop Pre-Assessment Work Plan
	Task 2	**Implement Pre-Assessment Work Plan**: • Characterize the Ecoregion • Identify MQs, CEs, and CAs • Develop Conceptual Models (CMs) for CEs • Summarize in Pre-Assessment Report
Phase 2: Assessment	**Task 1**	**Create Assessment Work Plan**
	Task 2	**Obtain Data and Develop Models for How to Conduct the Assessments**: • Inventory, Acquire, and Evaluate Data • Develop Process Models
	Task 3	**Develop Geoprocessing Models and Conduct the Assessments**: • Develop Geoprocessing Models • Conduct Analyses • Generate Findings • Assemble Data Packages
	Task 4	**Final REA Report**: • Summarize Assessment Findings and Their Applications

2.2 Purpose, Organization, and Content of the Final Report

2.2.1 Purpose, Organization, and Content

This report for the Madrean Archipelago Rapid Ecoregional Assessment (MAR REA) conveys the objectives, methods, and results of the MAR REA. The report is arranged as the main report and a large series of appendices. It is organized hierarchically to allow the reader to self select on the level of information desired; a manager may only wish to read select sections of the main report while a GIS specialist may desire to read detailed geospatial methods (i.e., Appendix C). The maps in this report are hyperlinked to BLM's REA GIS Portal to allow live investigation of the maps in a GIS environment.

Nine appendices accompany this report:

A. Methods for Selecting and Evaluating Feasibility for Conservation Elements, Change Agents, and Assessments. This appendix summarizes methods and results from Phase I: Pre-assessment.
B. Assessment Methods: Approaches and Rationales. This appendix provides a deeper explanation of the geospatial analysis methods used for the assessments in this REA, including graphic process models and description of inputs and outputs.
C. Technical Methods: GIS Documentation. This appendix is intended for GIS analysts wishing to understand the specifics of the GIS steps and specific input files used for the assessments conducted in this REA.
D. Terrestrial Ecological Systems: Conceptual Models and Ecological Status
E. Aquatic Ecological Systems: Conceptual Models and Ecological Status
F. Species and Species Assemblages: Conceptual Models and Ecological Status
G. Ecoregional Conceptual Model and Ecological Integrity Assessment
H. Mesquite Scrub Expansion: Restoration Opportunities
I. Climate Change: Assessment Methodology and Results

A glossary and list of acronyms are also provided at the end of this document.

The reader is occasionally referenced to three earlier REA products; these are available on the BLM's Madrean Archipelago REA website at http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/madrean.html:

- Pre-Assessment Work Plan (Crist et al. 2013b)
- Pre-Assessment Report (Harkness et al. 2013)
- Assessment Work Plan (Crist et al. 2013a)

2.2.2 Common Terminology

Following are key terms and abbreviations used throughout this document; a complete listing of terms and abbreviations is found in the glossary and acronym list at the end of this document.

- **AMT**: **Assessment Management Team**. This is the team of BLM staff and participating partners in the region that provided review and guidance for the contractor throughout the REA.

- **CA**: **Change Agent**. These are the features or processes that can negatively impact Conservation Elements (and in some cases can have neutral or beneficial effects on certain CEs). Development, invasive species, fire, and climate change effects are the four primary change agents addressed in this REA.
- **CE**: **Conservation Element**. These are the natural resource features assessed in the REA and include terrestrial and aquatic ecological systems, species, and species assemblages.
- **Condition**: used interchangeably with **Status** (see below)
- **Ecological status (**or **Status):** formal term in BLM **REA**s to describe the **condition** or integrity of areas of distribution of a **CE** based on presumed effects of change agents on the CE.
- **EIA**: ecological integrity assessment used to indicate the overall integrity or condition of the ecoregion as a whole.
- **Indicator**: Biophysical attributes that are used either directly or indirectly to measure the status of the **KEA**s, and therefore of the CEs
- **KEA**: **Key Ecological Attribute**. A KEA is a characteristic of a species' or ecosystem's biology, ecology, or physical environment that is critical to the resource's persistence in the face of both natural and human-caused disturbance. The combined **status** or **condition** of KEAs for a CE together determine the overall **ecological status** of the CE.
- **Landscape Condition Model** (**LCM**): the model used to calculate the status of CEs and other related assessments.
- **MAR**: **Madrean Archipelago Ecoregion**, specifically referring to the U.S. portion assessed in this REA.
- **MQ**: **Management Question**. These are questions developed by BLM and gathered during the REA that are important for guiding natural resource management and land use decisions. The **ecological status** assessments of CEs and other assessments conducted in the REA provide information and analysis results to help address the management questions.
- **REA**: **Rapid Ecoregional Assessment**
- **Scenario** or **KEA indicator scenario**: The aggregation of spatial datasets containing distributions of CAs that, combined, are indicators for the KEAs
- **Status**: formal term in BLM **REA**s to describe the **condition** or integrity of areas of distribution of a **CE** based on presumed effects of change agents on the CE.

2.3 Overview of the Madrean Archipelago Ecoregion

The following overview is a summary of the more extensive treatment provided in the Madrean Archipelago Ecoregion (MAR) Pre-Assessment Report (Harkness et al. 2013). The Madrean Archipelago (MAR) ecoregion is approximately 7.5 million hectares (18.5 million acres) and spans portions of four states in two countries: southeastern Arizona and extreme southwestern New Mexico in the United States, and northeastern Sonora and northwestern Chihuahua in Mexico. As defined for North America by the Commission for Environmental Cooperation[2] (CEC 1997), this ecoregion lies to the immediate east of the Sonoran Desert, to the south of the Arizona/New Mexico Mountains, to the west of the Chihuahuan Desert, and to the north of two ecoregions entirely within Mexico: the Sinaloa and Sonora

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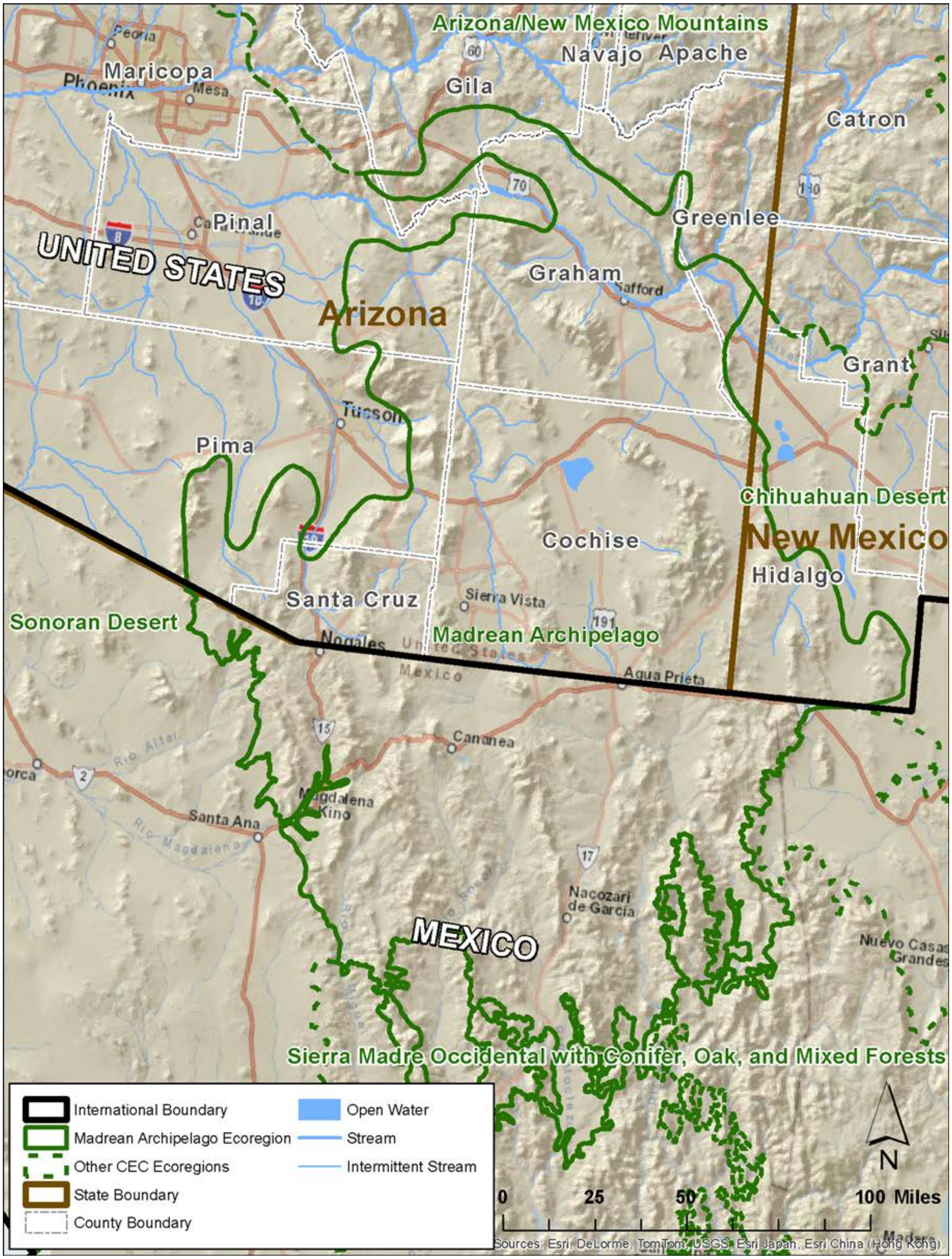
[2]The CEC was established in 1994 by Canada, Mexico, and the United States to implement the North American Agreement on Environmental Cooperation (NAAEC), the environmental side accord to the North American Free Trade Agreement.

Hills and Canyons with Xeric Shrub and Low Tropical Deciduous Forest, and the Sierra Madre Occidental with Conifer, Oak, and Mixed Forests (Figure 2-1).

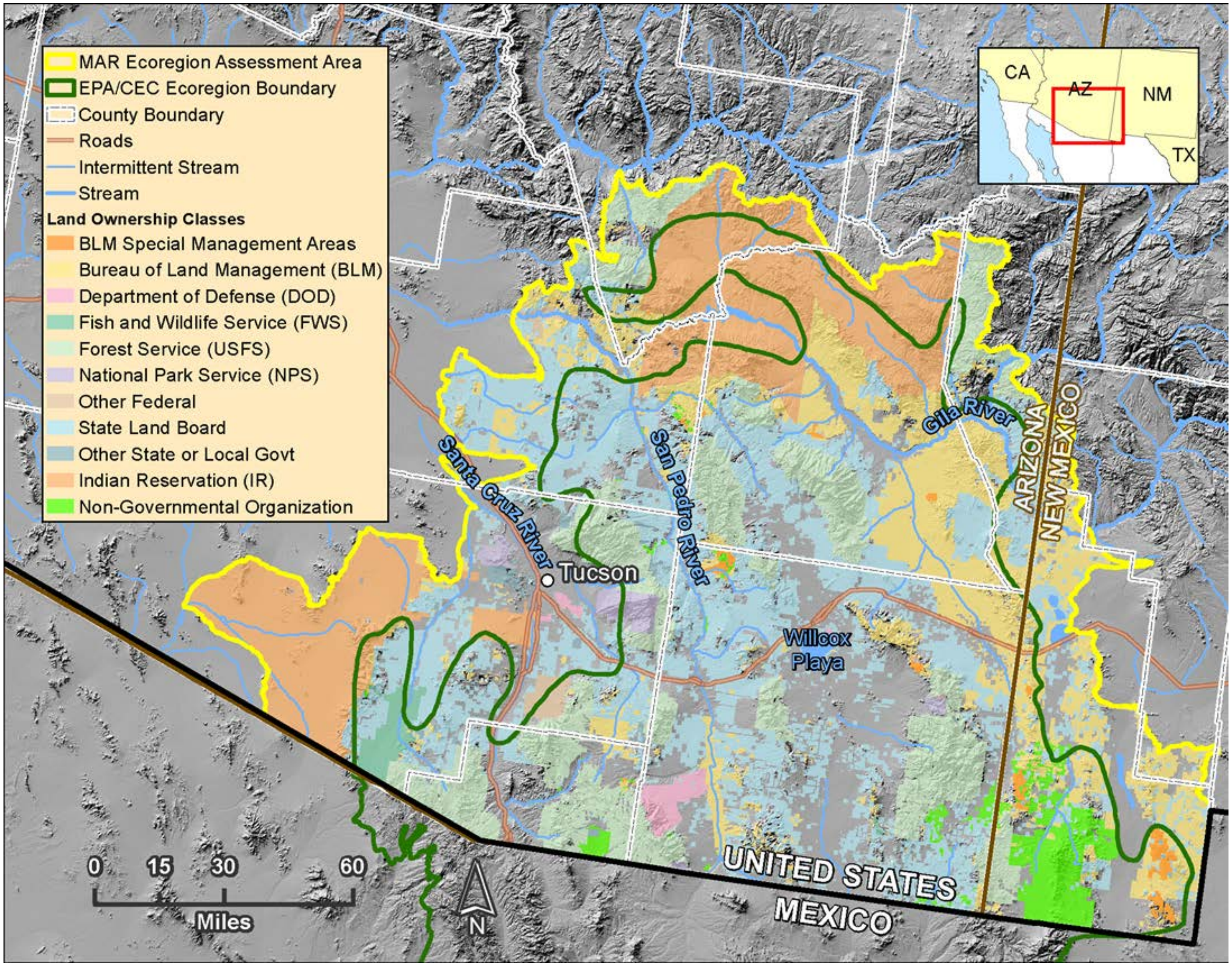
Figure 2-1. Map of the bi-national Madrean Archipelago ecoregion. The boundary of the Madrean Archipelago ecoregion is shown with the solid, dark green line; it is located in southeastern Arizona, southwestern New Mexico in the U.S., and northeastern Sonora and northwestern Chihuahua in Mexico.



2.3.1 Assessment Area for the Madrean Archipelago REA

The conceptual models for the Madrean Archipelago ecoregion (MAR) and the CEs draw on literature for the entirety of this bi-national ecoregion, as appropriate; for example, the CE conceptual model narratives typically discuss the CE across its range. However, the geospatial data and assessments only address the U.S. portion of the ecoregion. Defining the assessment area for the MAR followed the BLM REA standard methods. The ecoregion boundary (CEC, 1997) is the core of the assessment area but to ensure that influences affecting the periphery of the ecoregion are included in the assessments, the U.S. portion of the ecoregion was buffered with intersecting 5th-level watersheds to define the geographic area assessed in this REA. The REA assessment area (inclusive of the overlapping watersheds) encompasses approximately 6.4 million hectares (15.7 million acres) (Figure 2-2).

Figure 2-2. Map of the Madrean Archipelago REA assessment area. The area assessed for this REA is the U.S. portion of the Madrean Archipelago (green boundary as defined by CEC 1997) **plus** its intersecting 5th-level watersheds (yellow boundary) and by the border between the U.S. and Mexico.



2.3.2 Ecology of the Madrean Archipelago

This ecoregion is characterized by its unusual physiography, comprised of an archipelago of numerous isolated mountain ranges or “sky islands” surrounded by extensive intervening valleys or “desert seas.” The mountain ranges generally trend southeast to northwest. Including those located in the Mexico portion of the ecoregion, over 40 mountain ranges are found here, some reaching elevations over 2,715 m (8,900 ft) with the highest point of 3,267 m (10,717 ft) at Mt Graham (NRCS 2006). In contrast, the grasslands and semi-desert scrub occupying the smooth, intervening valleys of the ecoregion generally range in elevation from 2,620 to 4,590 feet (800 to 1,400 m).

These sky islands of the southwestern United States and northern Mexico are globally unique – the complex of basins and ranges extends from subtropical to temperate latitudes, hosting species from the Sierra Madre of Mexico and the Rocky Mountains of the United States (Warshall 1995), along with species characteristic of the Chihuahuan and Sonoran Deserts (Mau-Crimmins et al. 2005).The Madrean Archipelago is particularly biologically diverse due to its biogeographic setting between tropical and temperate regions, and to the great diversity of habitats resulting from the elevational gradients (Coblentz and Riitters 2004) coupled with geologic and soil substrate diversity. The biotic communities found along the Madrean Archipelago ecoregion’s gradients include subtropical desert (at the lowest elevations), subtropical thornscrub, semi-desert grasslands, oak savanna, deciduous riparian forest, oak-pine woodlands, and mixed conifer forests (Brown 1982, Marshall 1957, Mau-Crimmins et al. 2005, Warshall 1995). Interspersed with these upland communities are a variety of wetlands: marshes or ciénegas, ephemerally flooded playa lakes, and floodplains along mountain or lowland streams and rivers with gallery forests of deciduous trees and shrubs.

2.3.3 Human Context

Anthropogenic influences are a critical component of the ecoregion, as described in the ecoregion conceptual model (Appendix G). Anthropogenic activities and uses of the ecoregion also shape the issues facing natural resource managers in the ecoregion. This section of the report therefore fills a dual purpose: providing a brief narrative description of the human context that illustrates the anthropogenic role in the ecoregion conceptual model and introducing the subsequent section on natural resources-related issues facing the ecoregion.

2.3.3.1 Demographic Overview

The human population in the ecoregional assessment area (Figure 2-2) is estimated to be approximately 1.2 million (compiled from ADWR 2010, Community by Design 2011, and U.S. Census Bureau). Lying in the far western portion of the ecoregional assessment area (Figure 2-2), Tucson, AZ is the largest city in the assessment area, with a population nearing one million in the greater metropolitan area. In the U.S. portion of the ecoregion (Figure 2-2 solid green outline), the population is estimated to be under 200,000. This population is generally concentrated in smaller municipalities, a number of which are located along the Interstate 10 or Interstate 19 corridors. Sierra Vista, Nogales (AZ) and Douglas are the largest municipalities within the U.S. portion of the ecoregion, with populations of approximately 44,000, 21,000, and 17,000 respectively. Other cities and towns in the ecoregion include Safford, Willcox, Benson, and Bisbee in the United States, and Nogales, Agua Prieta, Cananea, Magdalena de Kino, and Nacozari in Mexico (see also Figure 2-1). Population densities outside these areas are low, often below five people per square mile (Gorenflo 2003 as summarized by Marshall et al. 2004); for example, Hidalgo County has a density of 1.4 people per square mile (Community by Design 2011).

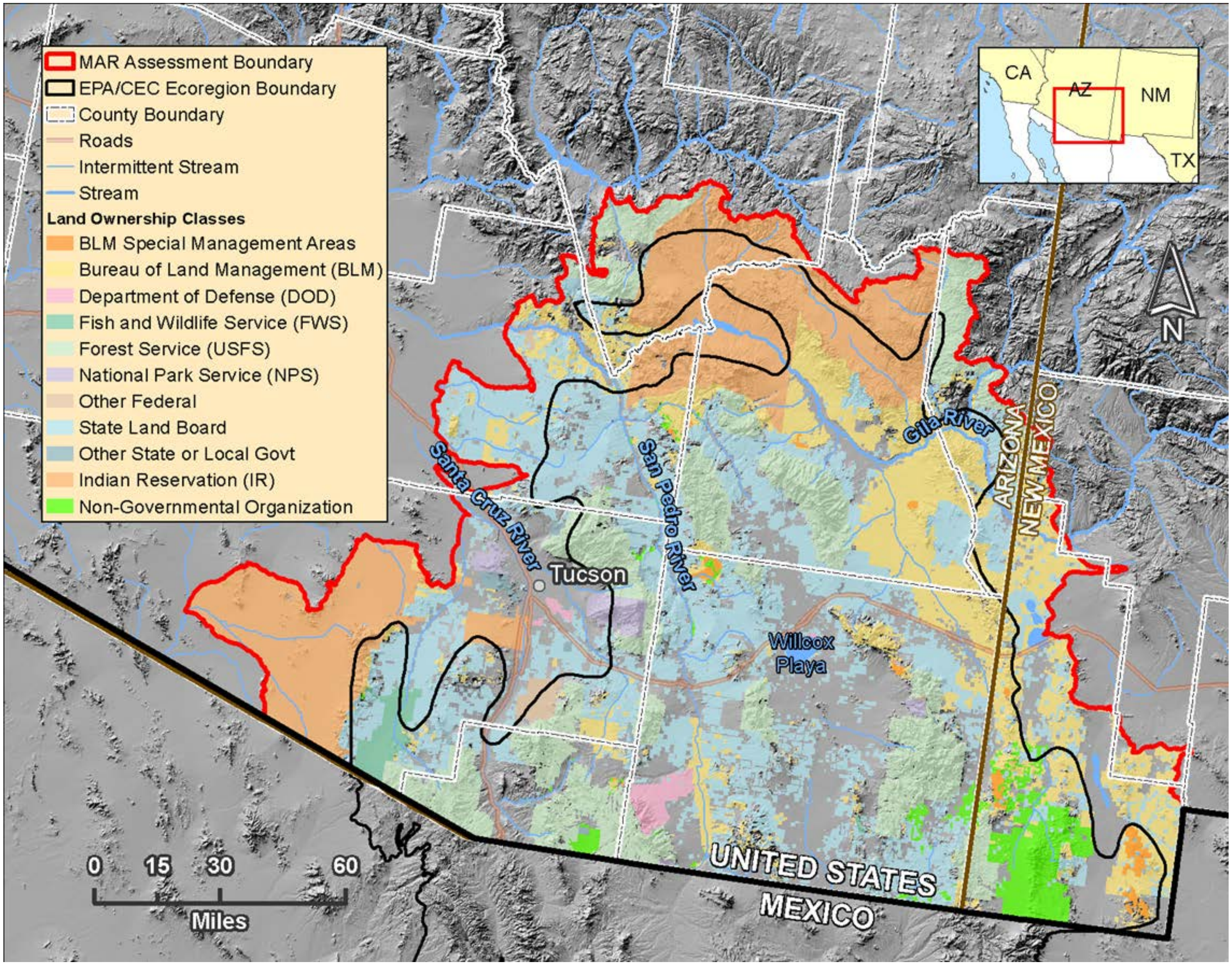
2.3.3.2 Land Ownership

As is common in the American West, the majority of the land in this ecoregion assessment area is in public ownership (Table 2-2). The patterns of land ownership are the result of historical European-American settlement patterns and government agency missions. Private lands tend to be concentrated in the valleys along waterways, in part due to the availability of water and productive soils. U.S. Forest Service lands are located in the sky islands – the mountain ranges that are home to the forest ecosystems in this region; land above approximately 1200 meters (4,000 feet) in elevation is generally National Forest. The foothills and lower elevations between the sky islands and the river valleys are predominantly managed either by the Bureau of Land Management or by Arizona's State Land Board. Within the total assessment region (15.7 million acres), total BLM ownership is 2,494,222 acres or about 16%; the area in BLM special management is 94,846 acres or 0.6% of the MAR. Buenos Aires National Wildlife Refuge is the largest USFWS refuge in the ecoregion. The Tohono O'odham Nation Reservation covers a significant area in the southwestern portion of the Madrean assessment area, and the San Carlos Apache Nation Reservation covers a large portion of the north central part of the ecoregion. The Animas Foundation, which is part of the Malpai Borderlands Group, manages the 129,900 ha (321,000 acre) Diamond A Ranch in the New Mexico portion of the ecoregion. Two large military facilities are located in this ecoregion as well: Fort Huachuca, near the Arizona-Mexico border, and the Willcox Dry Lake Bombing Range on the Willcox Playa. Typical ranching operations are usually comprised of a small area of private land (in the range of 16-65 ha (40-160 acres)) where the ranch is headquartered and contiguous grazing allotments that are leased from federal or state agencies. The broad ownership patterns of this ecoregion are illustrated in Figure 2-3. Areas with no ownership information, such as the Willcox Basin around the Willcox Playa, as well as ownership types not fitting in the other categories listed, are grouped as Other/Unspecified.

Table 2-2. Percentage of the Madrean Archipelago ecoregional assessment area in major categories of land ownership. Based on USGS' Protected Areas Database, v.1.3

Land Owner Type	Percentage of Madrean Archipelago assessment area
Federal	32.0%
State	24.9%
Private/Other/Unspecified	24.2%
Native American	15.9%
NGO	2.6%
Regional and Local Agencies	0.41%

Figure 2-3. Map illustrating land ownership in the Madrean Archipelago ecoregional assessment area. Map is based on USGS' Protected Areas Database of the United States (PAD-US), version 1.3 (USGS 2012). Land not otherwise designated is assumed to be privately owned.



2.3.3.3 Land Use

The predominant land use in the Madrean Archipelago in terms of spatial extent is cattle grazing; public lands which are not otherwise designated for conservation are generally available for grazing. Although estimated to occupy less than 1.5% of the ecoregion (based on LANDFIRE vegetation/land cover data), agriculture is another important land use in this ecoregion. Agricultural lands have replaced riparian and other lowland habitat and are responsible for a significant portion of water use in the ecoregion. Urban land use is focused in Tucson but smaller municipalities and other developed areas are also present. A relatively sparse network of transportation and utility corridors span the ecoregion. Mining is the largest industrial land use in this ecoregion; open-pit copper mines and other large mines exist in the region. Land uses and associated activities are a key change agent (development) affecting ecological systems and their driving or supporting processes.

2.3.4 Key Management Issues

The Madrean Archipelago ecoregion faces many issues relating to its natural resources as a result of the interplay between human activities and influences and the physical and ecological processes shaping the ecoregion. These issues have been summarized in a variety of reports and publications, such as the Heinz Center report on climate change and Arizona wildlife (Heinz Center 2011), volume 3 of the Arizona Water Atlas (ADWR 2010), the chapter on this ecoregion in the New Mexico Comprehensive Wildlife Strategy (NMDGF 2006), USGS' publication on U.S.-Mexico borderlands (Updike et al. 2013), and expanded upon in more detail in publications such as the periodic Sky Island/Madrean Archipelago conference proceedings (DeBano et al. 1995, Gottfried et al. 2013, Gottfried et al. 2005). Issues summarized in these reports were also identified in various forms in the MAR REA Development Forums (workshops conducted in the pre-assessment phase) and include the following:

- Climate change
- Water availability
- Invasive species
- Encroachment of woody species
- Altered fire regimes and fire suppression
- Livestock grazing
- Border control activities and infrastructure
- Development (residential, industrial, utilities, etc.)
- Agriculture

These issues inform the identification of specific change agents (CAs) that were identified for possible use in the REA assessments; not all CAs could be included (see data gaps in section 5.2.2 and appendices). For the purpose of having a standard terminology for and shared understanding of the CAs, the issues identified as being critical to this REA are organized into the four broad categories of CAs that are standard for BLM REAs:

1. Climate Change
2. Invasives
    - Non-native, invasive species
    - Managed non-native species
    - Native woody increasers
3. Fire

    - Recent burns
    - Fire regime status
4. Development
    - Urban/suburban, commercial, industrial development
    - Roads
    - Utilities
    - Mining
    - Energy development
    - Agriculture
    - Livestock grazing
    - Border-related infrastructure, including barriers, roads, lighting, and related features
    - Water usage associated with these activities or infrastructure

More details on the specific effects of each of these change agents on individual conservation elements are included in the conceptual models for the ecoregion (Appendix G) and each of the CEs (see appendices D-F).

3 Methods

The summary of methods applied in the Madrean Archipelago REA is divided into two parts: **3.1 Identification of Key Assessment Components**, summarizes the work conducted during pre-assessment to scope the assessments and develop conceptual models, and the second part, **3.2 Assessment Methods**, summarizes the geospatial assessment methods.

3.1 Identification of Key Assessment Components

This section briefly summarizes the methods used to identify the key REA components (conservation elements, change agents, and management questions) during the pre-assessment phase of the REA (see Appendix A for more details), as well as identify the final set of assessments to be conducted based on data evaluation and technical feasibility; complete details on pre-assessment methods are provided in the Pre-Assessment Report for this REA (Harkness et al. 2013) and its Appendix A. The pre-assessment findings, including the identified management issues, conservation elements, and change agents, formed the core of the Pre-Assessment Report.

3.1.1 Management Questions

Conducting assessments that can help address natural resources management questions is the foundation of an REA. Management questions are the questions for which information is needed in order to guide natural resource management and land use decisions. They are generally framed around a natural resource (or CE) and one or more CAs or other factors affecting the resource. REAs provide information and analysis results that can help address the management questions facing natural resource managers. MQs are the foundation guiding the development of the assessments that are conducted in an REA.

An initial set of approximately 200 MQs was identified by compiling issues and questions suggested by natural resource managers from around the MAR who participated in a series of Development Forums held early in the pre-assessment phase of the REA. These questions touched on the full spectrum of change agents and other human influences affecting resources in the MAR, and their synergistic relationships to the natural resources.

The contracting team compiled and organized the questions and issues thematically, both by change agent (e.g., climate change, fire, grazing, etc.), and by groups of conservation elements (upland systems, wetland systems, wildlife species, etc.). This allowed both the contractor and REA participants to see the patterns in the types of issues that are of greatest concern and should be addressed in the REA. Based on this thematic organization and review, the contracting team distilled the questions into a smaller, discrete series of management questions and concerns organized around a particular issue or change agent. These were then summarized in the relevant sections of the Current Issues chapter in the Pre-Assessment Report (Harkness et al. 2013) for this REA; for example, for fire-related management issues, see the section titled *Management Concerns Around Fire***.** These management concerns were grouped into four broad categories of assessments in the last chapter of the Pre-Assessment Report; together with the summaries of specific management concerns, these formed the basis of the assessments proposed in the REA work plan (Crist et al. 2013b).

3.1.2 Finalizing Assessments to Be Conducted

The work conducted in the pre-assessment phase provided the overall direction for the assessments to be conducted, as well as specific assessment needs. During the second phase of the REA, the management concerns and potential assessments were iteratively reviewed and translated into the assessments that were ultimately conducted. In addition to management needs, data availability and technical feasibility were two other key factors that determined which assessments could be conducted and how they might be approached.

In developing the work plan for the assessment phase of the REA, the contracting team reviewed the issues as outlined in the Pre-Assessment Report and preliminarily outlined the types of data and potential analytical approaches for conducting relevant assessments. This was presented to the AMT for review and the candidate list of assessments was finalized. During Task 2 of the assessment phase, data and modeling feasibility were conducted to determine the final set of assessments that were of priority and feasible.

Following are details on the selection of the change agents and conservation elements for the REA.

3.1.3 Conservation Elements

Conservation elements (CEs) are one of the core components of the REA. They are the natural resources – habitats, ecosystems, and species, or other features -- that are the focus of the assessment. The identification of conservation elements for this REA was a critical first step that took place over several months early in the REA through a process of reviewing and compiling relevant assessments and information on potential CEs, gaining input from stakeholders in the Development Forums, applying selection criteria, and engaging REA participants to obtain expert review and judgment to arrive at a final list. Representing the biota of an ecoregion with a small number of CEs is challenging; for this REA, criteria developed by BLM that sought to provide broad geographic coverage of the ecoregion through strategic selection of ecological system types were applied. REA participants identified ecological systems that were intended to be a representative cross-section of the region's diversity or are generally restricted to this ecoregion, as well as a suite of complementary and regionally significant species that are representative of other environments that were not adequately reflected by the ecological system types or that span ecological system types. CEs also needed to be of management concern; a brief summary of the CE selection process, including CE selection criteria, is provided below, additional details are provided in Appendix A of this report, as well as the Pre-Assessment Report. Eighteen CEs plus the unique mesquite upland scrub system were selected for assessment in the REA.

The ecosystem conservation elements for the MAR REA were selected from NatureServe's classification of terrestrial ecological systems (Comer et al. 2003). A terrestrial ecological system is defined as a group of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. A given terrestrial ecological system will typically manifest itself in a landscape at intermediate geographic scales of 10s to 1,000s of hectares and persist for 50 or more years.

3.1.3.1 Criteria and Considerations for Selecting CEs

The criteria and considerations listed here were applied to the compiled lists of ecological system and species CE candidates to inform development of a final set of candidate CEs for the AMT and Technical Team's consideration. Some of these considerations are relevant to both the species and ecological systems; others were relevant to only one or the other.

- Regional significance

    - Relevant to more than one BLM field office or other agency's local management jurisdiction [Both]
    - Dominant in the ecoregion [Ecosystems]
    - Broadly represent a cross-section of the region's diversity [Both]
    - Endemism [Both]
- Nexus with identified management issues [Both]
- Representation by associated ecological system (habitat) CE [Species]

3.1.3.2 Finalizing the Conservation Element List

Applying the above criteria resulted in approximately 20 candidate ecological system CEs and 65 candidate species CEs. Once the contracting team developed a set of final recommendations, based on the various input and sources described above, a series of webinars and conference calls were held with the AMT and Technical Team to review the candidates and arrive at the final list of 18 CEs. (Note that mesquite scrub is treated as both a CE because it has a conceptual model and as a stressor as indicated in the special assessment in section 4.4.2; it is not included in the count of 18 total CEs). The ecological system CEs are listed in Table 3-1 and the species CEs in Table 3-2 below. The details of the remaining steps in the review and selection process are described in Appendix A, in the section on CE selection.

3.1.3.3 Conservation Elements Selected for Bioclimate Envelope Modeling

Once the CEs were finalized, candidate CEs for bioclimate envelope modeling were identified based on which CEs were of greatest management concern, which CEs had been previously modeled by USGS, and which CEs were likely to have distribution data adequate for bioclimate envelope modeling. The list of candidates for bioclimate envelope modeling was reviewed and finalized by the AMT, based on the same considerations.

Table 3-1. Ecological system conservation elements (CEs) selected for the Madrean Archipelago REA. The ecological systems are organized in this table according to the four major divisions (valley upland system, montane upland system, connected stream and wetland, and isolated wetland) of the ecoregion conceptual model (Figure 3-1). Percent of ecoregion occupied by each system is calculated for the U.S. portion only; totals by division do not include other minor systems or developed and agricultural areas. The column "CS or BEM" indicates whether the CE was the subject of a case study (CS) and or a bioclimate envelope model (BEM).

Ecological System Name	Approx. % Ecoregion	Notes on Selection	CS or BEM
Valley Upland Division	**56.0%**		
Apacherian-Chihuahuan Mesquite Upland Scrub	19.5%	Non-natural ecosystem resulting from spread of mesquite into the uplands	BEM
Chihuahuan Creosotebush Desert Scrub	13.2%	Represents an important desert shrubland type	BEM
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	18.2%	Characteristic and most of its distribution is within the MAR	CS BEM
Madrean Encinal	5.1%	Characteristic and most of its distribution is within the MAR	BEM
Montane Upland Division	**13.4%**		

Ecological System Name	Approx. % Ecoregion	Notes on Selection	CS or BEM
Madrean Pinyon-Juniper Woodland	5.8%	Characteristic and most of its distribution is within the MAR	
Montane Conifer-Oak Forest and Woodland	2.8%	Characteristic and most of its distribution is within the MAR	
Mogollon Chaparral	4.8%	Represents important montane shrublands; characteristic of the MAR	
Isolated Wetland Division	**<1%**		
North American Warm Desert Playa and Ephemeral Lake	<1%	Important ephemeral wetland for many migratory birds; also invertebrate assemblage	
Connected Stream and Wetland Division	**4.3%**		
North American Warm Desert Riparian Woodland and Shrubland, Mesquite Bosque and Stream	3.3%	Major river and riparian areas which are critical habitat for many species	CS
North American Arid West Emergent Marsh/Ciénega and Pond	1.0%	Spring-fed wetlands; ciénegas are somewhat unique to the MAR.	
North American Warm Desert Lower Montane Riparian Woodland and Shrubland and Stream	<1%	Major river and riparian areas which are critical habitat for many species	

Table 3-2. Species conservation elements (CEs) selected for the Madrean Archipelago REA. The column "CS" indicates whether the CE was the subject of a case study (CS).

Category	**Species Name**	**Listing Status** (State or Federal)	**Notes on Species Selection**	**CS**
Mammal	Pronghorn (*Antilocapra americana*)	None	Strong interest and direction from the AMT to include this species that is of management interest and highly associated with grassland habitats in the MAR ecoregion.	
Mammal	Coues white-tailed deer (*Odocoileus virginianus couesi*)	None	This big game species is of management interest in the MAR ecoregion and adds different elevation range and habitat considerations than those represented by the pronghorn and desert bighorn sheep.	
Mammal	Desert bighorn sheep, all subspecies (*Ovis canadensis*)	None	This species is of high management interest to multiple entities in the MAR ecoregion because it is a game species. It inhabits a wide range of elevations.	
Mammal	Black-tailed prairie dog (*Cynomys ludovicianus*)	None	This keystone species is of high management interest to multiple entities in the region.	
Mammal	Nectar-feeding bats	See conceptual model	Nectar-feeding bats and their associated habitat are of high management interest to multiple entities in the region and there was high interest in this group from the AMT and the development forums.	CS
Bird	Grassland bird assemblage	See conceptual model	Strong interest and direction from the AMT to include grassland birds in order to provide needed landscape-level information at the diversity/assemblage scale.	
Reptile	Ornate box turtle (*Terrapene ornata luteola*)	None	In conjunction with the Chiricahua leopard frog, this species helps represent the herpetofaunal diversity; it has a wide distribution and research need associated with it. There was strong interest from the AMT in including this species.	

Category	Species Name	Listing Status (State or Federal)	Notes on Species Selection	CS
Amphibian	Chiricahua leopard frog (*Lithobates chiricahuensis*)	Federally Endangered, Arizona Threatened	This federally threatened species is of management concern to entities across the ecoregion and a diversity of management entities having stewardship over its habitat.	

3.1.4 Change Agents

Change agents (CAs) are those anthropogenically-driven or -influenced land uses, activities, or phenomena that can affect the ecological status, or "health," of CEs. They are drawn from the standard REA CA categories of 1) development, 2) climate change, 3) invasive species, and 4) fire. "Development" is a particularly broad category that includes any direct human use, activity, or infrastructure on the landscape, such as agriculture, border patrol activities, roads, urban development, or energy development, among many others. Cattle grazing is a major land use and management issue; therefore, it was included in the conceptual models and candidate management questions. However, as in other REAs, it was not included as a CA in the geospatial analyses due to lack of consolidated data on grazing locations and intensity. "Invasive species" is also an umbrella term that includes invasive non-native species, managed non-native species (e.g., sport fish), and "native woody increasers" such as mesquite. As with CEs and MQs, specific CAs relevant to this ecoregion (e.g., specific development activities such as mining, or specific non-native species such as Lehmann's lovegrass (*Eragrostis lehmanniana*) were identified through a combination of input from the Development Forums, review of large-scale assessments and other publications, and additional consultation with experts in various meetings and discussions, including the second AMT workshop. As described in section 3.2 below, the CAs were further refined based on the specific assessment needs as revealed in the conceptual models (below), development of detailed geospatial process models (Appendix B), and the data available.

3.1.5 Conceptual Models

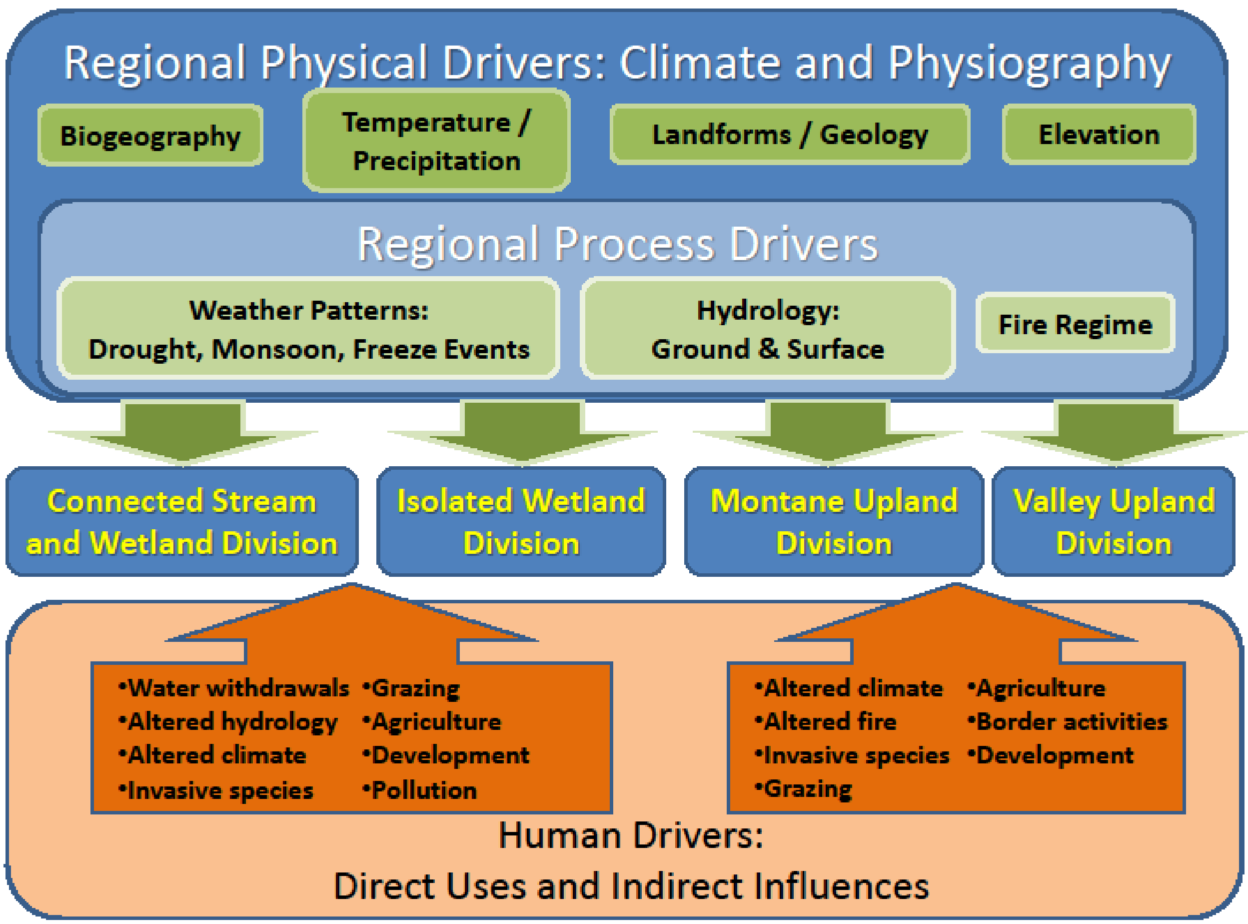
Conceptual models are an important component of a REA, and were developed for both the ecoregion as a whole and for the individual CEs. Conceptual ecological models assist with organizing current knowledge and communicating key assumptions about the environmental controls and dynamics that characterize the regional landscape and component CEs. Conceptual models form the basis for a science-based process, in that they force users to clearly state assumptions about critical components, and interactions among those components, for a given phenomenon.

3.1.5.1 Ecoregion Conceptual Model

The ecoregional conceptual model includes both text and diagrammatic representations of ecoregion scale biophysical and process drivers (Figure 3-1). Together the text and diagrams: 1) depict ecoregional ecological features, processes, and interactions among resources and change agents, 2) provide a science-based context as to how key ecological processes and attributes interact with one another and how they may be driven to change by change agents, and 3) provide a link to the Fundamentals of Land Health and Ecological Integrity (see USDI BLM 2006, 43 CFR 4180). Key processes are represented so that the conceptual model could be used in the ecological integrity assessment to depict the status of landscape units within the ecoregion. The individual CEs nest within the overarching conceptual model of the ecoregion.

The content for the ecoregional conceptual model (see Appendix G for the entire ecoregional conceptual model with description) was developed by several topic experts on the contracting team. In addition, the BLM and AMT contributed via recommending additional reports and literature. Many large-scale assessments have already been completed for this ecoregion, the adjacent Sonoran Desert, and the larger Chihuahuan Desert region within which it lies. The sky island region has also been the focus of several conferences devoted to the biodiversity, ecology, landscape ecology, fire ecology and conservation of the region. All of these assessment documents and reports were consulted for general and specific information for components of the descriptive portion of the ecoregion conceptual model.

Figure 3-1. Conceptual diagram for the Madrean Archipelago ecoregion, showing the most important physical and process drivers for the region as a whole, as well as important human influences and direct uses. The major patterns of ecosystems are represented by four broad divisions (e.g., upland versus wetland), which are shaped or influenced by both the natural and human drivers. While biogeography is not a direct physical driver, it is a major influence on the diversity of the MAR both spatially and temporally.



3.1.5.2 Conservation Element Conceptual Models

The same basic format for conceptual models was applied, with some variation, for each of the REA's terrestrial and aquatic ecosystems and the species or species assemblage CEs. Conceptual models combine text, concept diagrams, and tabular summaries in order to clearly state assumptions about the ecological composition, structure, dynamic processes, and interactions with major CAs within the ecoregion.

Information was first compiled about the CE's ecology and functioning in the landscape today. For the terrestrial and aquatic ecosystem CEs, the initial descriptive material was NatureServe's descriptions for ecological systems (Comer et al. 2003, NatureServe 2012); additional material was then added for each CE from recent studies. For the species and species assemblage CEs, species CE data was also obtained from NatureServe's central database. Additional information for each species was developed for the MAR ecoregion, much of this through literature review by taxonomic experts for the species CEs who generally stay current with the published literature and data for particular groups of species. State agency websites that provide and maintain a wealth of information for many species occurring in the state were also consulted. For all CEs, the conceptual models provide some range-wide information for the ecosystem or species, as well as information that is most relevant to the MAR assessment.

The text content for both terrestrial and aquatic ecosystems includes information such as distribution within the ecoregion; abiotic and biophysical setting (e.g., elevation, aspect, slope, substrates, hydrologic characteristics, landform setting, etc.); biotic composition (e.g., floristic composition, associated aquatic species where known); natural ecosystem dynamics (e.g., fire regime, flood regimes, insects or disease); and altered ecosystem dynamics or stressors (e.g., invasive plants, disrupted fire or flooding regimes, effects of pollutants). The information developed is intended to cover the full geographic distribution of the CEs, which may extend beyond the ecoregion, and does not specifically focus on its characteristics or dynamics as they occur within the MAR.

For the species CEs, major components of conceptual model information include distribution within the ecoregion; life history characteristics (e.g., reproductive behavior, population dynamics); major habitat requirements (e.g., food requirements, seasonality of use); key interactions with other species; and important vulnerabilities or stressors (e.g., diseases introduced from livestock, disruption of bat roosts by noise).

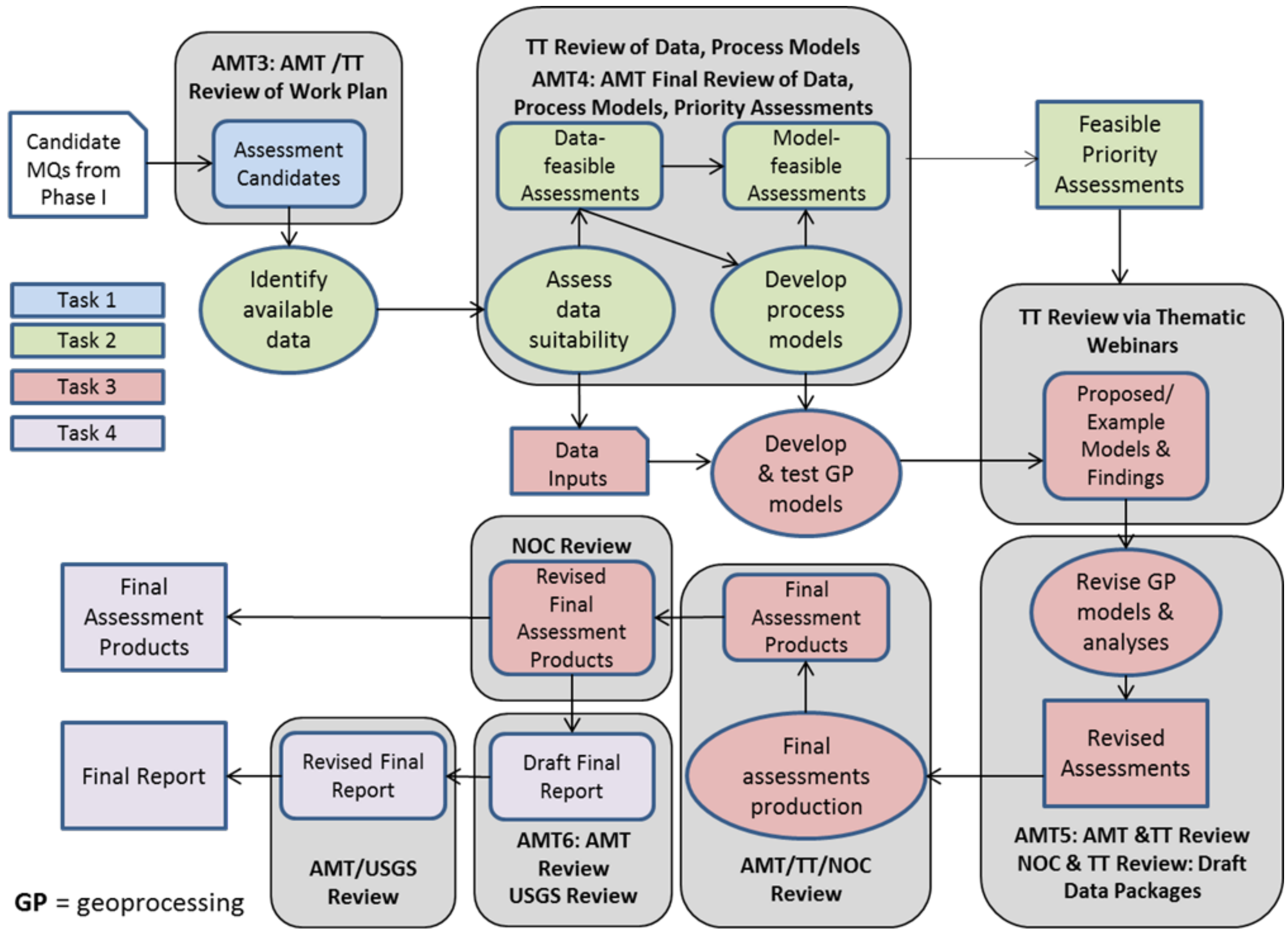
Characterizing the biotic and abiotic drivers for each CE, as reflected in the conceptual models, is critical to understand how the CE functions and is distributed in the landscape. It provides the foundation for identifying a limited suite of **key ecological attributes** (KEAs), which are the primary drivers of ecosystem condition and dynamics over time and space for each CE (Parrish et al. 2003, Unnasch et al. 2009). Ecological attributes include landscape-level biological characteristics (such as plant composition of terrestrial ecosystems), ecological processes (e.g., fire or hydrologic regimes), interactions with the physical environment (e.g., soil or water chemistry), and relevant anthropogenic change agents (such as impacts from development or invasive exotic species). Key ecological attributes are organized within the categories of Size, Condition (biotic or abiotic), and Landscape Context (Unnasch et al. 2009). Key ecological attributes (KEAs) were identified and defined for each CE, although not all of them were assessed in the REA.

An additional important component of each CE's conceptual model is a diagrammatic representation of the model. For all of the terrestrial ecosystem CEs models were utilized from other sources, such as studies by The Nature Conservancy of vegetation dynamics in southern Arizona ecosystems (Gori and Enquist 2003, Schussman and Gori 2006, Schussman 2006a, Schussman 2006b) or state-and-transition models developed by Natural Resources Conservation Service (NRCS) for Ecological Site Descriptions (NRCS 2014). For the aquatic and species CEs, new model diagrams were developed. See Figure 4-4, Figure 4-12, and Figure 4-23 in the case studies of CE status assessments for examples of CE conceptual model diagrams (as well as Appendices D, E, and F).

3.2 Assessment Methods

The Madrean Archipelago assessment included the "standard" assessments for calculating ecological status of each CE, overall ecological integrity of the ecoregion, and climate change trends. "Special assessments" address management questions not informed, or insufficiently informed, by the standard assessments. Below is a summary of the methods for each type of assessment; considerable additional detail on assessment methods are provided in appendices B and C. Figure 3-2 illustrates the work flow for the Assessment Phase of the REA, including the steps leading to finalizing the assessments to be conducted.

Figure 3-2. Work flow of assessment phase of MAR REA. This diagram identifies the four tasks of the second (assessment) phase of the REA and points of engagement with the AMT, Technical Team (TT) and National Operations Center (NOC). The diagram starts in the upper left and moves to the right and clockwise to finish in the lower left. The tasks are color-coded as follows: Blue – Task 1: identify candidate assessments; Green – Task 2: assess feasibility; Pink – Task 3: conduct assesments; and Pale Purple – Task 4: deliver report and data products. Review by AMT, TT, NOC, and other reviewers is shown in the gray rounded rectangles. Contractor tasks are shown in ovals, interim products are shown in rounded rectangles, and final products are shown in rectangles. GP = geoprocessing.



3.2.1.1 Data Inventory and Assessment

The candidate assessments determined the necessary data themes. A Data Needs review was conducted for each proposed assessment to identify the specific types of geospatial data required to complete each assessment. Data must come from existing sources because REAs specifically do not conduct the gathering or generation of new data, such as gathering field data, processing raw, remotely sensed data, etc. REAs may, however, derive new data sets from existing data where warranted. Available geospatial data were identified by the Contractor team and through topical webinars with the AMT and Technical Team members. Data were acquired and systematically reviewed to evaluate their suitability for use in the assessment. A detailed data inventory tracking form was provided to BLM, along with a list of key data gaps.

3.2.1.2 Process Models

As data were identified and evaluated for use in the proposed assessments, process models for conducting the assessments were also developed. Process models are box and arrow diagrams that map the analytical process from source data input, through geospatial analysis, to product output. Each proposed assessment that passed the initial data feasibility screening had a process model developed and reviewed. During the course of model development, additional iterations of data acquisition and evaluation were conducted as new data needs were identified. Appendix B contains the final process models used to conduct the analyses.

3.2.1.3 Assessments Conducted in the MAR REA

To aid in the final selection of assessments to be conducted for the REA, a memorandum was prepared that contained the proposed assessments and associated process models. This information was presented to the AMT and the memorandum was reviewed with some suggested revisions that informed the implementation of the geospatial analyses for the assessments. The assessments that were ultimately conducted for this REA are as follows:

- Ecological Status of CEs, Current
- Ecoregional Ecological Integrity
- Climate Space Trends, Recent
- Climate Space Trends, Future
- CE Distributions Intersected with Future Climate
- Bioclimate Envelope Models
- 2025 Risk Assessment (for three case study CEs)
- Mesquite Scrub Expansion: Restoration Opportunities
- Soil Erosion Potential

3.2.2 Change Agent and Conservation Element Distributions

To assess the CEs and CAs that were the focus of this REA, datasets reflecting their geographic distribution or extent were needed. CE and CA distribution data acquired and confirmed suitable earlier in the REA process were prepared for use in the REA assessments. The majority of CA distributions used in the MAR assessment required minimal pre-processing, including reprojecting to NAD_1983_Contiguous_USA_Albers, clipping to the MAR boundary, buffering by 16m (point and line data) and converting to ArcGIS Grid. A few CA datasets required additional minimal processing before being input to the NatureServe Vista decision support tool used in most of the assessments, including combining or subsetting. A few CA datasets required more substantial pre-processing or modeling as described in Appendix C.

The best available data to represent the distribution of CEs were investigated and reviewed. The primary source dataset for the ecosystems CEs is the NatureServe terrestrial ecological systems map (NatureServe 2013). This is a 30m raster dataset which used the SWReGap land cover map as a starting point and was refined and modified by NatureServe ecologists over the past several years. Other CEs data came from a variety of sources. Many CEs required modifications to their existing distributions, as described in Appendix C for each CE.

3.2.3 Ecological Status of Conservation Elements

Assessing ecological status of conservation elements (CEs) seeks to communicate, in map form, the condition of each location of a CEs distribution as a factor of change agents (CAs) present. Specifically the ecological status of a CE is defined by the current condition of its key ecological attributes (KEAs). The foundation of the approach for assessing ecological status of CEs is built on NatureServe's Ecological Integrity Assessment Framework (Faber-Langendoen et al. 2006, Unnasch et al. 2009), which the BLM adopted for use in REAs. This framework specifies the identification of measurable indicators for assessing the ecological status of each CE's key ecological attrbitues within an ecoregion (Rocchio and Crawford 2011, Unnasch et al. 2009). Indicators provide either direct or indirect measures of the condition of the KEAs.

Two aspects of the framework as implemented in the MAR REA are noteworthy. First, each CE has a customized response model characterizing how the CE responds to CAs; consequently, the CE indicator scores and ecological status results are more informative than if a single, uniform response model had been applied to all CEs. Where CEs respond to CAs very similarly, there are similarities in their response model outputs and associated indicator scores. Second, the status assessment was implemented in a commercial-grade decision support system, NatureServe Vista (Vista), that allows automated replication of the status assessments, testing of different parameters, and easy updating of all inputs (see also section 5.3).

Key Terminology for Status Assessments

- **CE conceptual model**: Conceptual models are the descriptive text and accompanying graphics that characterize the ecology and biology of the CEs, including descriptions of how change agents are expected to affect the **ecological status** or **condition** of CEs.
- **CE response model:** The set of numeric values that characterize the way a CE responds to direct exposure to a **CA** (site intensity value) and (optionally) within a specified distance from the CA.
- **Condition**: used interchangeably with **Status** (see below)
- **Ecological status (**or **status):** formal term in BLM **REA**s to describe the **condition** or integrity of areas of distribution of a **CE** based on presumed effects of change agents on the CE.
- **EIA**: ecological integrity assessment used to indicate the overall integrity or condition of the ecoregion as a whole.
- **Indicator**: Biophysical attributes that are used either directly or indirectly to measure the status of the **KEA**s.
- **KEA**: **Key Ecological Attribute:** A KEA is a characteristic of a species' or ecosystem's biology, ecology, or physical environment that is critical to the resource's persistence in the face of both natural and human-caused disturbance. The combined **status** or **condition** of KEAs for a CE together determine the overall **ecological status** of the CE.
- **KEA indicator scenario** (or **Scenario**): The aggregation of **CA** distribution maps used to assess the **indicators** associated with each of the **KEAs** for each of the CEs. The scenarios are input into the **LCM**.

- **Landscape Condition Model** (**LCM**): the geospatial modeling tool used to calculate the **ecological status** of CEs and conduct other related assessments (e.g., ecological integrity of the ecoregion). The **CE response models**, **KEA indicator scenarios**, and **CE** distribution maps are the key inputs that are run through the **LCM**.

3.2.3.1 Identifying Indicators of Ecological Status

The most accurate measure of ecological status of CEs requires field-based measurement of many factors (Comer and Faber-Langendoen 2013, Faber-Langendoen et al. 2006, Unnasch et al. 2009), or combinations of broad and fine-scale measurements (sensu USDI BLM 2006). However, an REA must rely on existing, primarily remotely-sensed data on CAs and other factors as indirect indicators of status. For example, presence of roads can fragment the size of CE patches/occurrences, presence of invasive species reduces biotic diversity, and dams on streams reduce aquatic connectivity. The lack of such features suggests, without other evidence, that ecological status should be high. This approach may be tested with field observations (which may be used to calibrate models) and updated with new or improved data. Therefore, an REA gives a partial measurement of ecological status for those measures derivable from remote sensing or ecoregion wide monitoring programs.

With these considerations in mind, indicators were chosen accordingly to measure a limited set of key ecological attributes for each CE (see Appendices D, E, and F for additional details on indicator selection). The selected indicators are dependent upon the data available to represent them geospatially; most of the indicators are indirect and stressor-based measures of current conditions (Table 3-3). There are two indicators for the aquatic CEs for which direct measures of status were feasible: native biotic integrity (based on native aquatic fauna), and aquatic habitat (Table 3-3).

Table 3-3. Key ecological attributes and indicators used for ecological status assessment of MAR conservation elements (*italics indicates applicable CE categories*). The definition of each key ecological attribute is provided, along with a brief characterization of stressors.

KEA Category: **KEA Names**	**Definition and Stressors**	**Indicators**	**Indicator Datasets** ***(and applicable CEs)***
Landscape Context: **Landscape Condition & Cover for Ecological System CEs** **Habitat Availability for Species & Assemblage CEs**	Ecological conditions and landscape dynamics that support ecological systems or species habitat are affected by fragmenting effects of land use. Land use impacts vary in their intensity where they occur, as well as their ecological effects with distance. The extent of natural ground cover for the watershed or within the CE distribution, versus the extent of different kinds of modifications to the watershed surface for human use (including roads, urban/rural areas, agriculture, mines, transmission corridors, and energy development). Development infrastructure directly removes habitat and can degrade habitat through fragmentation, noise, and other impacts.	Development	• Development features(e.g., roads, agriculture, urban development) within the footprint of CE occurrence **(*All CEs*)**
Biotic Condition: **Native Riparian/ Aquatic Faunal Composition**	The taxonomic and functional composition of the fauna is an important aspect of the ecological integrity of the ecosystem. This includes numerous native species including birds, mammals, fishes, reptiles, amphibians, and invertebrates; and the pattern(s) of natural variation in these compositions over time (seasonal, annual, longer-term).	Native Biotic Integrity	• Endangered species (presence of endangered species such as birds and amphibians) ***(All Aquatic Ecosystem CEs)*** • Native fish species and index of aquatic macroinvertebrates species ***(Riparian Aquatic Ecosystem CEs)***

KEA Category: KEA Names	Definition and Stressors	Indicators	Indicator Datasets *(and applicable CEs)*
Biotic Condition: **Non-native Riparian/ Aquatic Flora & Fauna Composition** **[Non-native Species for CLF]**	The taxonomic composition including woody and non-woody vegetation - terrestrial, wetland, and aquatic plants - and the pattern(s) of natural variation in this composition over time (seasonal, annual, and longer-term) is an important aspect of the ecological integrity of the ecosystem. Species vary in their sensitivity to different stresses such as competition from invasive species. Predation by non-native species is implicated as a contributing factor in the decline of ranid frogs in western North America and may be the most important factor identified so far in the current decline of the Chiricahua Leopard Frog.	Invasive Non-Native Riparian/ Aquatic Species	• Abundance of non-native invasive species such as tamarisk, cheatgrass, and others ***(All Aquatic CEs)*** • Presence of aquatic invasive species (such as bullfrogs and crayfish) ***(All Aquatic Ecosystem CEs, CLF[3] CE)***
Biotic Condition: **Vegetation Composition for Ecological System CEs** **Condition of Habitat for Species & Assemblage CEs**	The overall plant species composition and diversity of an ecosystem is an important aspect of its ecological integrity and largely defines it. These suites of species vary in their sensitivity to different stresses such as competition from invasive species. Animal species are dependant upon good quality forage and the structural characteristics of vegetation which provide them cover or good line-of-sight for predators. Alterations in the taxonomic, structural, and functional composition of the terrestrial floral assemblage beyond its natural ranges of variation therefore strongly indicate the types and severities of stresses imposed on the ecosystem or on the species utilizing it for habitat.	Invasive Plant Species	• Abundance of non-native invasive species such as cheatgrass and buffelgrass ***(All Upland Ecosystem and Species[4] CEs, except CLF)*** • Abundance of native woody increaser (mesquite) ***(All Upland Ecosystem and Species CEs, except CLF)***

[3] CLF = Chiricahua Leopard Frog

[4] Species CEs includes all Species Assemblage CEs

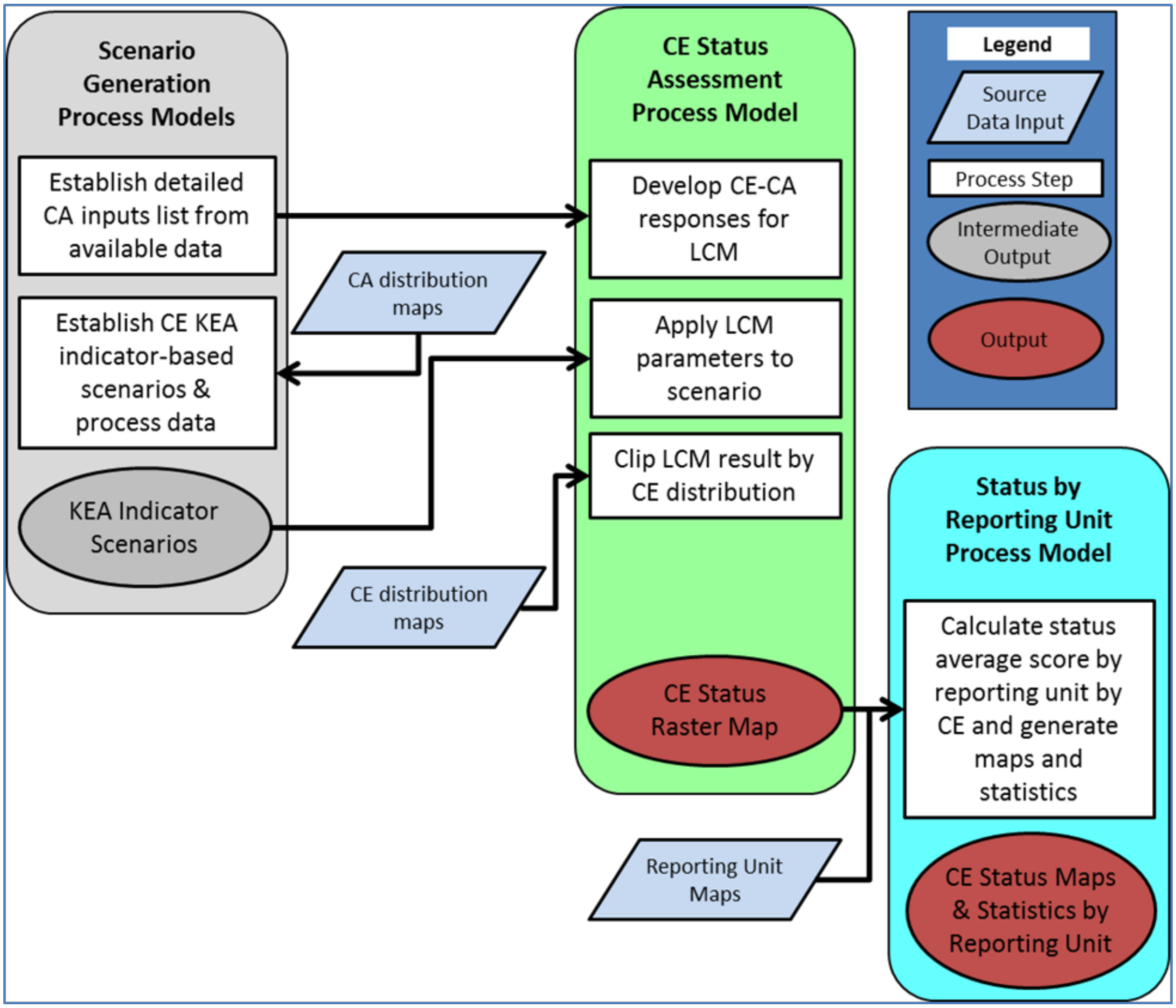
KEA Category: **KEA Names**	**Definition and Stressors**	**Indicators**	**Indicator Datasets** ***(and applicable CEs)***
Abiotic Condition: **Hydrologic Regime**	The pattern of surface flow in the stream channel and surface-groundwater interaction along the riparian corridor - as characterized by, for example, the frequency, magnitude, timing, and duration of extreme flow conditions and extreme water table elevations; the magnitude and timing of seasonal and annual baseflow and total discharge; and the magnitude of seasonal and annual water table mean elevation. Water use via diversions and pumping directly remove water from aquatic resources, which may cause stress to riparian and aquatic life.	Water Use	• Combined total surface and ground water use by groundwater basin (AZ) or county (NM) ***(All Aquatic Ecosystem CEs except NAWD Lower Montane and Foothill Riparian CE; CLF CE)***
Abiotic Condition: **Fire Regime**	Fire is a natural agent of disturbance in vegetation communities that maintains species composition, vegetation structure, and sustains ecological processes such as nutrient cycling. Fire can be removed (fire suppression) or can increase in frequency, leading to increases in fuel loads, changes in vegetation structure, and result in hotter, more destructive fires or loss of species not adapted to frequent fires.	Fire Regime Departure[5]	• Fire Regime departure ***(All Upland Ecosystem CEs, All Species CEs, except CLF*** • Recent Burn Severity ***(Desert Box Turtle, Grassland Bird Assemblage and CLF CEs)***
Abiotic Condition: **Geomorphology**	The geomorphology of the stream channel, banks and floodplain and its stability/turnover resilience to withstand and recover from high erosion events (rainfall, flooding).	Habitat Quality	• Proper Functioning Condition Assessment ***(Riparian Aquatic Ecosystem CEs)*** • Aquatic Habitat Quality Assessment ***(Riparian Aquatic Ecosystem CEs)***

[5] For species and assemblage CEs, fire regime departure is an indicator of habitat quality & condition

3.2.3.2 Overview of Geospatial Analysis of Ecological Status

Ecological status of CEs was assessed for the current timeframe and, when data were available, for the near-term future timeframe (2025); only climate change was assessed for the 2060 timeframe. Ecological status was assessed using a raster-based geospatial modeling tool, the Landscape Condition Model (LCM) (Comer and Faber-Langendoen 2013, Comer and Hak 2009), operating within NatureServe's Vista software. The LCM/Vista tool was used to model the effects of change agents on a conservation element's key ecological attributes (KEAs) for a particular timeframe and generate the CE status assessment maps, reporting unit maps, and status statistics. A summary and diagram (Figure 3-3) of the status assessment steps follow. Additional details on the approach are provided in Appendix B, detailed GIS processing steps are provided in Appendix C, and details on response models for CEs are found in appendices D, E, and F.

Figure 3-3. Ecological status assessment summary process model. This model provides an overview of the ecological status assessment process. Round-cornered boxes indicate component process models illustrated and described in greater detail in Appendix B. The general process begins by characterizing the KEA indicator scenarios (Scenario Generation Process Models box) and developing a response model for how CEs respond to CAs (CE Status Assessment Process Model box). The CE response values are applied to the scenarios to generate maps of indicator scores across the ecoregion CE Status Assessment Process Model box). The CE distributions are then intersected with the indicator maps to generate the CE Status Raster Maps (ecological status maps) in the CE Status Assessment Process Model box and then summarized (averaged) to reporting units (Status by Reporting Unit Process Model box). LCM = Landscape Condition Model that calculates condition scores from exposure of the CE to change agents.



3.2.3.3 Steps for Assessing Ecological Status

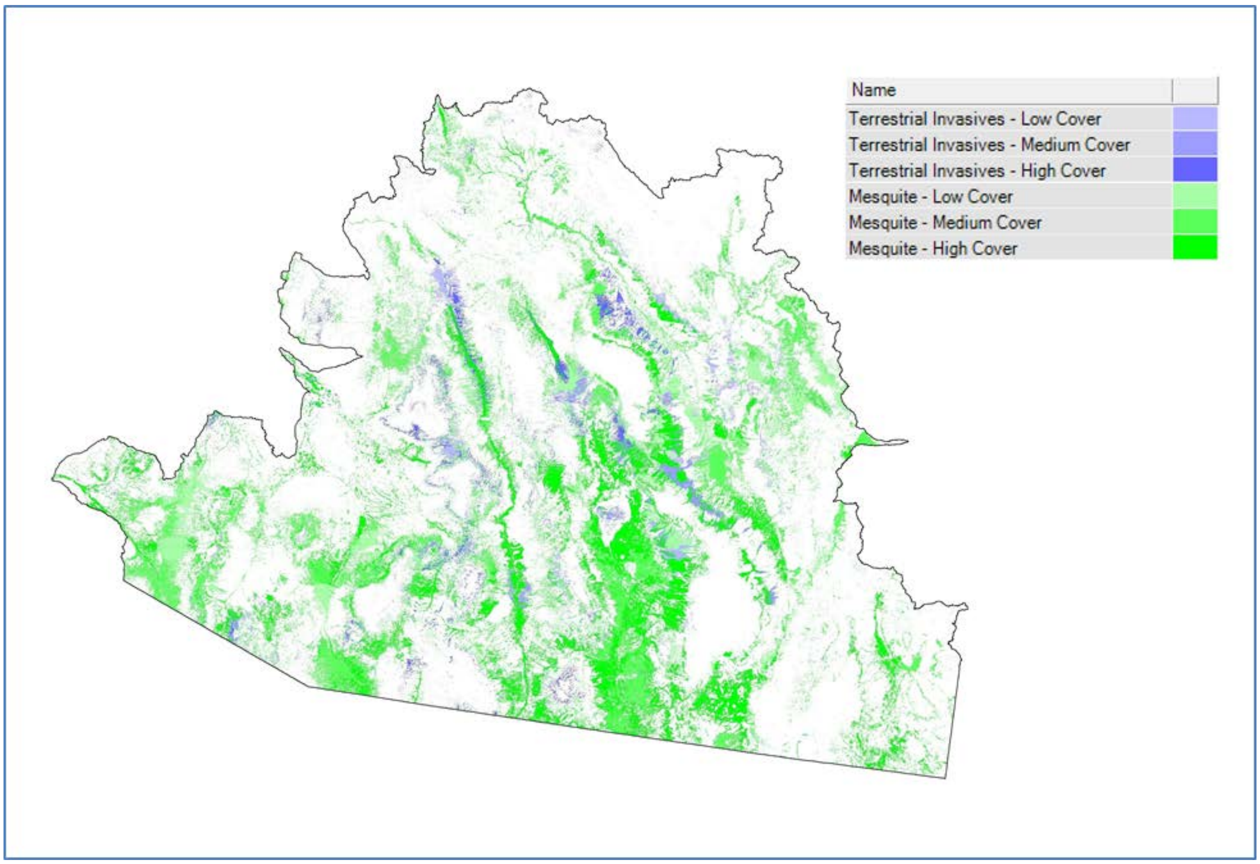
The individual steps for assessing the ecological status of CEs via the LCM tool are described in more detail below, with example tables and maps to illustrate each step.

1. Spatially aggregate indicator datasets into "KEA indicator scenarios" for each indicator

As noted in the previous section, indicators of ecological status were primarily based on stressors represented by change agents. For example, numerous spatial datasets including data representing roads, mine locations, transmission lines, oil and gas development, landfills, agricultural cropland, and others were combined into a single KEA indicator scenario for the development indicator (as listed above in Table 3-3); Figure 3-4 illustrates the invasive species scenario used to assess the invasives KEA indicator. Similarly, two modeled datasets for invasive species – one for native woody increaser plant species, the other for non-native invasive plant species – comprise the invasives indicator. These combinations of change agents for a single indicator are "KEA indicator scenarios" or simply "scenarios."

In some instances, existing source data provided direct indices of the status of a particular indicator, such as native aquatic faunal composition or aquatic habitat quality; these indicator datasets were utilized in the LCM such that high status values in the source dataset translated to (i.e., retained) high indicator scores, while low status values reduced indicator scores. Such datasets were also compiled into the appropriate KEA indicator scenarios.

Figure 3-4. Example of a KEA indicator scenario. The invasive species indicator scenario is comprised of invasive species change agents represented at different levels of density that could be associated to different levels of impact to the KEA indicator.



2. Characterize CE responses for each of the CAs

Once the KEA indicator scenarios of CA features were created, CE responses to the CAs needed to be characterized. Individual CEs may respond differently to the different CAs reflected in a given indicator. For example, pronghorn may have a stronger negative response to invasive species than Coues white-tailed deer. Similarly, grassland birds may have a stronger negative response to an altered fire regime than desert bighorn sheep, given their different habitat requirements and the effect of altered fire regime on habitat quality. The CE responses to the CAs were characterized by the contractor team ecologists and biologists based on information in the CE conceptual models using two variables; see example values in Table 3-4. The site intensity value reflects the response of the CE when it directly intersects the CA. Site intensity values are between 0 and 1, where 0 reflects the most negative on-site impact to the CE (removing all condition), and 1 reflects no effect on the CE at all (maintaining perfect condition).The distance value reflects the actual distance (in meters) that the CA effect is expected to continue offsite from the CA location, ie., the visual and auditory disturbance of a CA that may not directly impact habitat but affect the habitat value for an animal CE for example. The distance effect degrades over the specified distance, returning to 1.0 (no effect) at that distance. Note that the distance variable was used in only a few cases because it is a precise measure (meters) that is difficult to support using the conceptual models. The site intensity variable focused on the change agents' footprints to calculate status. While this method resulted in 30 meter resolution results, averaging those results to 4km (16 sq km) reporting units provides a general idea about pattern of habitat status vs. the 30m pixel results that cannot support decisions at the site scale in an ecoregional assessment. More detail on these functions is provided in appendices B and C.

Table 3-4. Example of CE response model inputs for a subset of the CAs for terrestrial ecological systems. Site intensity values are on a scale from 0.0-1.0. The lower the value, the greater the expected impact from the CA on the condition of the CE. Low impact mines or landfills are no longer active and have typically had vegetation restoration efforts, hence are low impact. The pedestrian border barrier is a tall, double wall of barbed wire fencing, usually with a dirt road and lighting alongside; it is considered to be a relatively high impact feature. These response values were used for all the terrestrial ecological system CEs; different values were used for some of the species CEs or for the aquatic CEs.

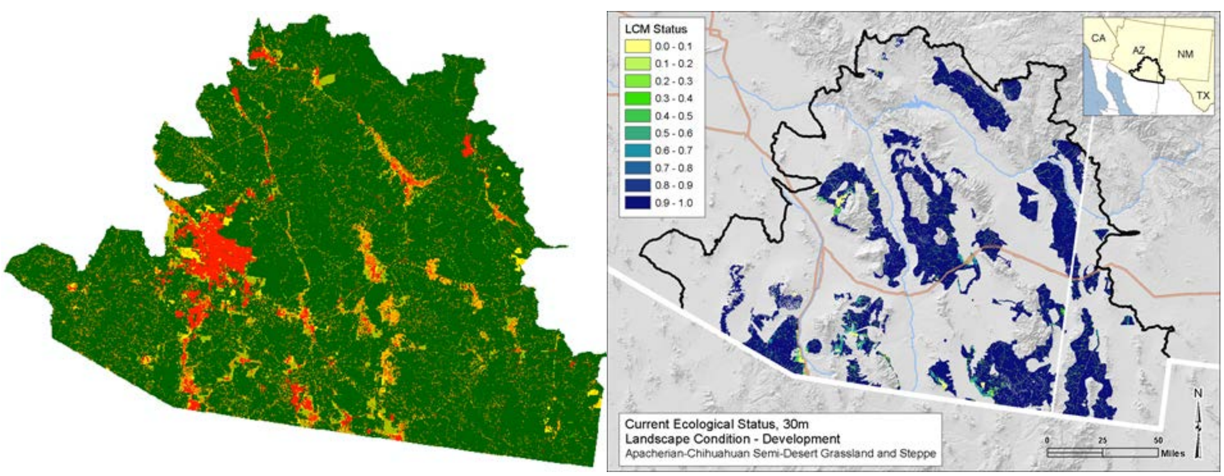
Indicator Component	**Site Intensity**	**Distance (meters)**
Development		
Infrastructure		
----Border Barrier - Pedestrian	0.2	N/A
----Border Barrier - Vehicle	0.4	N/A
----Communication Towers	0.3	N/A
----Below Ground Corridors	0.7	N/A
----Above Ground Corridors	0.5	N/A
Transportation		
----Dirt and 4-wheel Drive Roads	0.7	N/A
----Local/Rural/Private Roads	0.2	N/A
----Primary Highways w/ Limited Access	0.05	N/A
----Primary Highways w/o Limited Access	0.05	N/A
----Airstrips	0.5	N/A
----Railroads	0.5	N/A
Mining and Landfills		
----High Impact Mines/Landfills	0.05	N/A
----Medium Impact Mines/Landfills	0.6	N/A

Indicator Component	Site Intensity	Distance (meters)
Development		
----Low Impact Mines/Landfills	0.9	N/A

3. Run the LCM to generate the **response model output** for each indicator, for each CE

Once the KEA scenarios were built and the CE response values determined, these inputs could be run through the Landscape Condition Model (LCM) in Vista to generate the response model outputs for each of the indicators for the CEs. The LCM first applied the CE response values to a KEA scenario to derive a raster map of the indicator scores for that indicator across the entire ecoregion. When CAs within a scenario overlap, the resulting scores are multiplied to obtain a cumulative effect on status. Below (Figure 3-5, left map) is an example of a response model output for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE for the development indicator; it shows the development indicator scores that this CE was assigned, based on its responses to various stressors (this is an intermediate product and provided for visualization of the process only). Next, the response model output is clipped (automatically in Vista) to each CE's distribution to generate the map of indicator scores. The map on the right in Figure 3-5 shows the development indicator scores for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE; it was derived by clipping the response model output on the left in this figure to the distribution of the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE.

Figure 3-5. Maps illustrating response model output for the development indicator (left) and resulting development indicator scores (right) for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE. LCM Status = Landscape Condition Model Status of the indicator. Indicator scores range from a low status value of 0 (red on the left map, yellow on the right map) to a high status value of 1 (green on the left map, dark blue on the right map). The left map is an intermediate product in the process depicting indicator status before being clipped to the CE distribution and not delivered to BLM; it is a screenshot from the GIS.



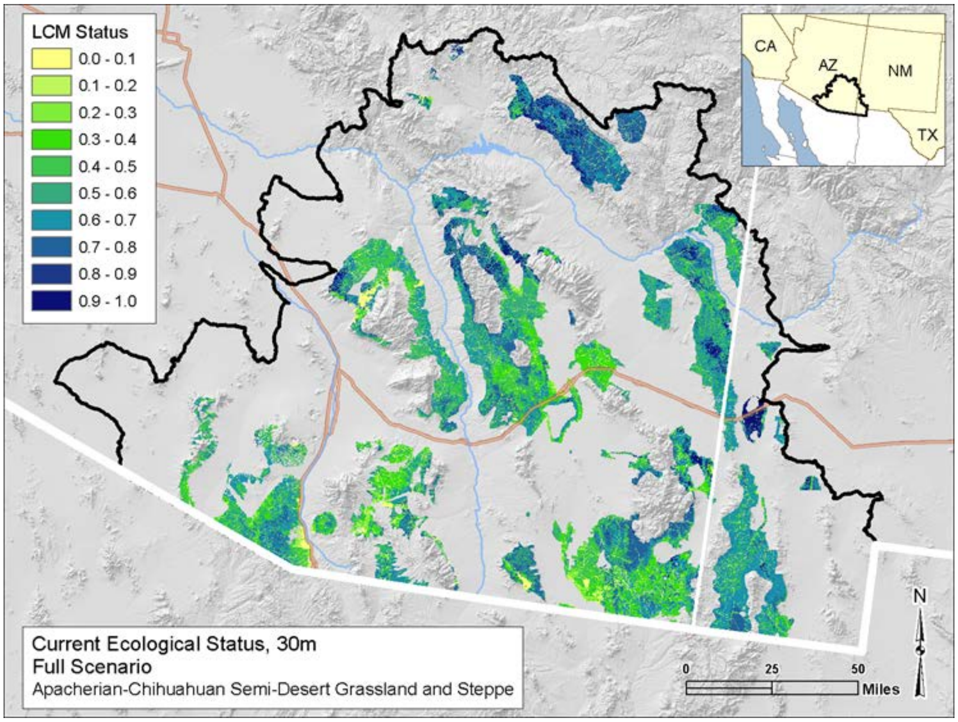
4. Combine the individual indicator scores to get the overall ecological status scores for each CE

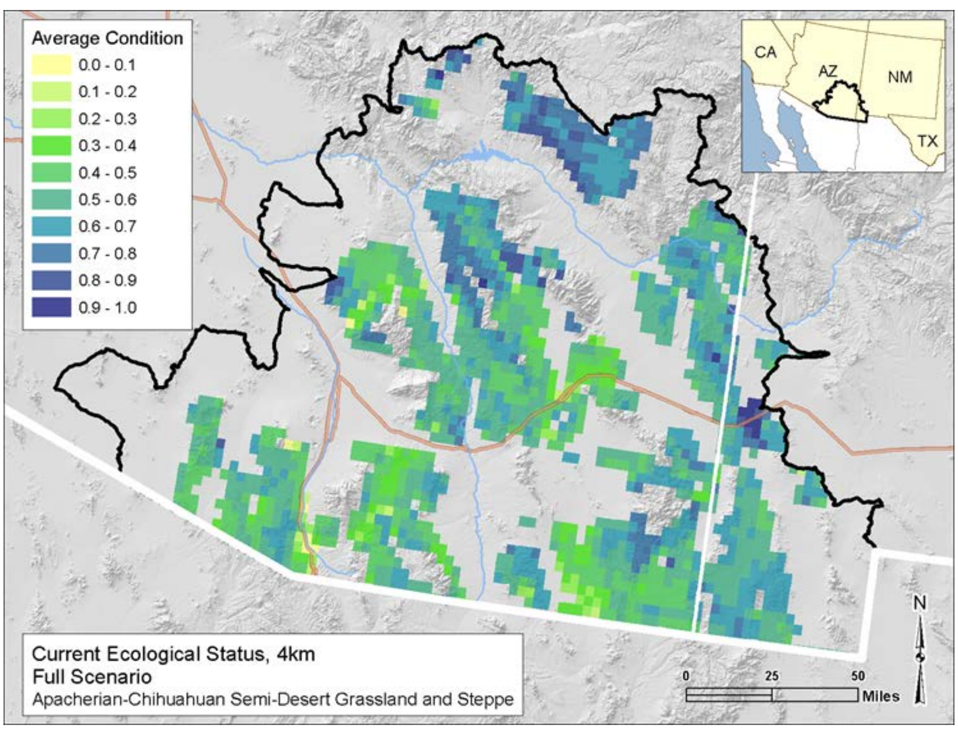
Each CE has multiple indicators that inform its overall ecological status. The individual KEA indicator scenarios for the CE were combined into an "overall scenario" and the response model for the CE was run on this scenario. The input datasets – the CE distributions and the various indicator datasets – have a 30-meter resolution, and thus the overall ecological status scores are also provided at the 30-meter resolution. The top map in Figure 3-6 below illustrates the ecological status scores for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE at the 30-meter resolution. The multiplicative cumulative effect of all combined CAs is evident in the lower status from the overall scenario.

5. Average the ecological status scores within reporting units

To see broader patterns of ecological status across a CE's distribution, the average of the CE's 30-meter status scores are calculated within specified reporting units – 4-km cells for terrestrial CEs and primarily 5th-level watersheds for aquatic CEs. For example, if there are 500 30m pixels of the CE each with a score for all indicators, those 500 30m pixels are averaged for the 4km grid cell, or 5th-level watershed. This step is automated in Vista during Step 4 above by specifying which reporting unit polygon map is desired for the result. The bottom map in Figure 3-6 illustrates the average ecological status scores for each 4-km cell across the distribution of the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE. Users of REA products can take the 30-meter ecological status scores and average them across other reporting units of interest as well (e.g., USFS ecological map units), to see status patterns in other relevant mapping units (either manually or within Vista).

Figure 3-6. Examples of overall ecological status maps, aggregated from the KEA indicator scenarios at 30m resolution of CE distribution (top), and averaged across the 4km reporting units (bottom) for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE. LCM Status = Landscape Condition Model Status of the indicator, or indicator score. Ecological status scores range from a low value of 0 to a high value of 1.





3.2.4 Ecoregion Ecological Integrity

Defining and characterizing ecological integrity for an ecoregion is a challenging task. BLM adopted a definition from Parrish et al. (2003) "…as the ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region. Integrity also requires that an ecosystem or species'…dominant ecological characteristics occur within their natural [or acceptable] ranges of variation and can withstand and recover from most perturbations…."

A standard method for calculating ecoregion ecological integrity has not been adopted for REAs. The approach used in this REA is intended to provide a wall-to-wall assessment of ecological integrity and thus is not a simple aggregation of CE status assessment outputs (because the collective spatial extent of the CEs does not cover the entire ecoregion). In contrast to other approaches that use a single generic development impact model, the MAR approach generalizes and integrates the CE responses in the model so that the integrity measures are ecologically meaningful to the categories of CEs while being generalized throughout the ecoregion.

Subsetting the ecoregion into broad, elevationally-based "life zones" allows assessment of conditions that might be quite different from one area to another. As described in Harkness et al. (2013), the ecoregion has a number of sky island mountain ranges in the midst of lower elevation grasslands and desert scrub communities. Generally, one could anticipate that the lower elevation regions are more impacted by the pervasive effects of infrastructure, urbanization, mining, and agricultural activities, along with significant abundance of both native and non-native invasive species. The characteristics of disturbance regimes (e.g. fire and hydrologic) vary significantly elevationally, as do the human-driven alterations of those regimes.

These varying characteristics of the ecoregion led to first treating upland integrity separately from aquatic integrity; and secondly dividing each of these (uplands versus aquatic) into major life zones within which the typical disturbance regimes and human stressors would be similar. Hence there are five life zone-based ecological integrity results presented below (Table 3-5). For the uplands these are: Montane Forest Life Zone, Valley Grassland Life Zone, and Desert Scrub Life Zone; and for the aquatic and wetlands: Aquatic Montane Life Zone and Aquatic Lowland Life zone. Of note: the life zones defined for the integrity assessment are related to, but different from, the major Divisions defined in the ecoregional conceptual model in section 3.1.5.1. For the integrity assessment of the uplands, desert scrub ecosystems were separated from the valley grasslands, due to significantly different fire regimes. For the wetlands and aquatic sytems, because the 5^{th} level watersheds were used to represent the distributions, the hydrologic functioning considered for the Divisions could not be represented.

Each of the three upland life zones was assessed for ecological integrity relevant to development, fire regime and invasives (Table 3-5); integrity of the aquatic life zones was assessed relevant to development, water use, and invasives (Table 3-5).

Each of these five life zones was assessed in Vista using the full scenarios created and described above for the individual upland or aquatic CEs. All indicators for each life zone were combined into an overall ecological integrity scenario and thence into a single ecological integrity score for each 30m pixel. The resultant 30m raster results were then averaged across reporting units: $4km^2$ grid for the uplands, and 5^{th}-level watersheds for the aquatic. The change in extent was a tabular analysis, comparing historical (pre-European settlement, from the Landfire modeled biophysical settings data) extent to the current extent of individual ecological systems (NatureServe 2013), for the ecoregion as a whole, and for each 4^{th} level watershed. Additional details on these methods are provided in Appendices B, C and G.

An additional analysis looked at the change in extent from historical pre-European settlement for a selected subset of all ecological systems occurring in the MAR. The intent of this is to understand how the abundance and diversity of ecosystems has changed, in particular which individual ecosystems have been severely reduced or mostly lost, and which new ecosystems or land cover types have replaced them. See Appendix G for more details of the methods.

Table 3-5. Life zones defined for ecological integrity assessment of the MAR; their definitions, indicators measured, and reporting units. All indicators for each life zone were combined into an overall ecological integrity scenario and thence into a single ecological integrity score for each reporting unit.

Life Zones	Definition	Indicators of Integrity	Reporting Units
Desert Scrub Life Zone	Desert regions of the MAR; selected desert ecological systems mapped in the MAR, excluding desert grasslands	Development, fire regime, invasive plants	4km
Valley Grassland Life Zone	Valleys and lower slopes with grasslands or savannas, including oak woodland, juniper savannas, all grassland ecological systems	Development, fire regime, invasive plants	4km
Montane Forest Life Zone	Forests, woodlands and shrublands in montane areas, selected ecological systems mapped in the montane (generally pinyon-juniper woodlands and higher in elevation)	Development, fire regime, invasive plants	4km
Aquatic Lowland Life Zone	All areas in all watersheds in the MAR below 1,524 m (5,000 ft) elevation	Development, water use, invasive plants and aquatic invasives	5^{th-}-level HUC
Aquatic Montane Life Zone	All areas in all watersheds in the MAR above 1,524 m (5,000 ft) elevation	Development, invasive plants and aquatic invasives	5th-level HUC

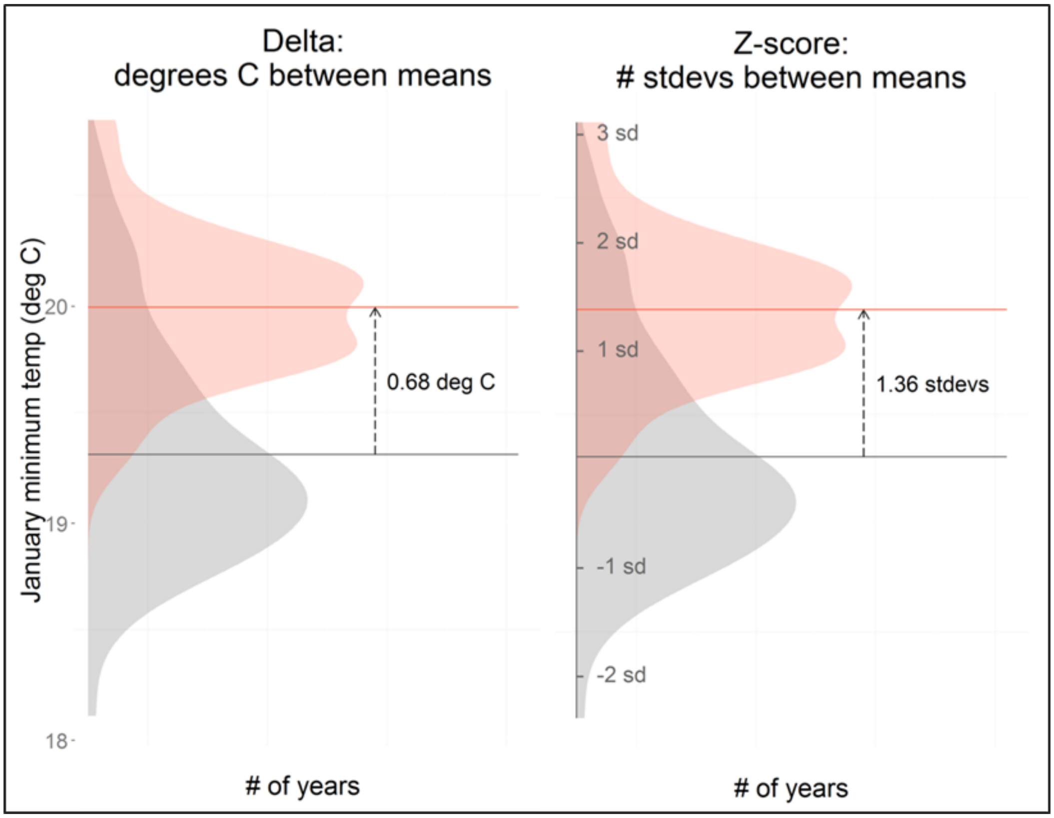
3.2.5 Climate Trends

The climate trend assessment examines current trends and future projections in the magnitude, significance, and spatial and seasonal patterns of change in various climate variables. Several spatial climate datasets and a suite of trend detection statistics are used to quantify how much climate change has already occurred in recent decades, and to characterize future changes projected by various global climate models run under a moderately aggressive scenario of growth in future greenhouse gas emissions.

3.2.5.1 Climate Change Metrics

The climate change metrics used for assessment of both recent and future climate trends involve comparison between two timeslices: either a recent (1981-2012) or future (2040-2069) timeslice compared to a baseline (1901-1980). These comparisons are referred to as "deltas" and "anomalies." The most basic climate change metric is the delta, which measures the difference between the mean climates of two time periods. One reason deltas are useful is that they report values of change in real climate units (for example, degrees C temperature or mm of precipitation), which makes the changes relatively easy to interpret. Anomalies (also known as z-scores or standard scores) normalize deltas by the standard deviation of the baseline climate, indicating how unusual the later time period is in relation to historical variability. Anomalies are then aggregated across the core climate variables (minimum temperature, maximum temperature, and precipitation) over all 12 months to derive a climate change exposure Index (CCEI).

Figure 3-7. Visualization of climate metrics used to compare two timeslices: deltas and Z-scores. Grey areas represent the distribution of baseline values and red areas represent the distribution of future values. The grey and red lines are the means of those distributions; a delta and z-score show the distance between those means in different metrics (degrees and standard deviations). The means of the distributions do not necessarily correspond to peak values because of non-normally distributed values.



In addition to using metrics comparing two timeslices, climate trends are also measured *within* a time period. Here, this method is applied to the recent 1981-2012 timeslice to better understand how climate change has been actually unfolding over the last several decades. The magnitude and statistical significance of recent climate change is measured with a combination of two statistical tests that are frequently used to quantify trends in climate data: the Mann Kendall trend test and Theil-Sen slope (Helsel et al. 2006; Onoz and Bayazit 2003). The result is a characterization of magnitude and geographic distribution of recent climate change that is statistically significant.

For in-depth descriptions and visualizations of climate change metrics, see Appendix I.

3.2.5.2 Recent Climate Trend Analysis

Analysis of recent climate trends was conducted using the PRISM gridded climate dataset (Daly et al. 2008) comprised of 800m rasters interpolated from weather station observations for every month of every year (and for annual averages) from 1901 through 2012. Three climate variables were used for this analysis: monthly average minimum temperature, monthly average maximum temperature, and monthly total precipitation. The PRISM time series was divided into an 80-year *baseline* average (1901-1980), and a *recent* 30-year average (1981-2012). For each 800m pixel in the MAR, deltas and anomalies were calculated comparing the recent period to the baseline, and trends were calculated within the recent period. Anomalies (z-scores) across all 36 rasters (3 variables for 12 months) were also combined into a single overall climate change exposure index (CCEI).

3.2.5.3 Future Climate Trend Analysis

Future climate trend analysis uses the 4km Climate Western North America (CWNA) downscaled spatial climate dataset (Wang et al. 2012). These climate data include 20th century values from 1901-2011, and downscaled projections of six different global climate models (GCMs) for the A2 greenhouse gas emissions scenario for the mid-century timeslice (2040-2069). From the 20th century data, a baseline average from 1901-1980 was created to match the analysis of current climate trends described above. In addition to the three "core" climate variables also analyzed for recent trends, three additional variables derived by CWNA from these core variables were also analyzed: monthly average climatic moisture deficit (CMD), monthly average number of frost-free days, and annual average frost-free period. For each 4km pixel in the MAR, the ensemble median of six GCMs was used to calculate deltas and anomalies comparing the projected future to the baseline. Anomalies for the core climate variables were also combined into a climate change exposure index (CCEI).

3.2.6 Conservation Element Overlay with Climate Trends

This analysis is a simple graphic overlay of the conservation element (CE) distribution maps with the future climate trend analysis result from above.

3.2.7 Bioclimate Envelope Models

Bioclimatic envelope modeling was used to help understand the potential impacts of climate change on the geographic distribution of the climate conditions that influence species ranges for a subset of four priority CEs. A bioclimatic envelope is the combination of climatic conditions which is described by a species' known distribution. Species distribution modeling algorithms estimate a CE's suitable bioclimate by relating known current CE localities to current climate variables, and project where in geographic space similar climate conditions occur. To project bioclimatic range shifts induced by changes in climate, values for future climate variables are obtained from downscaled climate models, and the distribution of suitable conditions for a given CE under future climates can be projected in geographic space. Here, future projections of the distribution of suitable climate conditions are generated for 4 CEs, using six alternative downscaled GCMs run under the A2 emissions scenario. Results from these six independent future projections were synthesized to show degree of climate model agreement in the geographic distribution of future bioclimatic suitability. The final step is a comparison between the modeled current bioclimate and projected future bioclimate to represent areas of potential future stability, contraction, and expansion. Areas of stability are areas having suitable bioclimatic conditions for a given CE under both current and future climate conditions. Areas of contraction are areas that are suitable under current conditions, but not in the future projections. Areas of expansion are areas where suitability is projected in the future, but are not suitable in the current model.

Bioclimatic envelope models were generated for four terrestrial ecosystems CEs: Apacherian-Chihuahuan Semi-desert Grassland and Steppe, Chihuahuan Creosotebush Desert Scrub, Madrean Encinal, and Apacherian-Chihuahuan Mesquite Upland Scrub. Individual species components of these ecosystems will most likely respond differently to climate change; therefore, these models are not intended to portray where, for example, the entire ecosystem will be in the future. The results, however, can be useful in management prioritization by suggesting which portions of the current CE range may experience the greatest and least climate stress in future decades.

For more detailed description of bioclimatic envelope methods, see Appendix I.

3.2.8 Other Assessments

In addition to the current scenario status and ecological integrity assessments described above, this section describes three additional assessments conducted for the MAR REA: 1) 2025 Risk Assessment, 2) Mesquite Scrub Expansion: Restoration Opportunities, and 3) Soil Erosion Potential Assessment.

3.2.8.1 2025 Risk Assessment

Insufficient data was available to conduct a comprehensive ecological status assessment for CEs for the 2025 timeframe. However, data were adequate to assess the development indicator in the 2025 timeframe; this indicator was therefore assessed for the three case study CEs. The *current* landscape condition scenario (used to assess the development indicator) for each of the CEs was copied and data representing additional high-confidence development CAs for expected *future* development were integrated to form the 2025 landscape condition scenario. The 2025 landscape condition scenario was run through the Landscape Condition Model using the CE response values for development-related features to generate 2025 ecological status maps for the three case study CEs.

Additionally, a national model of urban expansion (ICLUS SERGoM) was available but is too uncertain to integrate into the status map; instead potential future urbanization areas were treated as a “risk map.” Simple overlays of the risk map with the three CE distributions were created to further inform the 2025 status assessment results for the three case study CEs. Additionally, solar energy potential maps are presented alone but may be overlaid on the 2025 status assessment results via BLM’s online GIS portal.

3.2.8.2 Mesquite Scrub Expansion: Restoration Opportunities

This assessment seeks to identify upland areas of the MAR, currently invaded by mesquite, where land managers might be able to remove or control mesquite and restore natural grasslands. In order to not limit the assessment to areas now dominated by mesquite (i.e. to identify other places with restoration potential), and to account for possible mapping errors in the land cover data, the inputs to this assessment included the historical distributions of both grasslands and encinal, as well as the current distribution of the Mesquite Upland Scrub.

A map of mesquite distribution was created by combining the distributions of Apacherian-Chihuahuan Mesquite Upland Scrub (from the NatureServe (2013) map of ecological systems), the historical distribution for Apacherian-Chihuahuan Semi-desert Grassland and Steppe and Madrean Encinal (from LANDFIRE BpS), and the historical distribution of all grasslands as well as degraded grasslands from the TNC Grassland Assessment (Gori et al. 2012).

The distribution map was used as an input to the restoration assessment in Vista, along with the landscape condition scenario used for the terrestrial ecosystem conservation elements (see Appendices B and C for details about this scenario), data for the percent cover of mesquite (from Integrated Landscape Assessment Project, ILAP), and data for soil types (SSURGO and STASGO data compiled by ILAP).

For the landscape condition scenario, the site intensity and distance values used for the terrestrial ecosystems response model were retained (see Appendix D for a list of those inputs and values), but the output from that response model was then broken into three categories of suitability (Table 3-6) for restoration of mesquite-invaded uplands (highly suitable for restoration, moderately, or not suitable).

For the percent cover of mesquite, the continuous cover from 0 to over 90% was broken into the same three categories of suitability (Table 3-6). These cover breaks were those used to evaluate degradation of grasslands by mesquite and juniper invasion discussed in the conceptual model (Gori et al. 2012). Twenty-five percent cover was identified in the mesquite conceptual model as the break between somewhat suitable and not suitable; however, for this assessment the break of 30% is used in order to be more inclusive of possibly suitable areas. Areas with 0-5% cover of mesquite were not considered in the evaluation; in effect this means those areas are highly suitable from the standpoint of mesquite cover.

Table 3-6. The two variables of development and mesquite cover, and classification of each into three categories of suitability for restoration of mesquite invaded uplands. These variables are not correlated; for example, areas of high mesquite cover (i.e. not suitable) may overlap with areas of little to no development (i.e. highly suitable).

Suitability Category	Development Response Model	Mesquite Cover	Comments
Highly Suitable	.75 to 1	5-15%	Areas with 0-5% cover of mesquite were not considered in the evaluation; in effect this means those areas are highly suitable from the standpoint of mesquite cover
Moderately Suitable	.41 to .74	15-30%	Even with up to 30% mesquite, the site could still have a grass layer
Not Suitable	0 to .4	>30%	With >30% cover - grass layer lost due to shading from scrub

The soils of the MAR were the third variable selected for use in this assessment, since soil characteristics influence the types of vegetation present. Some soils have higher potential for restoration success than others. A soils dataset was available from ILAP that compiled all SSURGO polygons and then filled in the missing areas with STATSGO data. This combined dataset was then attributed by ILAP with a small subset of the available data on soils from either SSURGO or STATSGO. This ILAP dataset included the soil taxonomy along with a few variables of soil texture and depth. Soil taxonomy is a good way to evaluate soil properties that affect restoration potential. The Great Group level with 40 soil types for the MAR was determined to be the most appropriate scale for ecoregion-wide assessment. Using the Great Group classification level, unsuitable soils such as Natraquolls within the highly suitable soil orders such as Mollisols, can be identified. Great Groups were evaluated using guidance from soils classification references such as Buol et al. (1980) and USDA- Soil Survey Staff (1999). As with the other two variables, soil Great Groups were classified as Highly Suitable, Moderately Suitable and Not Suitable for restoration of mesquite-invaded uplands. See Appendix H for a table listing the Great Groups and how they were classified into suitability categories.

Once the categories of restoration suitability for each of the three variables were determined, the spatial data were combined into a single scenario of 30m resolution data, for evaluation in Vista. A categorical response model was used, wherein any pixel deemed not suitable for one variable was assigned not suitable (Table 3-7) even if the other two variables were suitable in that pixel. In sequence, any pixel with a moderately suitable value would override highly suitable in the other two variables. Hence, the only pixels assessed as highly suitable are those where all three variables were highly suitable (Table 3-7).

Table 3-7. Decision matrix used in the Vista evaluation for categories of suitability for each of the three variables.

Development / Soils Suitability	Mesquite Cover Highly Suitable (5-15%)	Mesquite Cover Moderately Suitable (15-30%)	Mesquite Cover Not Suitable (>30%)
Either Development **or** Soils Not Suitable	Not Suitable	Not Suitable	Not Suitable
One Moderately Suitable, the other Highly Suitable	Moderately Suitable	Moderately Suitable	Not Suitable
Both Development **and** Soils Highly Suitable	Highly Suitable	Moderately Suitable	Not Suitable

3.2.8.3 Soil Erosion Potential Assessment

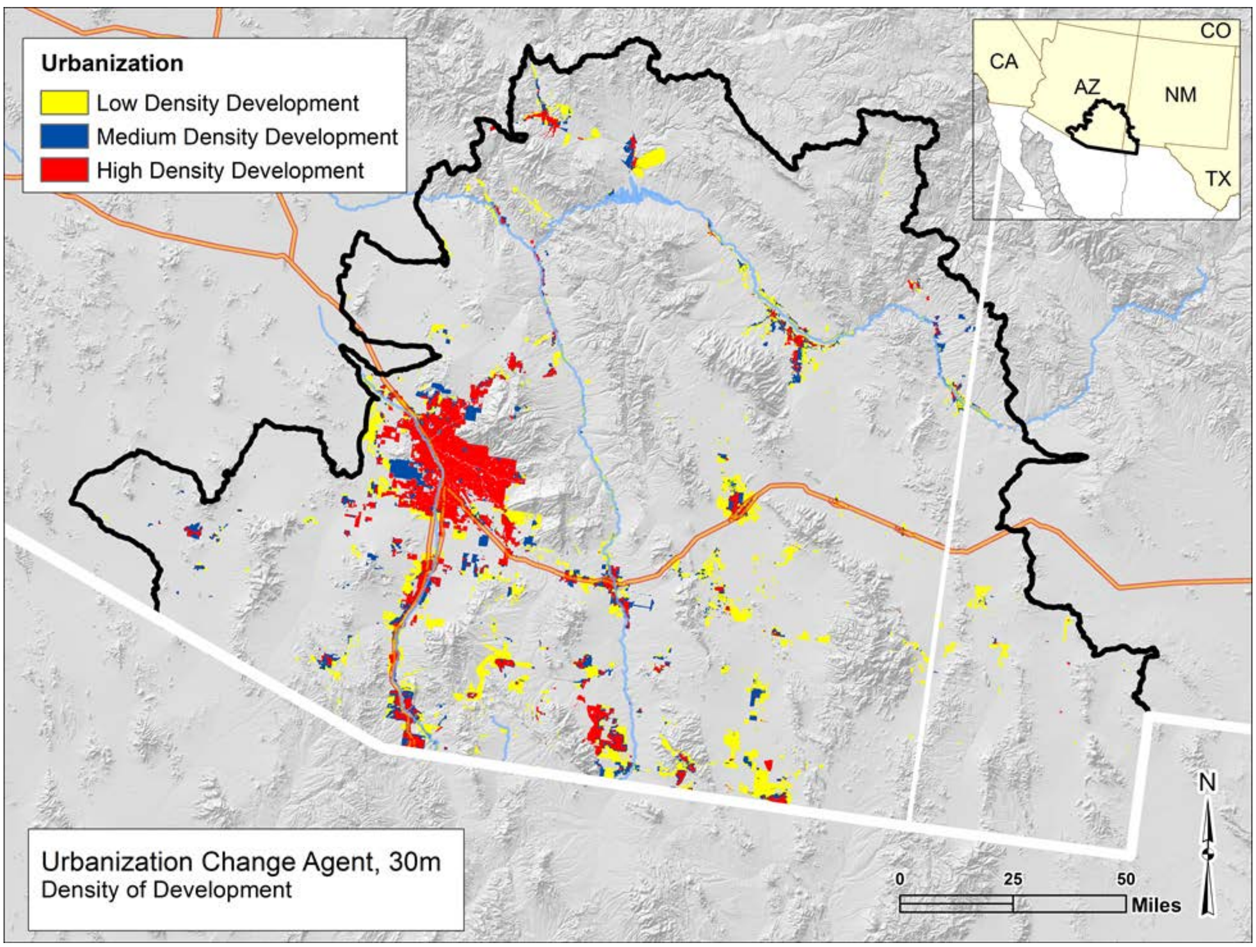
This assessment seeks to identify areas of the ecoregion with high risk for water erosion. These would include areas with the soils characteristics that pre-disposes them to erosion combined with steep slopes (following the methods used in the Colorado Plateau REA soil erosion assessment; Bryce et al. 2012). SSURGO and STATSGO data both include a soils characteristic called the "kwfact" which is a calculated value which accounts for the soil properties such as texture that make the soil susceptible to erosive events. The SSURGO definition for this attribute is "an erodability factor which quantifies the susceptibility of soil particles to detachment and movement by water. This factor is adjusted for the effect of rock fragments." A digital elevation model was used to find areas of steep slopes, and these were combined with the kwfact soils attribute, as follows: all soils with a kwfact >0.36 OR slope >40% were selected, and combined with all soils with kwfact >0.2 AND a slope of 35%-40%.

4 Results

4.1 Change Agents

This REA did not address management questions specifically about the change agents (CAs) themselves, such as where do invasive species coincide with high fire risk (other than climate changes—see section 4.3). The role of CAs was to model the current CE status and ecological integrity assessment (EIA) and to inform future risk to CEs in 2025. CA products were delivered as source and derived (when applicable) individual data layers which can support additional assessment of management questions (e.g., Figure 4-1). For the ecological status and ecological integrity assessments, CAs were integrated into Key Ecological Attribute indicator scenarios as described in the methods above, and effects of CAs are described in the results and interpretation for CE status and EIA below.

Figure 4-1. Example of a development change agent. The urbanization change agent comes from a model of urban density ICLUS SERGoM generated by EPA.



4.2 Current Ecological Status

4.2.1 Upland Systems: Overview

Ecological status was assessed for the six MAR upland CEs: Chihuahuan Creosotebush Desert Scrub, Apacherian-Chihuahuan Semi-Desert Grassland and Steppe, Madrean Encinal, Madrean Pinyon-Juniper Woodland, Mogollon Chaparral, and the Madrean Montane Conifer-Oak Forest and Woodland. The Apacherian-Chihuahuan Mesquite Upland Scrub was assessed individually with a different purpose and approach, see Section 4.4.2 Mesquite Scrub Expansion: Restoration Opportunities below for those results. These assessments show the ecological status results for the combination of the three stressor-based indicators – development, fire regime departure, and invasives – used for each upland CE. The scoring is on a continuous scale from 0 to 1, with the highest score of 1.0 indicating no ecologically relevant impacts, and the lowest score of 0.0 indicating impacts that essentially eliminate all natural cover and ecological functions.

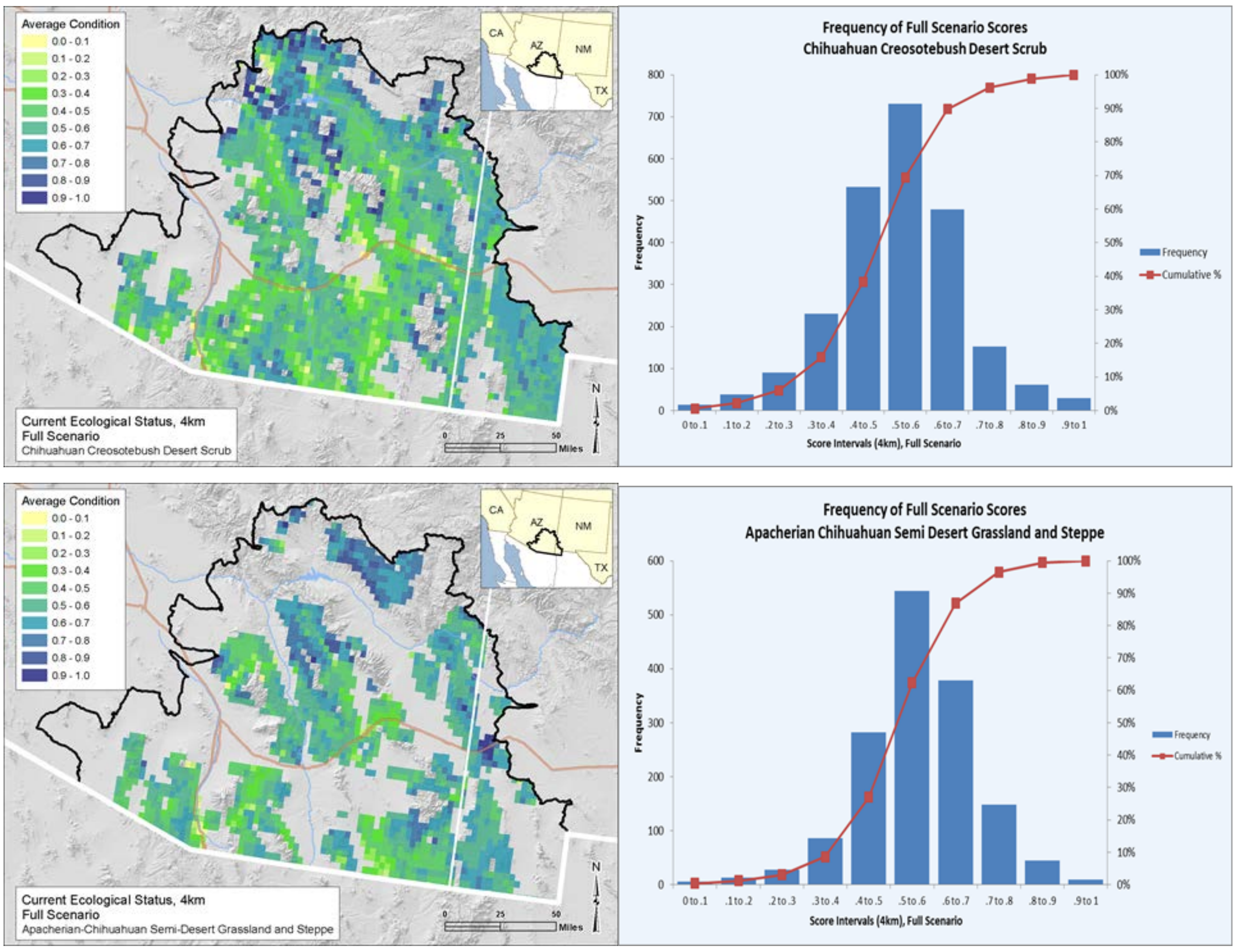
The set of maps in Figure 4-2 illustrate all three of the indicators combined into a single ecological status score, summarized to the reporting unit (e.g., 4km grid) by averaging the ecological status scores from all the pixels of the CE within the reporting unit. See Appendix D for complete results at the 30 m analysis unit level and for results for each indicator individually. The combined (cumulative) status scores are significantly lower than the individual scores for each indicator because the combined (cumulative) effect is multiplied across the indicators. Next to each map is a histogram showing frequency distribution of the 4km ecological status scores for the CE, with cumulative percent. The results shown in the frequency diagram indicate the general degradation of the CE across its range in the ecoregion.

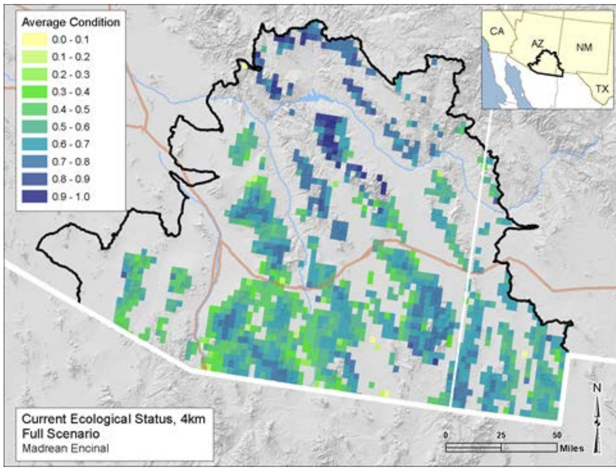
Overall, the assessment shows that lower-elevation CEs, Chihuahuan Creosote Desert Scrub and to a lesser extent, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe, are the most impacted by CAs within the ecoregion. Development and invasives (which are often associated with development and human land use) are driving the degradation. This is most noticeable near urban and major transportation areas where there is a lot of infrastructure.

Higher elevation CEs such as Madrean Pinyon-Juniper Woodland, Mogollon Chaparral, and the Madrean Montane Conifer-Oak Forest and Woodland are least impacted by development and more impacted by altered fire regimes. Some of these CEs show severe departure of the disturbance regime from its historical variability. The highest elevation stands are typically more departed because fragmentation of the landscape can impact the movement of fires that start in lower elevation savannas and woodlands and burn upslope into the montane zones. This spatial result is supported by research documenting the results of fire exclusion in the REA. Active and passive fire suppression over the last century has excluded fire from much of these woodlands (Gori and Bate 2007, Schussman and Gori 2006, Swetnam and Baisan 1996, Turner et al. 2003). However, the level of disturbance from invasives is less in these higher elevation CEs.

The middle elevation CEs, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe and Madrean Encinal, are greatly affected by both altered fire regime and invasives, with development also common in lower elevation stands. With fire exclusion, theses CEs are vulnerable to increases in native shrub cover, especially invasive mesquite and juniper. Also, the introduction of two invasive, non-native, perennial grasses, Lehmann and Boer lovegrasses (*Eragrostis lehmanniana* and *Eragrostis curvula*) has impacted many locations of these CEs. These species were frequently planted in the past to revegetate depleted ranges (Anable et al. 1992, Cable 1971, Gori and Enquist 2003). The impacts from development are typically more severe and permanent than altered fire regime and invasives.

Figure 4-2. **Overall ecological status scores for upland system CEs illustrated in maps (left) and graphs of frequency distribution (right).** The CE status results are arranged from low to high elevation CEs (Creosotebush Desert Scrub up to the Madrean Montane Conifer-Oak Woodland). Maps show the ecological status scores **for each 4km cell**, which is an average of status scores for all 30m pixels of the CE's distribution. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs. Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of grid cells in each interval (left, and blue columns) and the cumulative percentage of the grid cells for each interval (right, and red line with boxes).




Average Condition
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
N
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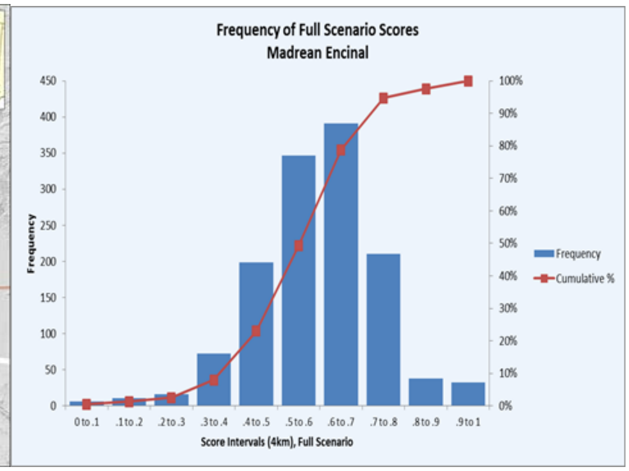
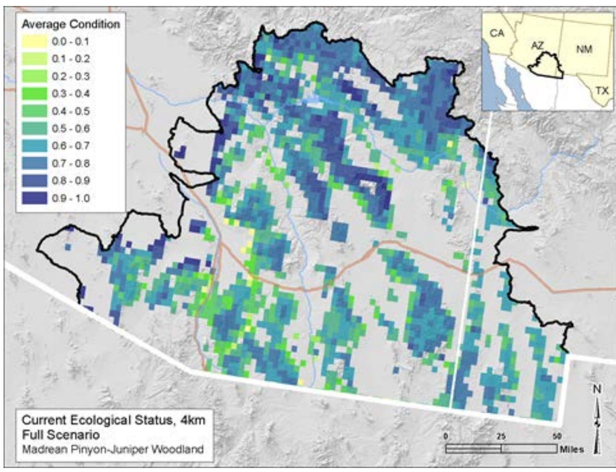
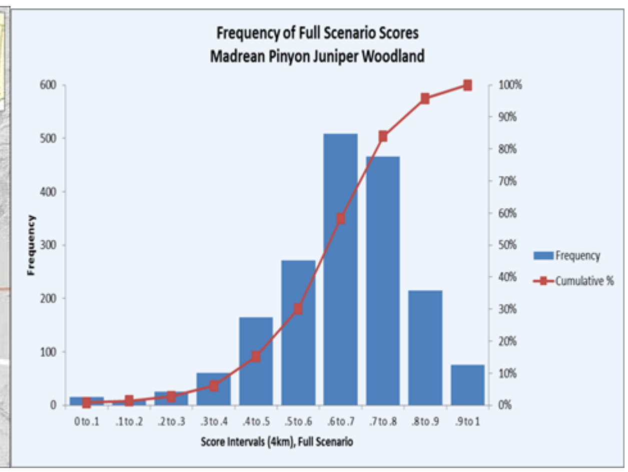
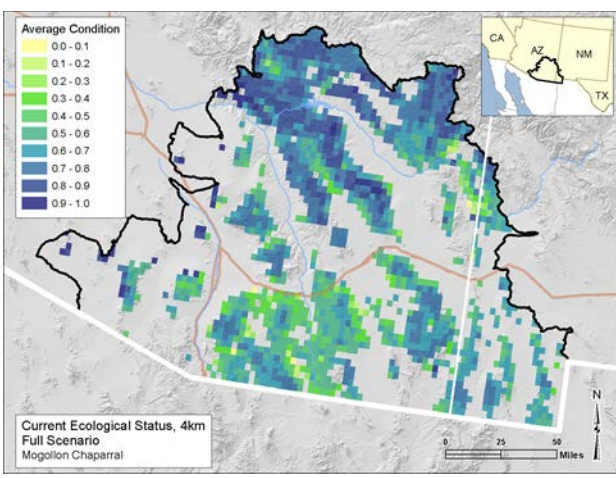
Current Ecological Status, 4km
Full Scenario
Madrean Encinal


Frequency of Full Scenario Scores
Madrean Encinal
Frequency
Frequency
Cumulative %
Score Intervals (4km), Full Scenario
0 to .1
.1 to .2
.2 to .3
.3 to .4
.4 to .5
.5 to .6
.6 to .7
.7 to .8
.8 to .9
.9 to 1


Average Condition
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
N
0 25 50 Miles
Current Ecological Status, 4km
Full Scenario
Madrean Pinyon-Juniper Woodland


Frequency of Full Scenario Scores
Madrean Pinyon Juniper Woodland
Frequency
Frequency
Cumulative %
Score Intervals (4km), Full Scenario
0 to .1
.1 to .2
.2 to .3
.3 to .4
.4 to .5
.5 to .6
.6 to .7
.7 to .8
.8 to .9
.9 to 1


Average Condition
0.0 - 0.1
0.1 - 0.2
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0.3 - 0.4
0.4 - 0.5
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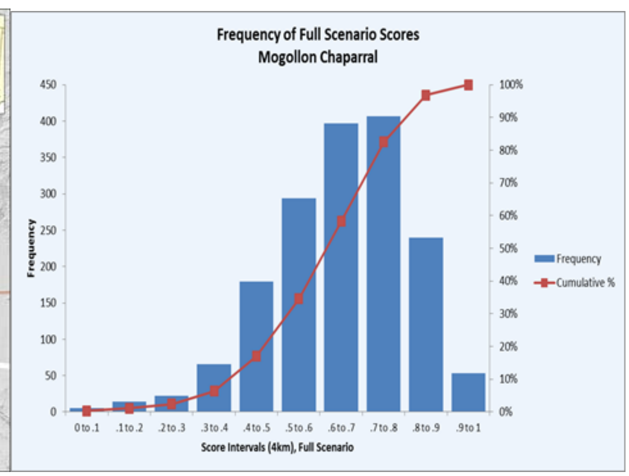
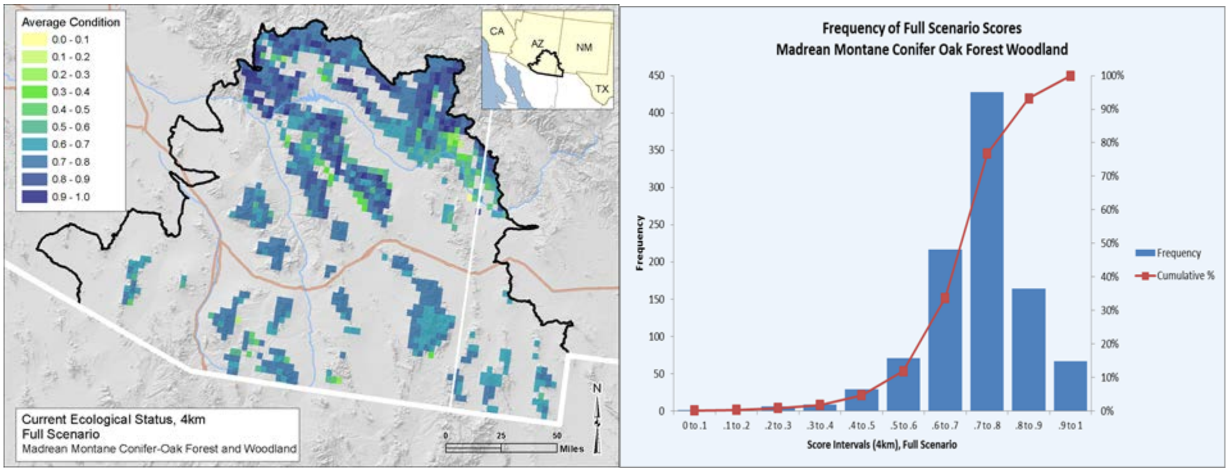
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
N
0 25 50 Miles
Current Ecological Status, 4km
Full Scenario
Mogollon Chaparral


Frequency of Full Scenario Scores
Mogollon Chaparral
Frequency
Frequency
Cumulative %
Score Intervals (4km), Full Scenario
0 to .1
.1 to .2
.2 to .3
.3 to .4
.4 to .5
.5 to .6
.6 to .7
.7 to .8
.8 to .9
.9 to 1

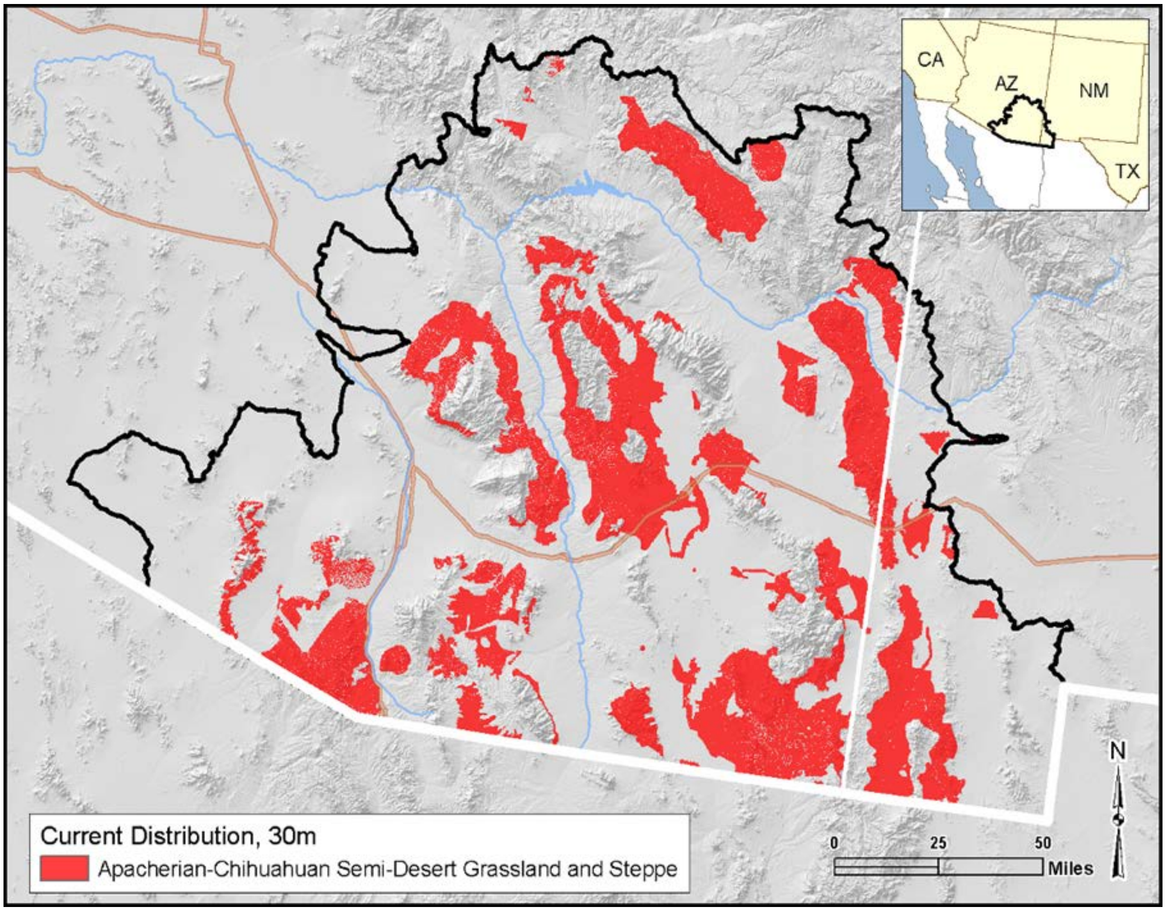


4.2.1.1 Upland Ecological System Case Study: Apacherian-Chihuahuan Semi-Desert Grassland and Steppe

4.2.1.1.1 Description

This ecosystem is a broadly defined desert grassland and mixed shrub-succulent type that is typical of the Borderlands of Arizona, New Mexico and northern Mexico (Apacherian region) but extends north into the Mogollon Rim and throughout much of the Chihuahuan Desert. It is characterized by the dominance of a typically diverse layer of perennial grasses with scattered stem succulents, shrubs, and short trees. **Figure 4-3** shows the current distribution of the CE, by 30m pixel. The CE is abundant on foothills and adjacent alluvial fans that encircle mountain ranges and on middle elevation piedmonts and valleys. The main key ecological attribute of this semi-desert grassland ecosystem historically (before 1890) was frequent, low severity fire (fire return interval (FRI) of 2.5 to 10 years) (Bahre 1985, Kaib et al. 1996, McPherson 1995, Wright 1980). Additional evidence that frequent fire is a key ecological attribute of this ecosystem is that many common shrubs, subshrubs and cacti are fire-sensitive and individuals are killed when top burned, when they are young (< 10 years old) (McPherson 1995), while native perennial grasses quickly recover from burning (Bock and Bock 1992; Martin 1983; Wright 1980). The complete description of this ecosystem is found in the Apacherian-Chihuahhuan Semi-Desert Grassland conceptual model in Appendix D.

Figure 4-3. Current distribution of Apacherian-Chihuahuan Semi-Desert Grassland and Steppe within the MAR. The distribution is mapped at a 30-meter resolution and was derived from the grassland mapping and assessment completed by The Nature Conservancy (Gori et al. 2012).



4.2.1.1.2 Change Agents

Change agents, and the specific stressors they generate, can cause alteration to the key ecological attributes (KEAs) for individual occurrences of this ecosystem type. Occurrences of this grassland ecological system can be directly affected by livestock grazing, direct and indirect fire suppression, land development, and non-native plant species invasion. Grazing of native vegetation by livestock at incompatible stocking rates, season of use, or duration can be detrimental to grass vigor resulting in decline of grass cover and shifts in species composition to more grazing tolerant or less palatable species (Milchunas 2006). Over time this often results in increased woody cover or bare ground and erosion. Heavy grazing can indirectly increase fire return intervals by removing fine fuels that carry fire (Swetnam and Baisan 1996). Fire suppression has led to an increase the abundance of woody species, as well as changes in woody species composition and hence to an uncharacteristic fire regime in many stands (Barton 1999, Gori and Enquist 2003, Muldavin et al. 2002, Turner et al. 2003). Development impacts are common in this CE and can contribute to altered fire regimes, increased erosion, direct habitat loss/conversion, increased groundwater pumping, fragmentation, invasive non-native species dispersal and disruption of wildlife migration patterns (Bahre 1991, Finch 2004, McPherson 1997). Invasive species have replaced native vegetation with non-native grass species such as Lehmann and Boer lovegrasses (*Eragrostis lehmanniana* and *Eragrostis curvula)*. These species are better adapted to frequent fire and increase in relative abundance over native grasses after burning (Anable et al. 1992, Cable 1971, Gori and Enquist 2003, Schussman 2006a).

4.2.1.1.3 Key Ecological Attributes

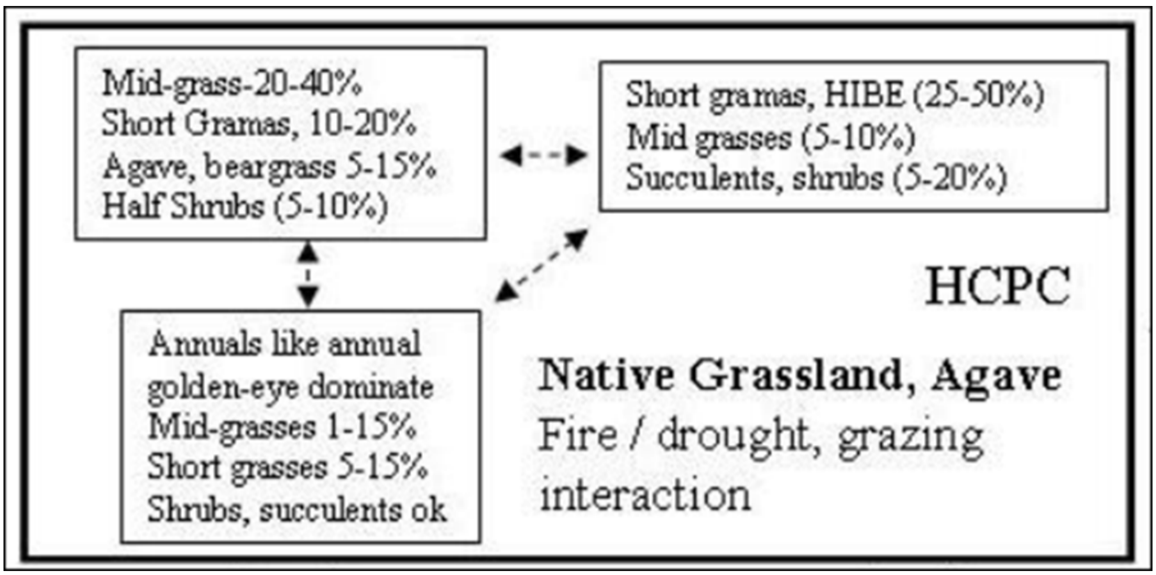
A **key ecological attribute** of a focal ecological resource is a characteristic of the resource's biology, ecology, or physical environment that is critical to the resource's persistence in the face of both natural and human-caused disturbance. Alteration of such a characteristic beyond some critical range of variation will lead to the degradation or loss of the resource within decades or less. For a deeper explanation of key ecological attributes, see Appendix B and for more details about KEAs and indicators for terrestrial ecological systems, see Appendix D. The KEAs identified for assessment for this conservation element are those that had data available (see Table 3-3) and include the following:

1) Landscape Condition: Anthropogenic infrastructure and land uses can have a direct effect on the condition of a landscape where an ecosystem is found. The indicator measured is development - the amount of anthropogenic disturbance by development and agricultural cropland in the ecosystem.
2) Fire Regime: Fire is a natural agent of disturbance in upland vegetation communities that maintains species composition, vegetation structure, and sustains ecological processes such as nutrient cycling. The indicator measured is fire regime departure as indicated by the Vegetation Condition Class (VCC) dataset produced by Landfire.
3) Vegetation Composition: The overall taxonomic and functional composition of the plant species assemblage is an important aspect of the ecological integrity of a terrestrial ecosystem.The indicator measured is cover of invasive species, both native woody increasers (mesquite cover) and non-native grasses and forbs.

4.2.1.1.4 *Conceptual Model Illustration*

Conceptual state-and-transition models for historical conditions for this CE were developed by several ecology teams (Muldavin et al. 2012, Schussman 2006a), and NRCS for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe. Below is a conceptual historical state-and-transition model of the Historic Climax Plant Community (HCPC) for NRCS ESD R041XA107AZ from the 041-Southeastern Arizona Basin and Range MLRA (NRCS 2014). This model is representative of the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE (Figure 4-4). States are represented by the boxes; transitions, due to either disturbance or succession, are represented by arrows. See Appendix D for further explanation of state-and-transition models and their uses by NRCS, as well as a complete description of this particular model.

Figure 4-4. Conceptual state and transition model of historical conditions for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE. This model is the Historic Climax Plant Community (HCPC) portion of a larger model from NRCS ESD R041XA107AZ Loamy Slopes 16-20" p.z., *Agave palmeri - Nolina microcarpa* / *Bouteloua curtipendula - Eragrostis intermedia*. The acronym HIBE refers to the grass *Hilaria belangeri*.



4.2.1.1.5 *Individual Indicator Results*

As described above, the assessment of this CE focused on indicators for KEAs for which spatial data were available: landscape condition, fire regime, and vegetation composition (Table 3-3). All three indicators are indirect stressors. The development indicator was assessed using the Landscape Condition scenario, fire regime departure indicator was assessed using the Fire Regime scenario, and cover of invasive species indicator was assessed using the Vegetation Composition scenario. The results are presented using a common framework, in which the indicator – or the combination of all indicators – is scored on a scale from 0.0 to 1.0, where 0.0 indicates a condition of complete replacement of reference ecological conditions due to the impacts of stressors, and 1.0 indicates a condition of no alteration of reference ecological conditions. The same color ramp is used for all results, yellow to dark blue, where yellow equals low scores, green moderate scores and dark blues high scores.

The development indicator is stressor-based and shows the spatial extent and intensity of human modifications (i.e., extent and intensity of development) to the land surface that alters ecosystems or habitat in the MAR ecoregion. The indicator takes into account the density of urban development; infrastructure such as above- and below-ground distribution corridors, communication towers, and border barriers; a wide range of transportation features; mines and landfills; recreational development; agriculture; and energy development.

The second indicator is an indirect measure of fire regime. It is based on the Vegetation Condition Class (VCC) dataset produced by Landfire, which was developed to compare historical reference conditions with current conditions for an individual ecological system type. The result of VCC is a ranking of departure from expected historical range of variability, which can be interpreted as "how has the disturbance regime [for the REA purposes and relevant to this ecoregion: fire regime] changed from its historical variability for this individual CE." Only Severe Vegetation Departure (0.65) and Moderate Vegetation Departure (0.75) were used and are displayed in the map; no to minor departure was scored as 1 (dark blue in the map).

The invasive species indicator serves as an indirect measure of vegetation composition, by measuring the cover of invasive species. It includes a combination of non-native grass and forbs and native woody increasers (mesquite cover). The scores range from 0.65 to 0.90. Either or both non-native invasive and native invasive woody cover may occur in a single pixel. If both occur, then scores for that pixel were multiplied to create a new combined, lower score.

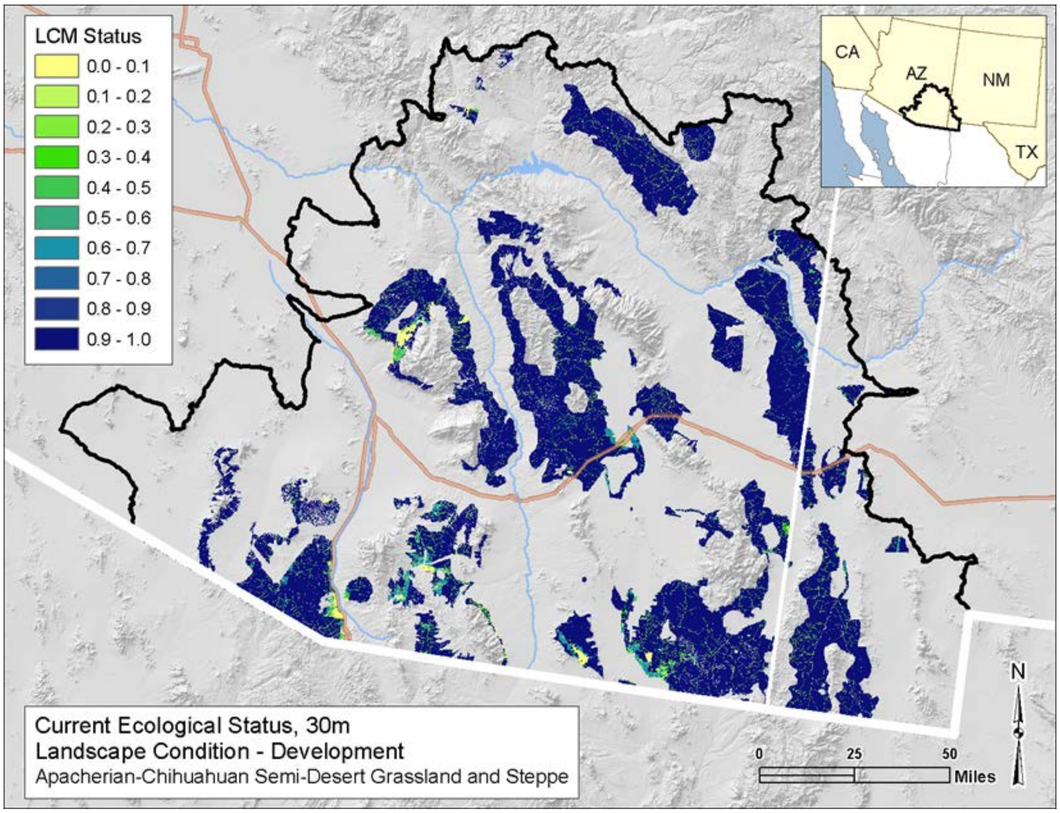
It is important to note that most development impacts are scored much lower than non-development change agents; for example, site intensity for urbanization is scored from 0.05 to 0.6 for high to low density development, respectively. This is because development typically has a much stronger on-site impact than the other indicators. However, except for urban development, most landscape condition impacts occur at smaller scales than can be displayed in these maps, but still are pervasive throughout much of the ecoregion. In particular, effects of many of the very small, local areas of development, or small linear features (e.g. dirt roads) will not be obvious at the scale of the development indicator map.

The maps below (**Figure 4-5**, **Figure 4-6**, and **Figure 4-7**) show the ecological status results for each of the three individual indicators – development, fire regime departure, and invasives – for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe.

Landscape Condition: Development Indicator

The results for the development indicator shown in **Figure 4-5** show several large areas and corridors of intense development throughout the ecoregion, representing areas of municipal and agricultural development. Development impacts are especially noticeable in and around residential communities in the ecoregion such as Bisbee, Fort Huachuca, Oro Valley, Portal, and Rio Rico; and along corridors associated with interstate highways 10 and 19, and many other larger roads. There are many small roads and other development features within this CE's extent (difficult to see at the ecoregion-scale in the map), causing fragmentation and other impacts to the grasslands.

Figure 4-5. Current scores for the development indicator for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe for each 30m pixel. At the ecoregion scale, many development features are not readily visible (i.e. secondary roads or highways, railroads, small agricultural fields). LCM Status = Landscape Condition Model Status of the indicator. Yellow (equivalent to 0) indicates high impacts from the CA, dark blue (equivalent to 1) indicates little to no impact from the CA. LCM Status = Landscape Condition Model Status of the indicator.

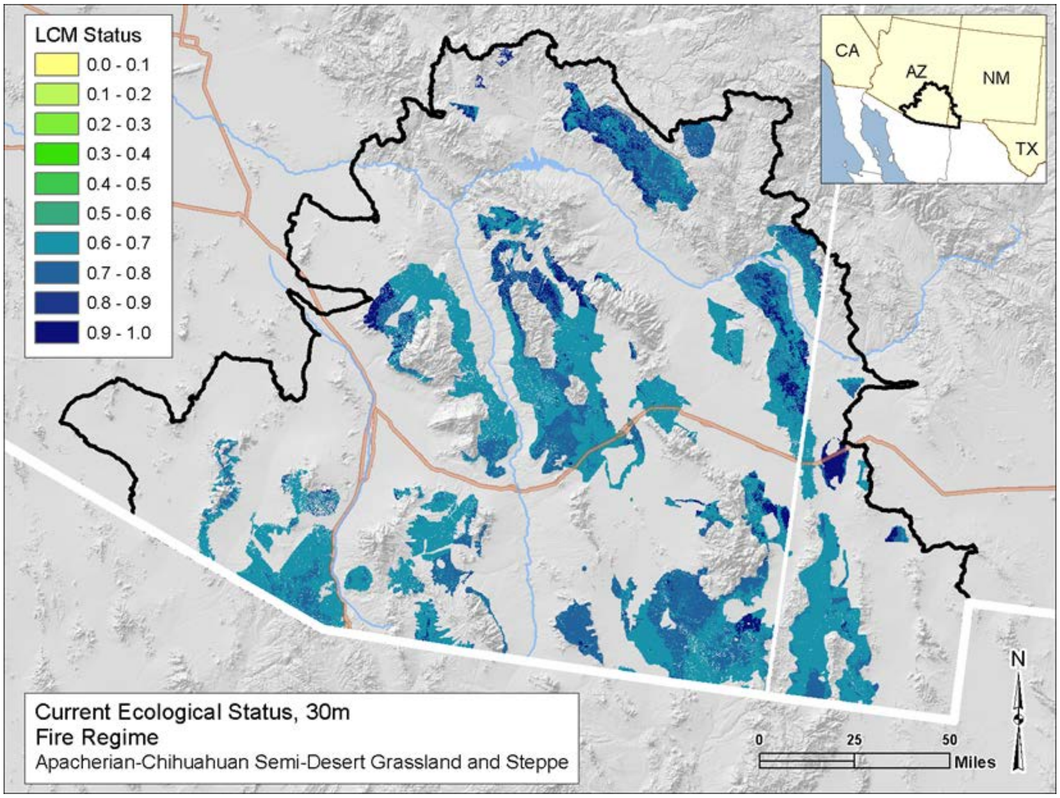


Fire Regime Departure Indicator

The second indicator is an indirect measure of fire regime. It is based on the Vegetation Condition Class (VCC) dataset produced by Landfire, which was developed to compare historical reference conditions with current conditions for an individual ecological system type (see Appendix B and Appendix D for details).

As illustrated in **Figure 4-6**, much of this CE's extent is in severe departure throughout the ecoregion. Areas with moderate departure are small patches and often restricted to higher elevations. These results are consistent with research documenting the results of fire exclusion in the MAR ecoregion. Historically, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe burned frequently; these grasslands were maintained as open grasslands with low shrub cover by fire return intervals of 2.5 to 10 years (Brown and Archer 1999, McPherson 1995, Robinett 1994, Wright 1980). Active and passive fire suppression over the last century has excluded fire from much of this ecological system (Gori and Enquist 2003, Schussman 2006a). Fire exclusion allows increased woody species cover and leads to an uncharacteristic fire regime in many stands (Barton 1999, Gori and Enquist 2003, Muldavin et al. 2002, Turner et al. 2003). This altered (uncharacteristic) fire regime greatly influences ecosystem processes, resulting in grasslands becoming dominated by woody vegetation and eventually converted to shrublands or woodlands.

Figure 4-6. Current scores for the fire regime departure indicator for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe for each 30m pixel. Only 3 classes of fire regime condition are scored: no to little departure (dark blue), moderate departure and severe departure (lighter blues). LCM Status = Landscape Condition Model Status of the indicator.



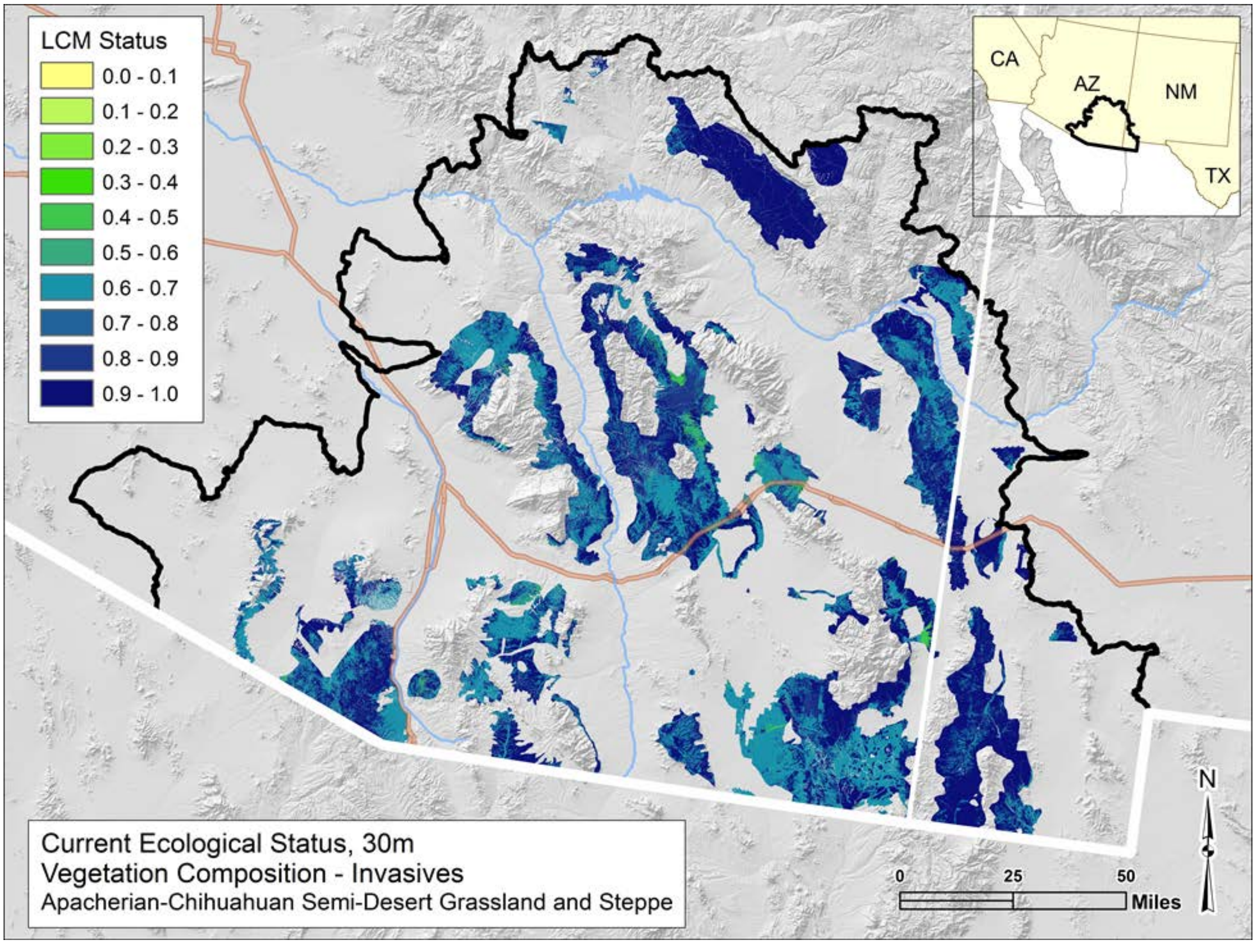
Invasive Species Indicator

The invasive species indicator serves as an indirect measure of vegetation composition, by measuring the cover of invasive species. It includes a combination of non-native grass and forbs and native woody increasers (mesquite cover); see Appendix B and Appendix D for details. Either or both non-native invasive and native invasive woody cover may occur in a single pixel. If both occur, then scores for that pixel are multiplied to create a new combined, lower score.

Figure 4-7 indicates moderate (>10 -15%) to high (>25%) cover of exotic grasses and forbs or invasive mesquite in the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE for the ecoregion. There are significant areas with low or no cover of invasive species in small patches often at higher elevations, and in large patches in Natanes Plateau and ranges in the boot heel of New Mexico. Areas with high cover of both non-native grasses and forbs and invasive mesquite are indicated in yellow patches east of the Galliuro Mountains.

These results are also consistent with research documenting the results of fire exclusion in the REA. With fire exclusion, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe is vulnerable to increases in native shrub cover, especially invasive mesquite and juniper (Gori and Enquist 2003). The introduction of two invasive non-native, perennial grasses, Lehmann and Boer lovegrasses (*Eragrostis lehmanniana* and *Eragrostis curvula*), has greatly impacted many semi-desert grasslands in this ecoregion (Anable et al. 1992, Cable 1971, Gori and Enquist 2003).

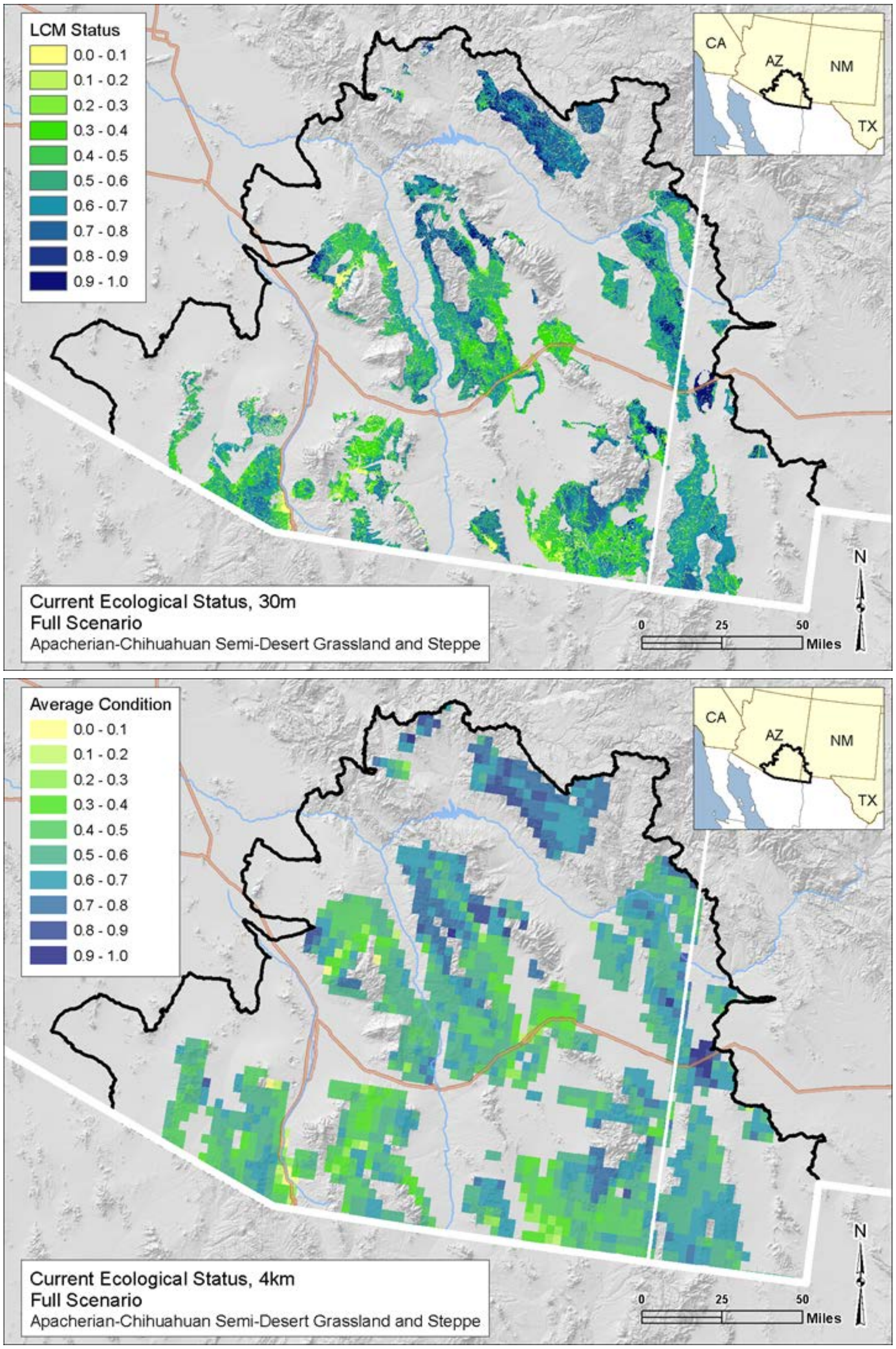
Figure 4-7. Current scores for the invasive species indicator for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe for each 30m pixel. LCM Status = Landscape Condition Model Status of the indicator. Higher cover of mesquite or invasive exotics scores between 0.4 and 0.6 (light greens), while lower cover scores between 0.6 and 0.8 (light blues).



4.2.1.1.6 Overall Ecological Status Assessment

The first map in **Figure 4-8** illustrates the three indicators combined into a single ecological status score per pixel of the CE's distribution. The combined, per-pixel status scores are significantly lower than the individual scores for each indicator. The overall status scores for each pixel were summarized to the reporting unit (e.g., 4km grid) by averaging the status scores from all the pixels of the CE within the reporting unit. The results, shown in the second map of Figure 4-8, indicate the widespread general degradation of the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE across its range in the ecoregion. Some 90% of the 4km grid cells fall at or below the 0.7 scores. There are a few local areas of better ecological condition, a result of low level of development, low or no cover of invasive species, and moderate fire regime departure.

Figure 4-8. Current overall ecological status scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe for each 30-meter pixel of its distribution (top) and 4km grid cells (bottom). LCM Status = Landscape Condition Model Status of the indicator. The score for each 4km cell is an average of all 30m pixels that are scored for the CE. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs. See Figure 4-2 for a histogram showing the frequency distribution of the 4km grid cell results.



4.2.1.1.7 Future Status and Risk

This conservation Element was also assessed for ecological status for the 2025 timeframe, see section 4.4.1 2025 Risk Assessment and Figure 4-45 below for those results. In addition, the distribution of this CE was compared to the climate change exposure index; those results are in section 4.3.5 Climate Trends and CEs.

4.2.2 Aquatic Systems: Overview

Ecological status was assessed for the four MAR aquatic CEs: 1) North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream, 2) North American Warm Desert Lower Montane and Foothill Riparian Woodland, Shrubland and Stream, 3) North American Warm Desert Ciénega, Marsh and Pond, and 4) North American Warm Desert Playa and Ephemeral Lake. (Hereafter the nominal "North American Warm Desert" will be replaced with the acronym "NAWD"). The overall ecological status by reporting unit for each CE is presented in Figure 4-9 and Figure 4-10, represented by 5th and 6th level watersheds (see Appendix E for complete results at the 30 m analysis unit level). These assessments take into account all of the indicators, both the stressor-based indicators of landscape development, invasive species, and water use; and the direct indicators of native biotic integrity and habitat quality.

The ecological status results primarily are driven by the stressor-based indicators, and suggest the majority of the distribution of the NAWD Riparian Woodland, Shrubland, Mesquite Bosque and Stream, the lowest elevation riparian CE, is in poorer condition than the higher elevation riparian CE, the NAWD Lower Montane and Foothill Riparian CE. This is because more development and higher water use occurs along riparian corridors and alluvial fill found in valley bottoms. These areas also generally contain the most developed part of the ecoregion, whereas the foothill and montane riparian areas have far less development and water use impacts. The Ciénega CE has more evenly distributed status scores, but again shows that pattern of more impact closer to the heavily populated areas of the ecoregion. The playas have the most limited distribution in the ecoregion; there are large known playa complexes (the Lordsburg and Willcox playas) and a handful of smaller ones. These aquatic resources are also impacted by development, namely roads and railroad beds that cut across the face of playas and change the way water can move into and across the area. Water use and development understandably would have the strongest impacts on the aquatic systems in the ecoregion. Removing or intercepting water that previously supported such systems, or converting the locations of such systems to other land uses, necessarily severely degrades or eliminates these types of systems.

The status results can also be viewed statistically (**Figure 4-9, Figure 4-10**). The graphs to the right of each map show the number of watersheds by status score category, with a running cumulative percentage of watersheds containing that CE. Fifth-level watersheds (HUC 10) are the reporting unit for the riparian CEs, while 6th level watersheds (HUC 12) are used for the Ciénega and Playa CEs, because they have much smaller footprints on the landscape. Again it is clear that the NAWD Riparian CE has many more watersheds in the lower range of scores than the foothill and montane riparian CE. The Ciénega CE has a wider spread of scores than the NAWD Riparian CE, as some occurrences are at higher elevations away from heavily developed areas. The 6th level watersheds containing playas are very limited, but still show the Willcox playa has the most degraded ecological status, due to roads, railroad beds, and abundant invasive weeds. Overall the assessment shows that aquatic resources in valley basins at the lowest elevations near the heavily developed areas have the lowest status scores due to greater CA effects.

Figure 4-9. Overall ecological status scores for riparian CEs illustrated in maps (left) and graphs of frequency distribution (right). Ecological status scores are averaged across 5th-level watersheds for the Riparian CEs; maps show only those watersheds with occurrences of NAWD Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE (upper) and NAWD Lower Montane and Foothill Riparian and Stream CE (lower). Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of watersheds in each interval (left) and the cumulative percentage of the grid cells for each interval (right).

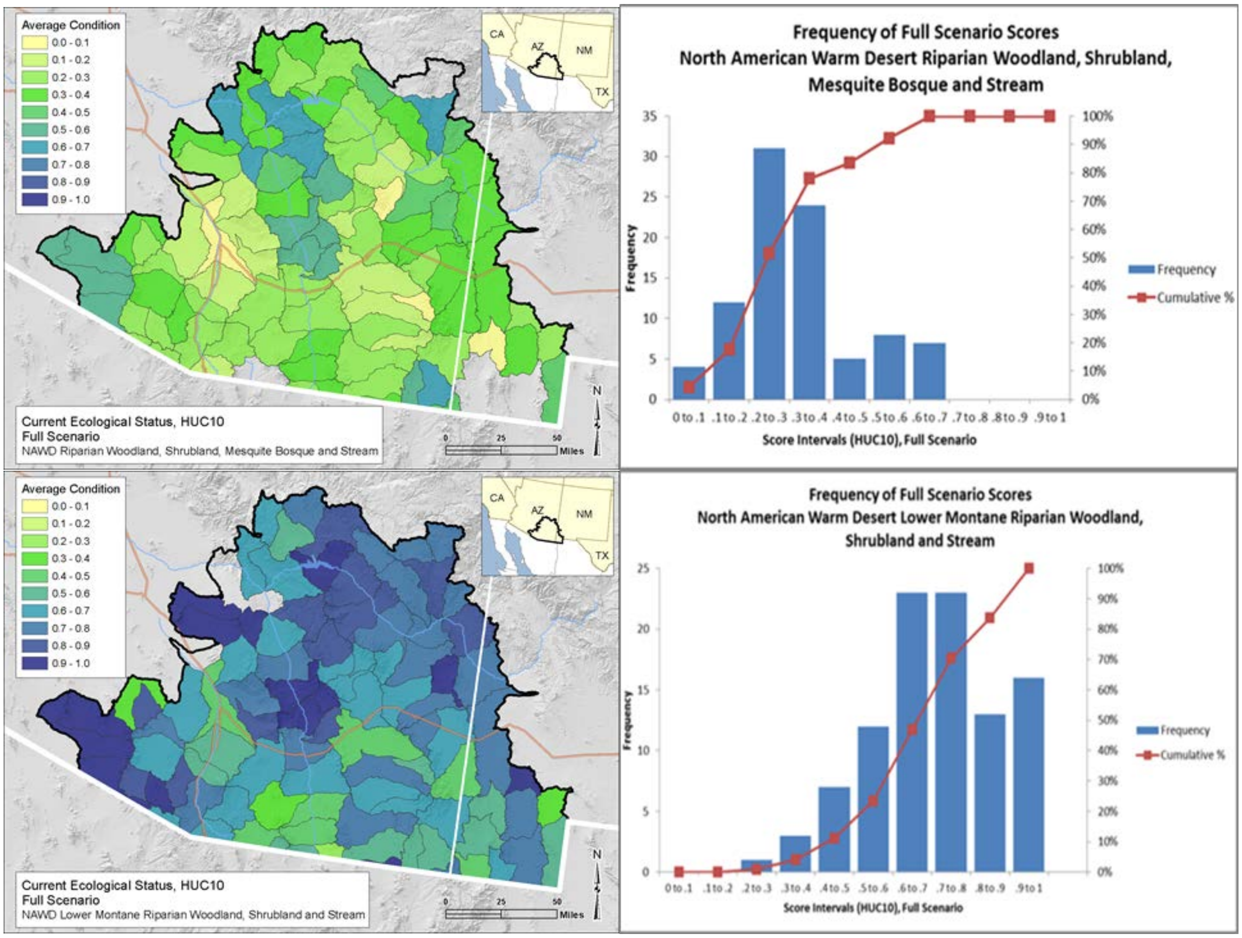
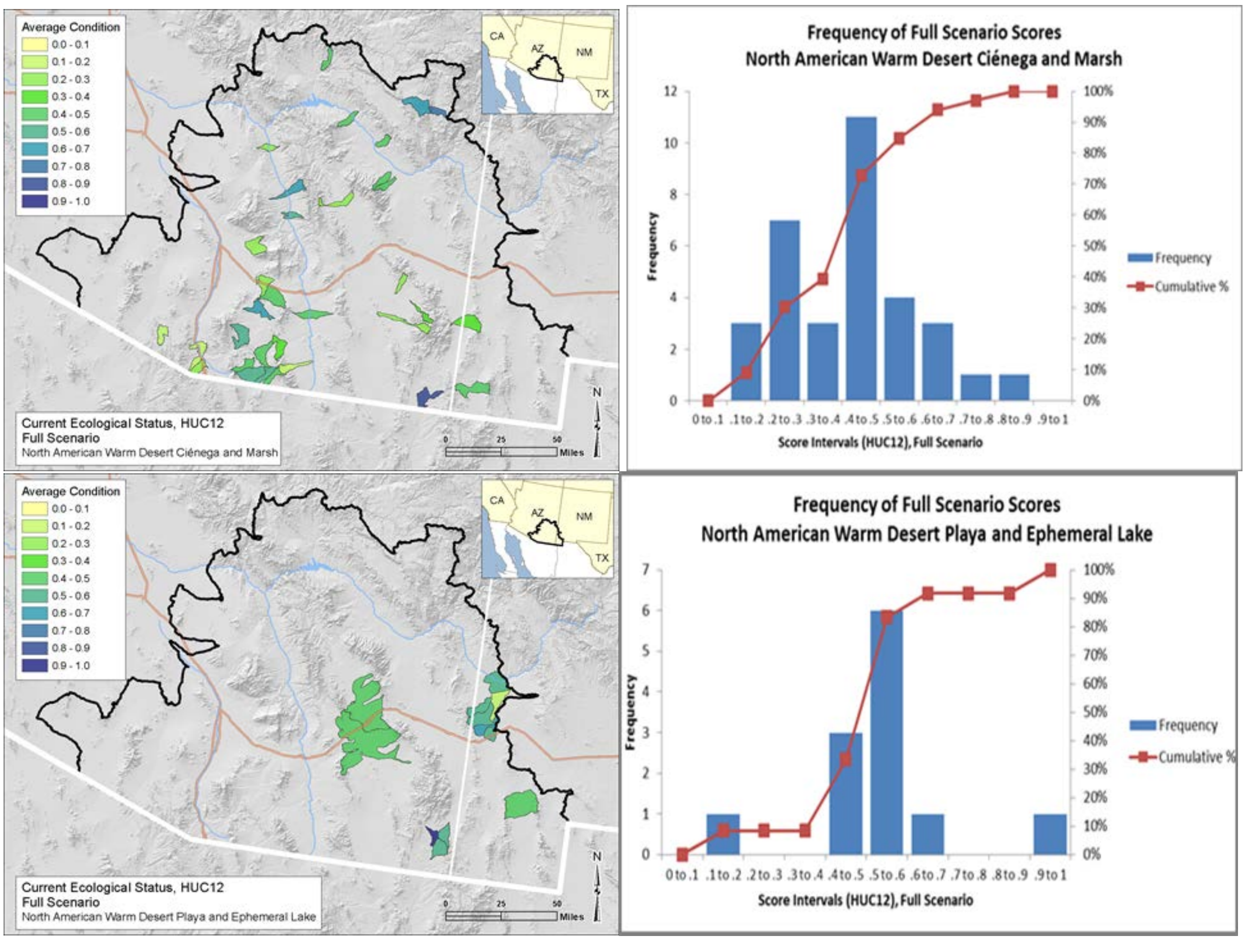


Figure 4-10. Overall ecological status scores for ciénega and playa CEs illustrated in maps (left) and graphs of frequency distribution (right). Ecological status scores are averaged across **6th-level watersheds** for these CEs; maps show only those watersheds with occurrences of NAWD Ciénega, Marsh and Pond (upper), and NAWD Playa and Ephemeral Lake CEs (lower). Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of grid cells in each interval (left) and the cumulative percentage of the grid cells for each interval (right).



4.2.2.1 Aquatic Ecological System Case Study: North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream

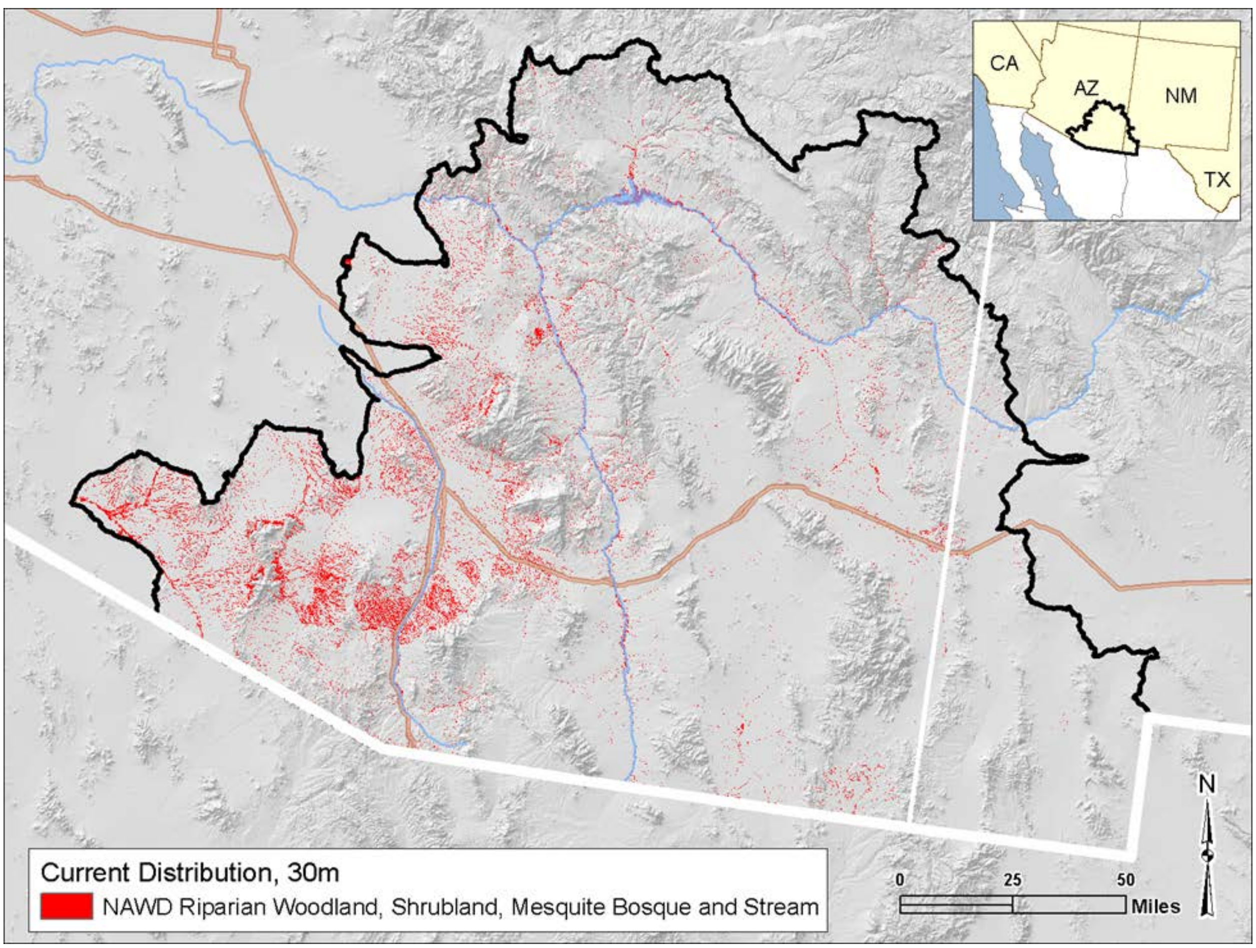
4.2.2.1.1 Description

This ecological system consists of riparian vegetation corridors, perennial and seasonally-flowing streams, and riparian mesquite bosques that occur at low elevations (< 1200 m, ~4000 ft.) (Comer et al. 2003, Stromberg et al. 2009). Riparian mesquite bosques are a specific type of riparian vegetation community associated with ephemeral, intermittent, or perennial stream water courses. They are not the same as upland mesquite woodlands, which are distinguished separately in the land cover datasets used for this assessment. Riparian mesquite bosques occur only where the mesquite roots can reach groundwater. However, they can become established at times when groundwater alongside a water course stood close enough to the land surface for seedlings to take root, e.g., following a large flood. After these initial conditions, the depth to groundwater may decline but the bosque will persist if the mesquite can extend their roots deeper as this water table recedes. Riparian mesquite bosques therefore may occur today on dry terraces elevated above present-day water courses (Leenhouts et al. 2006).

The vegetation in the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE is a mix of riparian woodlands and shrublands. The aquatic fauna and flora are highly variable depending on flow characteristics, including past occurrences of flood events that have resulted in riparian vegetation across terraces that are today elevated above the water course. Several special-status terrestrial and aquatic species are associated with this ecosystem, including the yellow-billed cuckoo *(Coccyzus americanus)*, southwestern willow flycatcher *(Empidonax trailii extemus),* Gila trout *(Salmo gilae),* and spikedace *(Meda fulgida).* The critical importance of this aquatic system in an arid ecoregion, as well as its unique flora and fauna, are key reasons why it was chosen as a conservation element for this Rapid Ecoregional Assessment.

Figure 4-11 shows the current distribution of the CE, by 30m pixel. The CE occurs in two settings: along stream corridors and along dry washes (aka dry stream channels) across adjacent foothills and terraces where shallow groundwater dynamics have permitted the establishment of riparian mesquite bosques. Not all pixels are visible on the map display at this scale.

Figure 4-11. Current distribution of North American Warm Desert Riparian Woodland, Shrubland and Mesquite Bosque and Stream CE within the MAR.



4.2.2.1.2 Change Agents

Change agents, and the specific stressors they generate, can cause alteration to the key ecological attributes (KEAs) for individual occurrences of this ecosystem type. Stressors identified in the MAR include development and water use. Development includes areas of urban, residential, commercial, and industrial development; cultivation, including irrigated agriuculture; urban and rural, roads; railroads; power lines; solar arrays; well platforms; and the like. Development eliminates conservation element occurrences; fragments the distribution or connectivity of the conservation element (Debinski and Holt 2001); alters watershed hydrologic function, including infiltration, evapotranspiration, and runoff; and results in pollutant "point" discharges including irrigation and municipal wastewaters, and diffuse runoff of pollutants and eroded soil (e.g., Boody and DeVore 2006, Chipps et al. 2006, Pimentel et al. 2004). Water development projects can have multiple effects on aquatic conservation elements, eliminating or fragmenting element occurrences, changing the amount and timing of surface inflow and groundwater-fed baseflow, introducing pollutants and excess sediment, and fragmenting hydrologic connectivity with dams and other barriers (Poff et al. 2010, Stromberg et al. 2006). For the MAR assessment, the data on development affecting aquatic conservation elements come from the same datasets used to assess the impacts of development on other conservation elements. However, the types of development included in the assessment of development impacts on aquatic conservation elements, and their scoring, differ slightly from those used elsewhere in this assessment to reflect the specific ways that development can affect aquatic ecological resources, as described in Appendix B. The data on water use included in the MAR assessment consist of data on surface- and ground-water consumption by human activities (including livestock watering) by groundwater basins in AZ and by county in NM (see map in Figure E-3 in Appendix E). These data were converted to measurements of total annual water consumption per unit of area, to provide an indicator of the likely relative impact of water removal on aquatic conservation elements (see full rationale in Appendix E). The MAR assessment of the impacts of invasive species on aquatic conservation elements focused on aquatic invasive species. Aquatic invasive species can have profound effects on the amount of oxygen available; can introduce toxins; can prey on, infect, or directly compete with native species; and have been shown to completely replace the native ecosystem habitat (e.g. tamarisk) (USGS 2011).

4.2.2.1.3 Key Ecological Attributes

A **key ecological attribute** of a focal ecological resource is a characteristic of the resource's biology, ecology, or physical environment that is critical to the resource's persistence in the face of both natural and human-caused disturbance. Alteration of such a characteristic beyond some critical range of variation will lead to the degradation or loss of the resource within decades or less. For a deeper explanation of key ecological attributes, see Appendix B, and for more details about KEAs and indicators for the aquatic CEs, see Appendix E. The KEAs and their associated indicators identified for assessment are those with available data (see Table 3-3) and included the following:

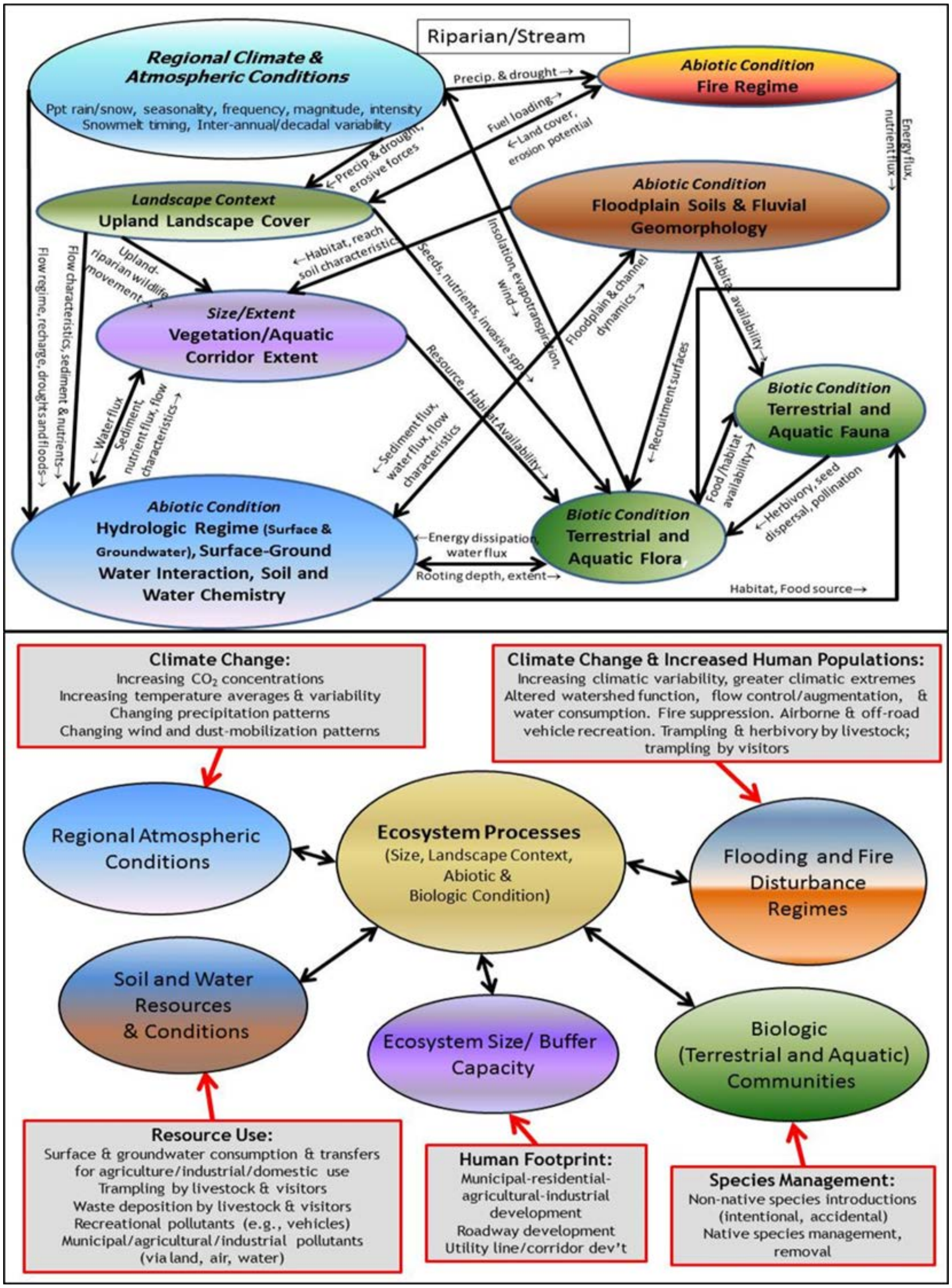
1) Landscape Condition: Anthropogenic infrastructure and land uses can have a direct effect on the condition of aquatic ecosystems. The indicator measured is development – the amount of anthropogenic disturbance by development and agricultural cropland in the ecosystem.
2) Native Riparian/ Aquatic Faunal Composition: the indicator measured is the presence and abundance of native fish, endangered species and freshwater macro-invertebrate index.
3) Non-Native Riparian/ Aquatic Flora and Fauna Composition: the indicator measured is the presence and abundance of non-native invasive species.

4) Hydrologic Regime: the indicator measured the relative amount of total surface and ground water use within pre-defined areas for which the data were available: Groundwater Basins (in Arizona) and Counties (in New Mexico).
5) Geomorphology: The indicator measured the condition of the stream channel, banks, and floodplain, and amount of cover to withstand erosional forces.

4.2.2.1.4 Conceptual Model Illustration

Below is the conceptual model diagram (Figure 4-12) illustrating the relationships between the key ecological attributes (ovals) of the warm desert stream and riparian system. The diagram also indicates which of the key ecological attributes (ovals) are affected by various stressors (boxes). For example, groundwater pumping and resulting reductions in stream flow are a source of stress on aquatic animals dependent on stream flow for wildlife habitat and nutrients. This diagram is intended only as a general, conceptual overview and does not attempt to quantify these relationships.

Figure 4-12. Conceptual model diagram for the North American Warm Desert Riparian Woodland, Shrubland and Mesquite Bosque and Stream CE. Top section shows key ecological attributes (KEAs) (ovals) and natural processes (arrows) that have direct and indirect relationships. Small arrows indicate which KEA is affected; for example, Landscape Context is impacted by Fire Reigme through the change in vegetative cover and erosional potential. The lower half retains only the KEAs (ovals) without the arrows showing relationships; major stressors have been added and indicate which KEAs they impact. Diagram design is based on Scott et al. 2006.



4.2.2.1.5 Individual Indicator Results

As described above, the assessment of this CE focused on indicators for KEAs for which spatial data were available: 1) development, 2) native biotic integrity, 3) invasive non-native riparian/aquatic species, 4) water use, and 5) habitat quality (Table 3-3). Three are indirect measures: development for landscape condition, invasive species for native biotic condition, and water use for hydrologic regime. Two indicators are direct measures of status: native biotic integrity (a measure of native fish, endangered species and macro-invertebrates); and habitat quality (a measure of channel stability and physical structural components for the floodplain and channel). Direct measures of status complement the indirect measures. However, both of the direct measures had relatively small numbers of sample points spread across the ecoregion, i.e., much smaller data sets compared to the indirect measures. As a result, the overall ecological status assessment results are primarily determined by the indirect, stressor-based indicators. The direct measures convey the condition of their KEAs for limited number of locations.

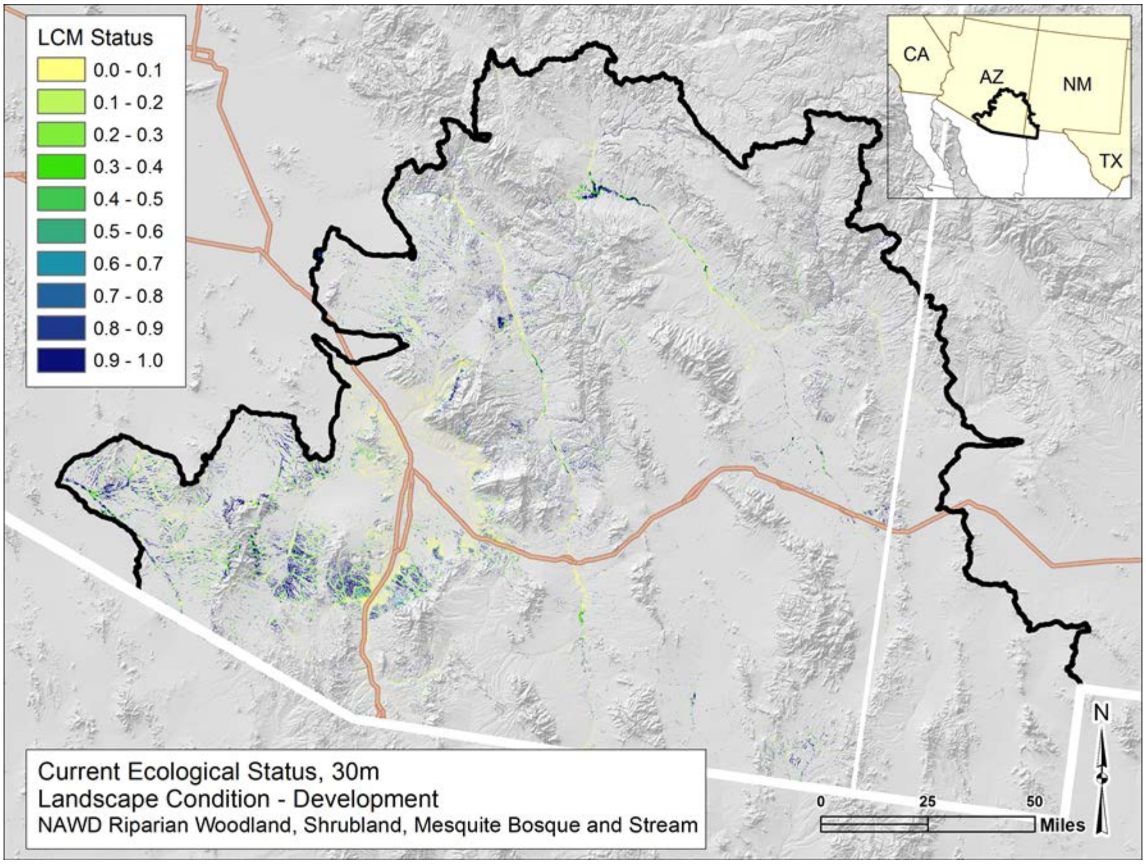
The results are presented using a common framework, in which the individual indicators, as well as the overall ecological status, are scored on a scale from 0.0 to 1.0, where 0.0 indicates a condition of complete replacement of reference ecological conditions due to the impacts of stressors, and 1.0 indicates a condition of no alteration of reference ecological conditions. The same color ramp is used for all results, yellow to dark blue, where yellow equals low scores, green moderate scores and dark blues high scores.

Landscape Condition: Development Indicator

The ecoregion has several large areas and corridors of intense development throughout the ecoregion, representing areas of municipal and agricultural development. Development impacts are especially noticeable in the Tucson metropolitan area; in and around every residential community in the ecoregion; and along corridors associated with interstate highways 10 and 19, US highways 70 and 191, and many other larger roads. Smaller roads lie along almost all larger riparian corridors in the ecoregion, where they result in lower development indicator scores as well.

As a result, as seen in Figure 4-13, the majority of pixels in the distribution of the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE register scores below 0.5 for the development indicator. The few pixels with scores above 0.5 mostly represent mesquite bosques located away from the main riparian corridors. However, most mesquite bosques located away from the main riparian corridors are impacted by development; only a minority in remote locations is unaffected. (As noted above, the CE pixels are represented to scale, and so appear very small on an ecoregion-wide map, making isolated pixels difficult to discern).

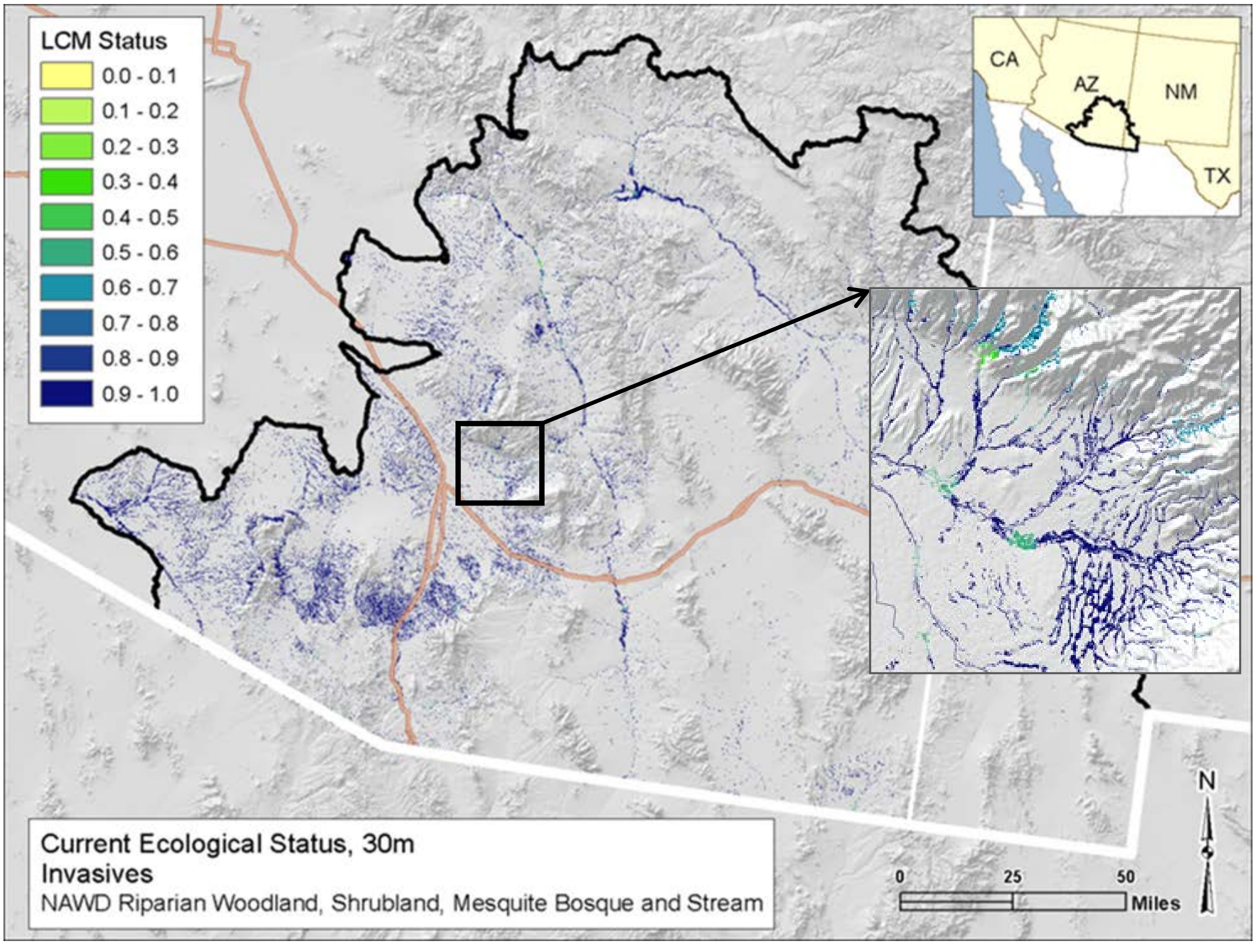
Figure 4-13. Indicator scores for Landscape Condition –Development indicator for North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. Data are by 30 m pixel which appear very small on an ecoregion-wide scale map, making isolated pixels difficult to discern. LCM Status = Landscape Condition Model Status of the indicator.



__Aquatic and Terrestrial Invasives Species Indicator__

This indicator measures the presence of of non-native invasive species, including 39 taxa of terrestrial plants, including woody species such as tamarisk and herbaceous plants such as cheatgrass and red brome (*Bromus tectorum, Bromus rubra*); as well as a several aquatic species (including bullfrogs, crayfish, non-native fish, and pondweed). In Figure 4-14, indicator scores of 0.35 for invasive species indicates a combination of aggressive aquatic animals and abundance of terrestrial plant species, 0.5 indicates the presence of highly aggressive aquatic species such as bullfrogs or crayfish, and a score of 0.7 indicates the presence of less aggressive aquatic species such as non-native salamanders, OR high abundance (>25% cover) of non-native terrestrial plant species. There are numerous stretches of the Gila and San Pedro River that have scores <0.4 due to aggressive exotic fish and tamarisk invasions, and certain reaches with very low scores of 0.1 where several invasive species are found. The area of this CE's distribution with invasive indicator scores less than 0.9 only constitute 8% of the CE's entire distribution, so it is very difficult to see these areas on an ecoregional scale map.

Figure 4-14. Indicator scores for Aquatic and Terrestrial Invasive Species indicator for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. Inset is of the Tuscon area with scores of <0.4. LCM Status = Landscape Condition Model Status of the indicator. It is recommended to view this data with a GIS application to see the patterns of high infestations.

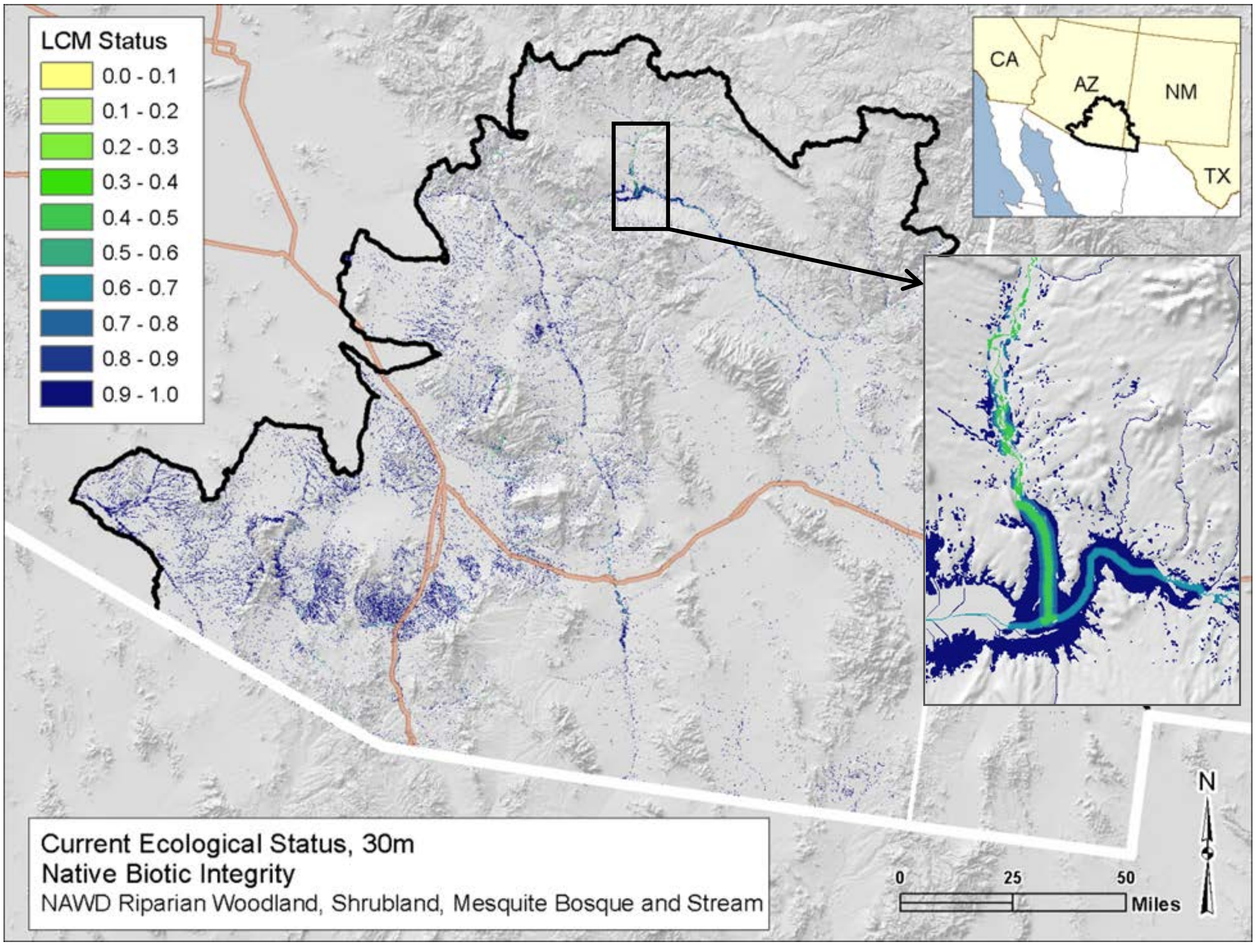


__Native Biotic Integrity Indicator__

This indicator measures how much of expected native species are present (a combination of information on native fish, endangered species, and a benthic macro-invertebrate Index). While this is a limited data set, the data points are well distributed throughout the major rivers and tributaries of the Arizona portion of the REA. This data shows that nearly 20% of sampled riparian corridors are in excellent shape, about half (47%) are in moderate condition, and the remaining (36%) are missing most if not all expected native species. Stream reaches with null data were not scored. An absence of data does not mean that the stream has high or low native biotic status; it means only that it has not been surveyed. The presence of native biota contributed to a higher score for this indicator, while absence decreased the score. Scores of 0.35 indicate that surveys turned up no native fish and few endangered species, and registered a low benthic macro-invertebrate score. It was rare to have all three sources of native biotic integrity measured at the same sampling location. A score of 0.5 means no native fish occur or the benthic macro-invertebrate index score was poor; a score of 0.7 indicates 1-3 native fish were present or 1-4 endangered species were recorded. The area of this CE's distribution with scores less than 0.9

only constituted 8% of the CE entire distribution, so it is very difficult to see these areas on an ecoregional scale map.

Figure 4-15. Indicator scores for the Native Biotic Integrity indicator for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. LCM Status = Landscape Condition Model Status of the indicator. Inset is of the Gila River at San Carlos Reservor with scores of 0.7 and 0.4, where expected native fish were not found. Null data are scored dark blue. Only about 8% of the CE had data.

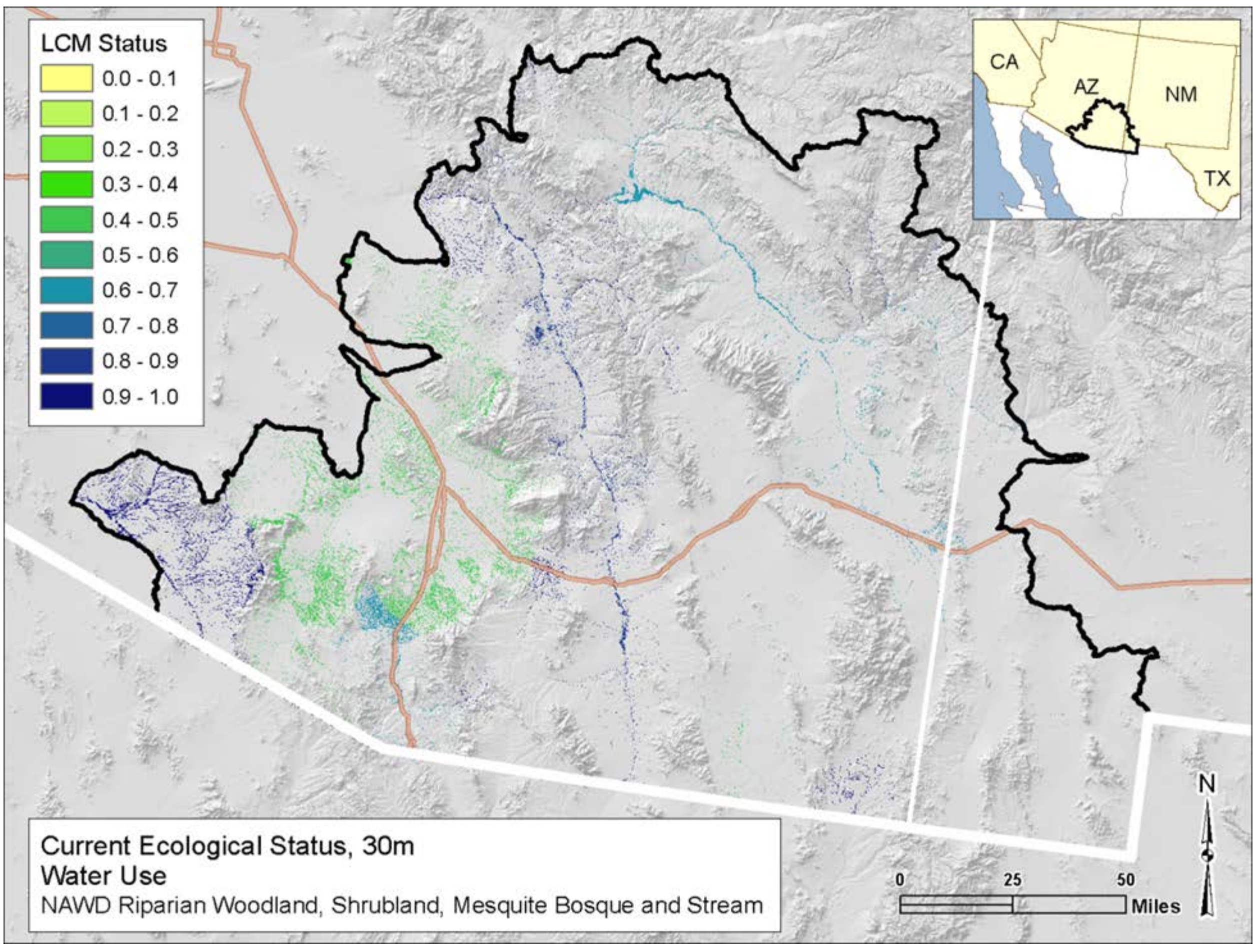


Water Use Indicator

The indicator for water use measures relative intensity of consumption of both surface and ground water from within-ecoregion sources. Each pixel of the aquatic CE on the map shows the water use indicator score of the Arizona groundwater basin or New Mexico county in which the pixel lies. The same score was applied throughout each entire groundwater basin or county, and are scored relative to each other in terms of total water use. This is a coarse-scale indicator, and cannot differentiate variations at the finer scale, such as any differences in effects on aquatic resources lying upstream vs. downstream of a diversion. Rather it broadly shows, for example, that more water is being used (and therefore a greater stress is implied for aquatic CEs) in the Tucson region relative to the San Pedro area. The results (Figure 4-16) indicate high rates of water use in the Tucson AMA and Douglas basin (0.3-green colors around Tucson, and east of the upper San Pedro, south of Willcox); medium-high usage

(0.6- turquoise colors) in the Safford groundwater basin (along the Gila River), and Santa Cruz AMA basins (just south of Tucson); medium (0.7 medium blue colors) in the Upper and Lower San Pedro groundwater basins; and lowest usage (0.9 -- dark blue colors) in the Aravaipa Canyon, Cienega Creek, and San Simon Wash (far southeastern corner) groundwater basins, AZ (see Appendix E, Figure E-3 for a map of the groundwater basins and NM counties). The areas of high rates of water use are all basins in Arizona with either dense municipal development (Tucson AMA) or large areas of intensive irrigation (Pinal AMA, Douglas and Willcox basins).

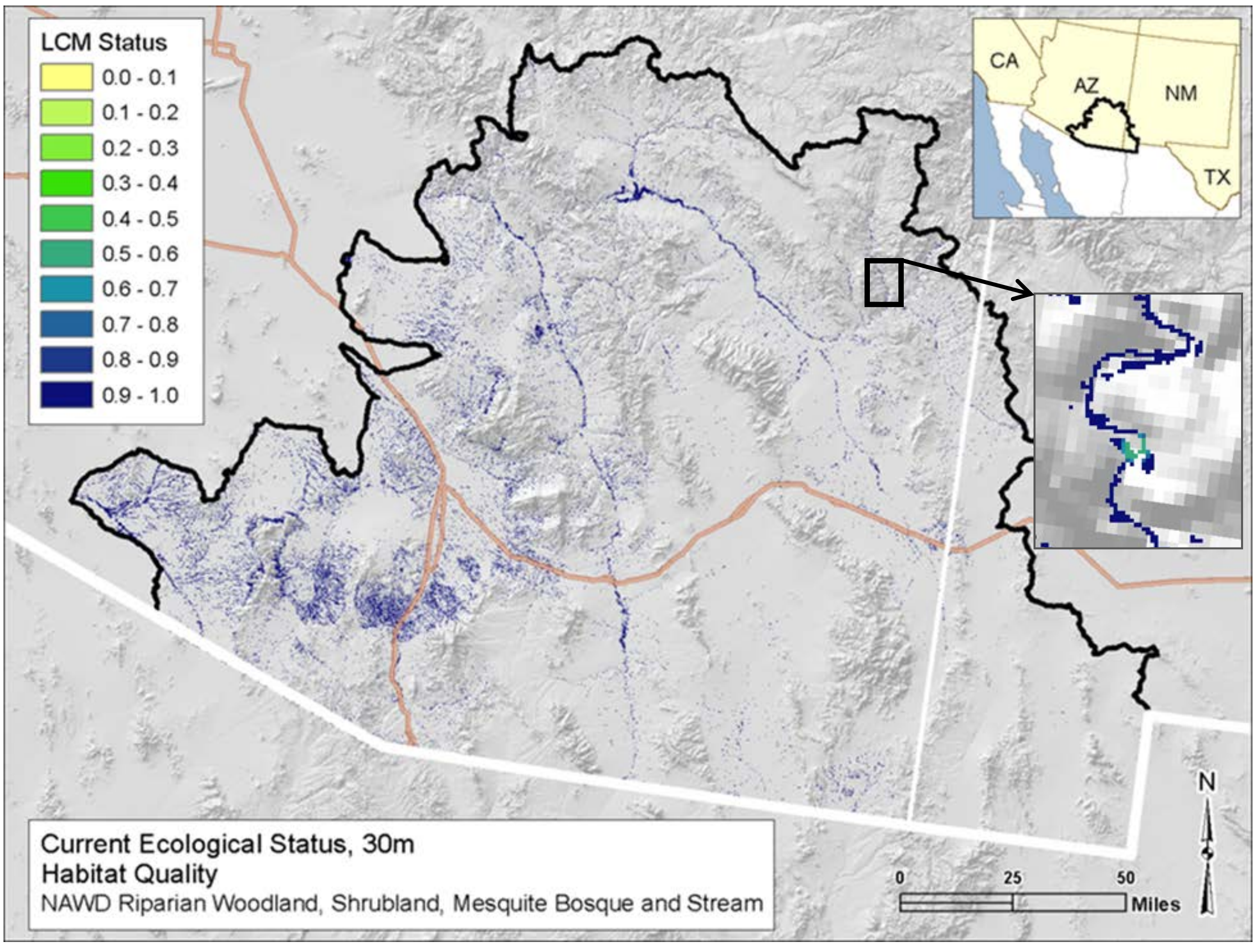
Figure 4-16. Indicator scores for Water Use indicator for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. LCM Status = Landscape Condition Model Status of the indicator.



<u>**Habitat Quality Indicator**</u>

This indicator measures the geomorphic condition and combines field-based Proper Functioning Condition (PFC) and Aquatic Habitat assessments. It indicates how well the channel bed, banks and floodplain soils may hold up during rainfall and runoff events. This is an extremely limited spatial data set and while the data points are distributed throughout the Arizona portion of the REA, there were not many points. BLM does collect PFC data within this REA, but those data were not available in a comprehensive, standardized, ecoregion wide format (Masters, E., personal communication 2014). High scores indicate Proper Functioning Condition or high aquatic habitat scores, where there is vegetative cover and proper ratios of pool to riffles. Lowest scores (0.49) are places where both PFC and aquatic habitat scored poorly. Areas with scores <0.9 constitute <.05% of the entire CE distribution, so it is very difficult to see such results spatially on an ecoregion wide map (Figure 4-17). Of the combined PFC and Aquatic Habitat scores for this CE across the MAR, half (50%) scored very well, nearly half (49%) scored in moderate condition, and only 1% scored very poorly.

Figure 4-17. Indicator scores for Habitat Quality for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. LCM Status = Landscape Condition Model Status of the indicator. Very few individual pixels scored low. Zoomed-in area is Eagle Creek, near Eagle Creek Road, with scores of 0.5-0.6.

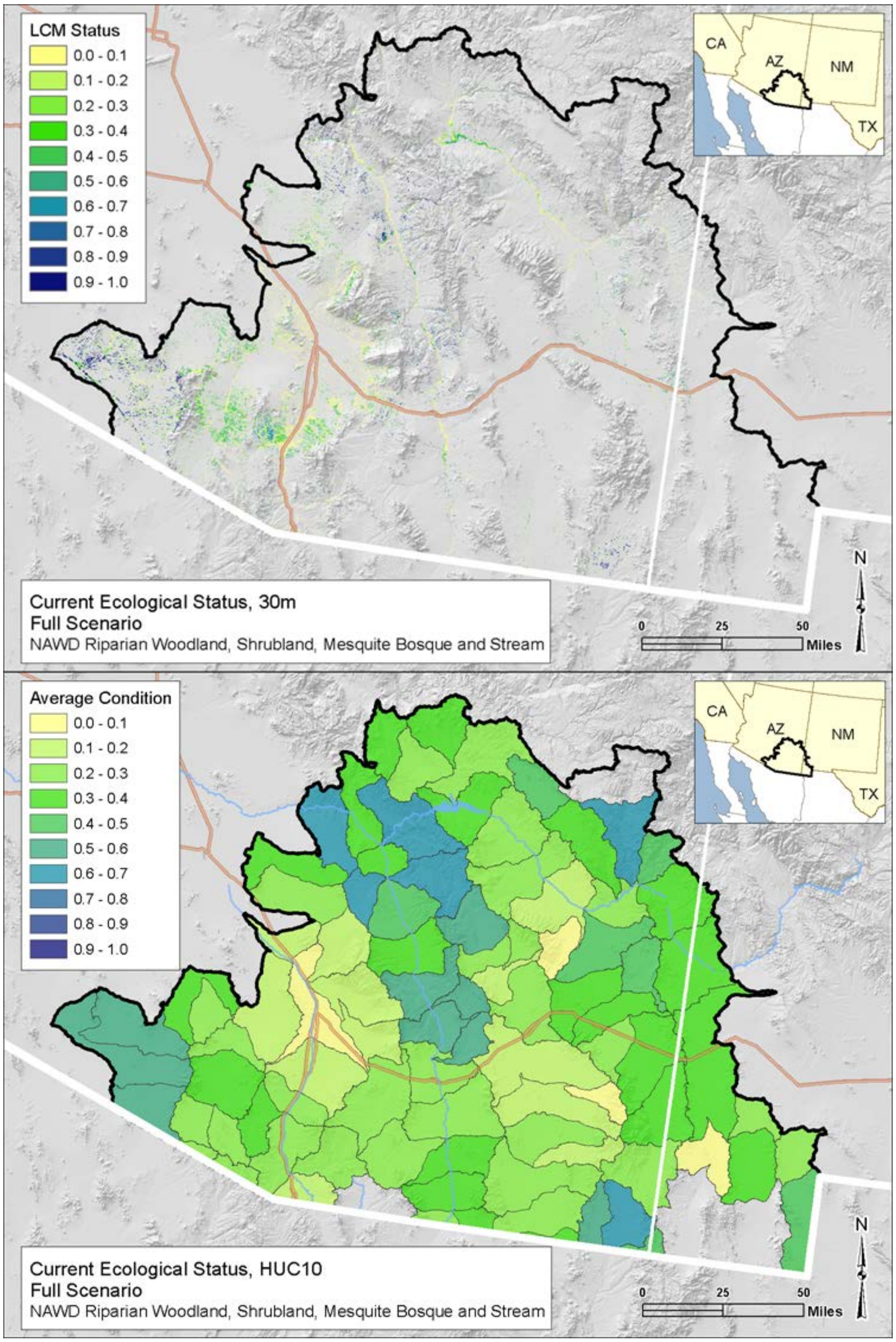


4.2.2.1.6 Overall Ecological Status Assessment

The overall ecological status assessment combines all the indicator scores together. Figure 4-18 shows the overall ecological status of the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE. The upper panel shows the results by 30m pixel; the lower panel, averaged across 5th-level watersheds (HUC10). The results primarily reflect the stressor-based indicators, which together produce status scores < 0.5 for most pixels. Fifty-eight watersheds have low status scores (< 0.4), including four with very low status scores (< 0.1). These contrast with only 20 watersheds having intermediate status scores (> 0.4), including five with status scores of 0.4-0.5, eight with status scores of 0.5-0.6, and seven with impact scores of 0.6-0.7. No watersheds had high status scores (scores > 0.7). The majority of the distribution of this CE is in moderate to poor condition.

The Gila River corridor downstream from the San Simon River confluence, most of the San Pedro River corridor, and most of the Santa Cruz River corridor south of Tucson show high levels of impact from development, water use, and invasive species. Some areas exist with moderate or high scores representing riparian communities that have increased in abundance due to the formation of San Carlos Lake, a reservoir on the Gila River (i.e. more than what was along the river prior to the reservoir creation), and mesquite bosques located away from the main riparian corridors. The four most altered watersheds containing this CE are located in the areas of Animas, NM; and the areas of Safford, Willcox, and the Tucson metropolis, AZ. The seven least altered watersheds containing this CE occur in the far west-southwestern corner of the ecoregion west and south of Sells, AZ; in the northern third of the lower San Pedro River basin; in the lower San Francisco River basin; and surrounding San Bernardino National Wildlife Refuge.

Figure 4-18. Overall ecological status scores for the North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream CE for each 30-meter pixel of its distribution (top) and all 5th-level watersheds containing pixels of this CE (bottom). LCM Status = Landscape Condition Model Status of the indicator. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs. See Figure 4-9 a histogram showing the frequency distribution of the 5th-level watershed results.



4.2.2.1.7 Future Status and Risk

This CE was also assessed for ecological status for the 2025 timeframe; see section 4.4.1 2025 Risk Assessment below for those results. In addition, the distribution of this CE was compared to the climate change exposure index; those results are in section 4.3.5 Climate Trends and CEs.

4.2.3 Species: Overview

Ecological status was assessed for five of the six individual species CEs and for the two species assemblages: pronghorn (*Antilocapra americana*), Coues white-tailed deer (*Odocoileus virginianus couesi)*, desert bighorn sheep (*Ovis canadensis*), desert box turtle (*Terrapene ornata luteola)*, Chiricahua leopard frog (*Lithobates chiricahuensis)*, grassland birds, and nectar-feeding bats. Black-tailed prairie dog (*Cynomys ludovicianus*) was not assessed beyond providing a potential habitat model because management questions tied to reintroduction are highly locally driven and therefore not readily addressed by the standard status assessments or data collected for this REA; see its conceptual model in Appendix F. It is unclear how change agents might affect such a carefully managed species; therefore, a status assessment was not conducted for this CE. The overall ecological status for each CE is presented in Figure 4-19, Figure 4-20, and Figure 4-21, aggregated to the 4 km reporting units (or 6^{th}-level watersheds in the case of the leopard frog); see Appendix F for complete results at the 30-meter analysis unit level. These status summaries take into account all of the stressor-based indicators that were assessed for each species, which include combinations (specific to each CE) of development, invasive species, fire regime departure or recent burn severity (which affect habitat), and water use.

While fire regime and its alteration from the historical range of variability is not a direct measure for individual species, the habitat for all of the species CEs can be affected by the impacts of recent fires (e.g. increased sedimentation in Chiricahua leopard frog habitat due to erosion triggered by severe fires (USFWS 2007a) or shifts in vegetation structure or plant species composition within the foraging range of bighorn sheep (Etchberger et al. 1989). Hence measuring fire regime alteration or presence of recent severe burns provides information about areas where species habitat may be in poor status related to the fire regime. Similarly, invasive species, whether exotic grasses or native mesquite, have impacts on the plant species composition and vegetation structure of habitat supporting these species.

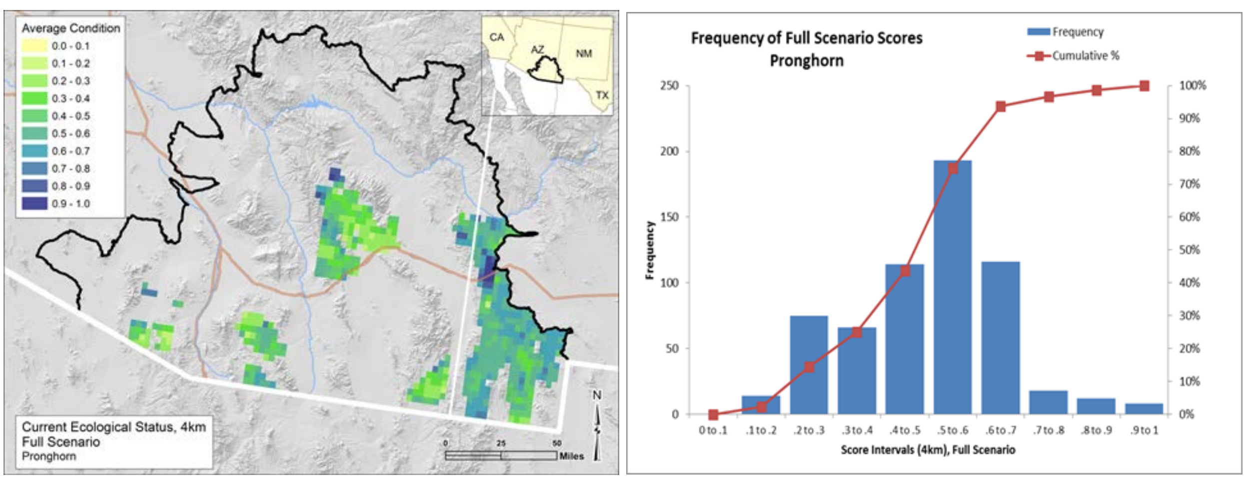
Of the ungulates assessed in this REA, Coues white-tailed deer habitat has somewhat better ecological status than that of pronghorn or desert bighorn sheep, with status scores concentrated between 0.5 and 0.8. While invasives and altered fire regimes are affecting its habitat, the type and diversity of food plants it can consume and variety of habitat it utilizes suggest these factors may be somewhat tolerated by this species. While approximately 50% of the expected distribution for pronghorn has status scores concentrated around 0.5 to 0.7, another 40% of its expected distribution scores less than 0.5. Altered fire regimes and invasive species are the two factors driving the lower scores in most areas; this is consistent with this species' reliance on healthy grassland habitat. Over 70% of desert bighorn sheep habitat scores 0.5 or lower, driven almost entirely by altered fire regimes; studies in other parts of this species' range indicate fire suppression has altered density and composition of vegetation in desert bighorn habitat, resulting in loss of suitable habitat or herd declines (Cannings et al. 1999, Davidson 1991, Etchberger et al. 1989, Wakelyn 1987).

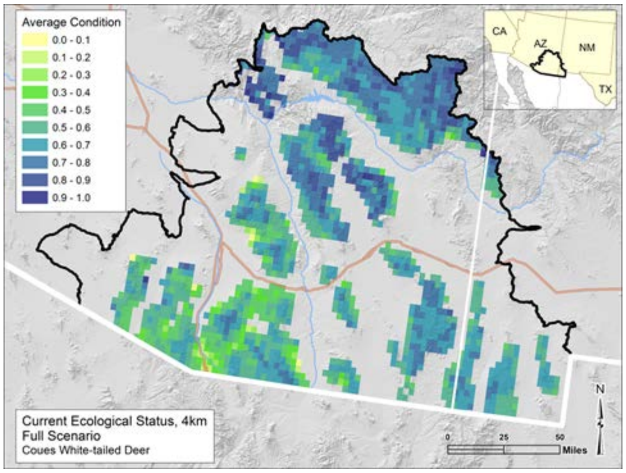
The ecological status scores for desert box turtle habitat lie largely in the middle range, from 0.4 to 0.7. Based on the indicators assessed in this REA, altered fire regime and encroachment by native woody increasers are the most widespread change agents present in desert box turtle habitat.

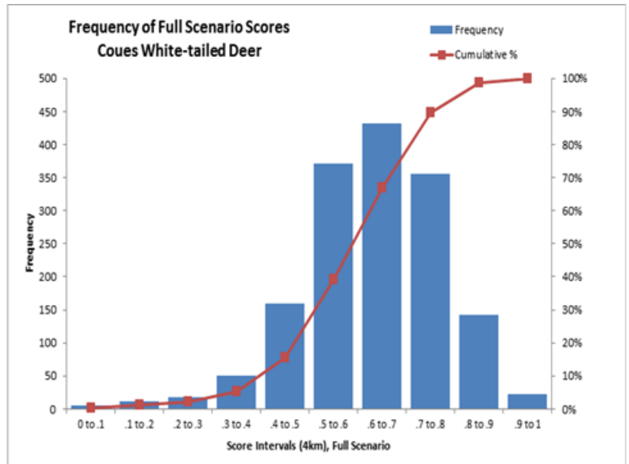
The results for Chiricahua leopard frog show a spread of ecological status scores. Water use, recent burns, and development features are the main variables affecting the status of its habitat; invasive species such as bullfrog directly affect the leopard frog. However, it should be noted that the distribution for this CE was represented by selecting all of the 6th-level watersheds having any overlap with any of the recovery units identified in the USFWS Chiricahua Leopard Frog (*Lithobates chiricahuensis*) Recovery Plan (USFWS 2007); consequently, the distribution mapped for this REA is much more extensive than its current actual distribution. The use of the 6th-level watersheds provides a watershed-based (e.g., accounts for downstream effects of upstream stressors) and landscape-scale evaluation of potential stressors upon possible reintroduction locations, known critical habitat, or management zones for the species. Relative to each other, the scores by watershed might suggest areas with higher degrees of development or water use impacts which could be addressed through mitigation efforts; alternatively they suggest areas with fewer impacts where protection from development activities could be prioritized.

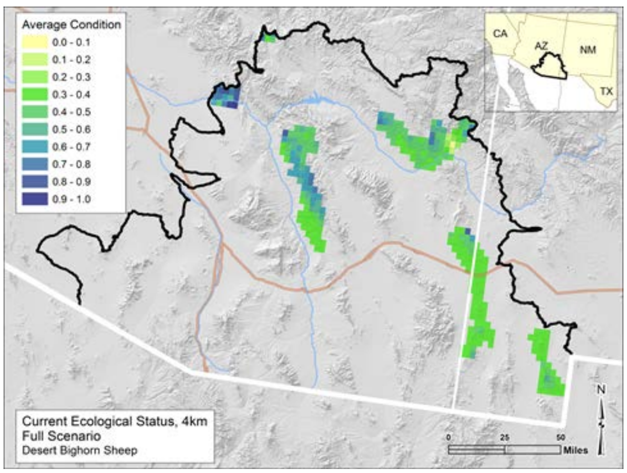
The results for both of the species assemblages, grassland birds and necter-feeding bats, indicate that large portions of their habitat distributions are impacted by altered fire regimes and invasives species. Approximately 80% of the expected distribution of the grassland bird assemblage has status scores between 0.4 and 0.7, while 70% of the bat assemblage distribution is within that range. Altered fire regimes and invasives species are both known to affect the condition of grassland habitat on which these species rely. The results for the nectar-feeding bat assemblage assessment are discussed further in the case study below.

Figure 4-19. **Overall ecological status scores for the three ungulate species CEs illustrated in maps (left) and graphs of frequency distribution (right).** Maps show the ecological status scores **for each 4km reporting unit**, which is an average of status scores for all 30m pixels of the CE's distribution. Maps show only those reporting units containing habitat for these CEs. Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of grid cells in each interval (left) and the cumulative percentage of the grid cells for each interval (right).




Average Condition
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
Current Ecological Status, 4km
Full Scenario
Coues White-tailed Deer
0
25
50
Miles
N


Frequency of Full Scenario Scores
Coues White-tailed Deer
Frequency
Cumulative %
Frequency
Score Intervals (4km), Full Scenario
0 to .1
.1 to .2
.2 to .3
.3 to .4
.4 to .5
.5 to .6
.6 to .7
.7 to .8
.8 to .9
.9 to 1


Average Condition
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
Current Ecological Status, 4km
Full Scenario
Desert Bighorn Sheep
0
25
50
Miles
N

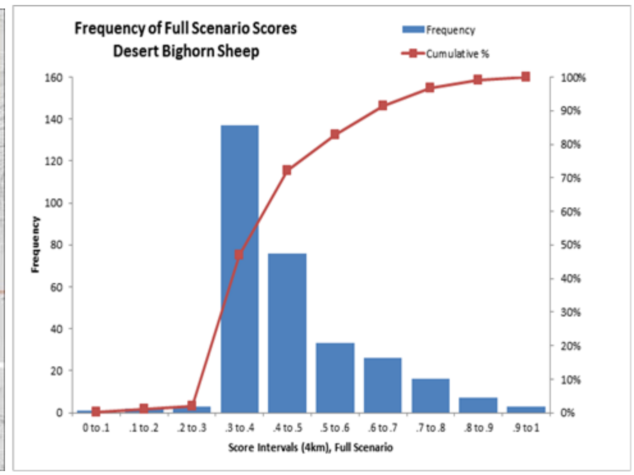

Frequency of Full Scenario Scores
Desert Bighorn Sheep
Frequency
Cumulative %
Frequency
Score Intervals (4km), Full Scenario
0 to .1
.1 to .2
.2 to .3
.3 to .4
.4 to .5
.5 to .6
.6 to .7
.7 to .8
.8 to .9
.9 to 1

Figure 4-20. **Overall ecological status scores for the box turtle and leopard frog CEs illustrated in maps (left) and graphs of frequency distribution (right).** Maps show the ecological status scores **for each 4km reporting unit** (box turtle) or **for each 6th-level watershed** (leopard frog), which is an average of status scores within each reporting unit or watershed for all 30m pixels of the CE's distribution. Maps show only those reporting units or watersheds containing habitat for these CEs. Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of grid cells in each interval (left) and the cumulative percentage of the grid cells for each interval (right).

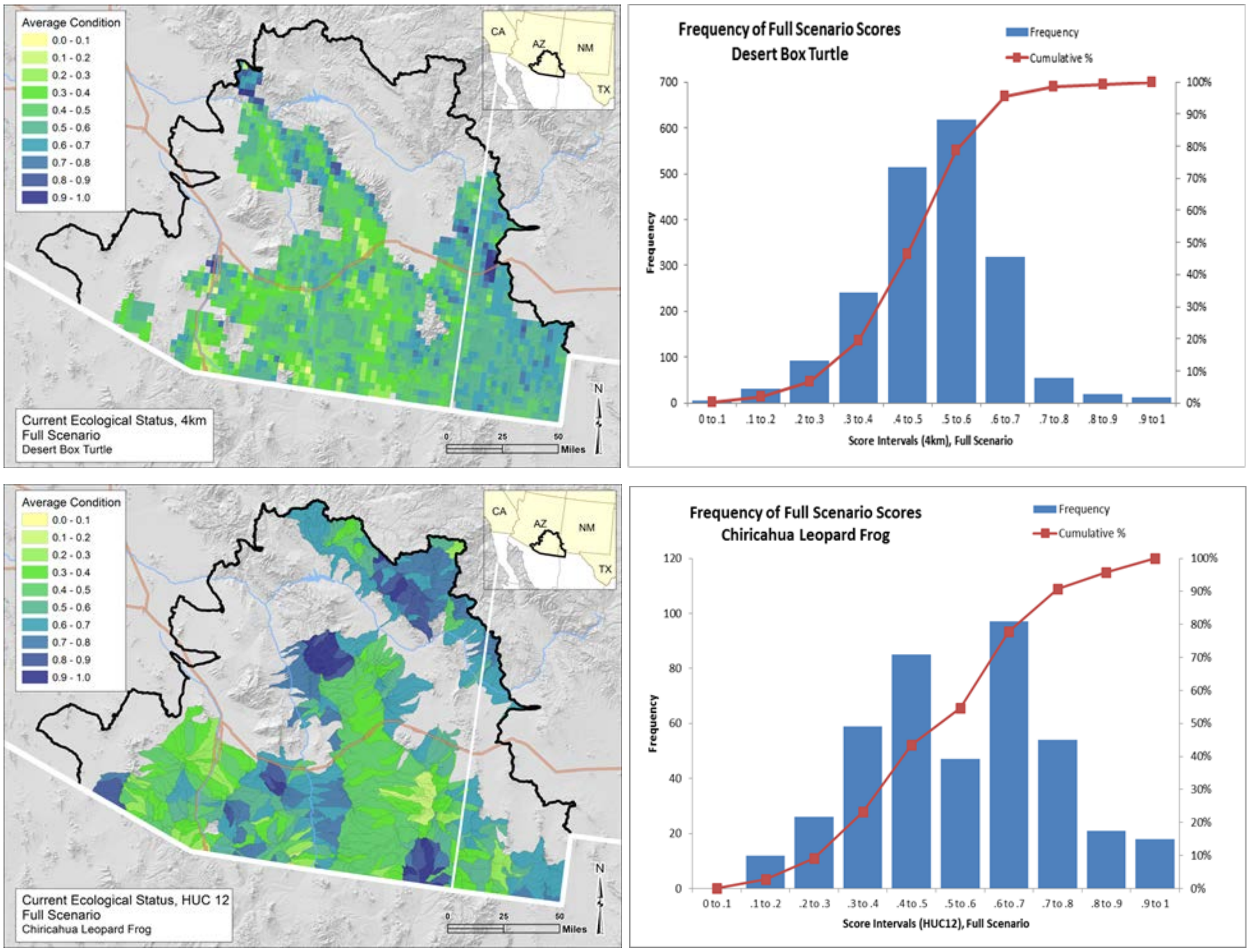
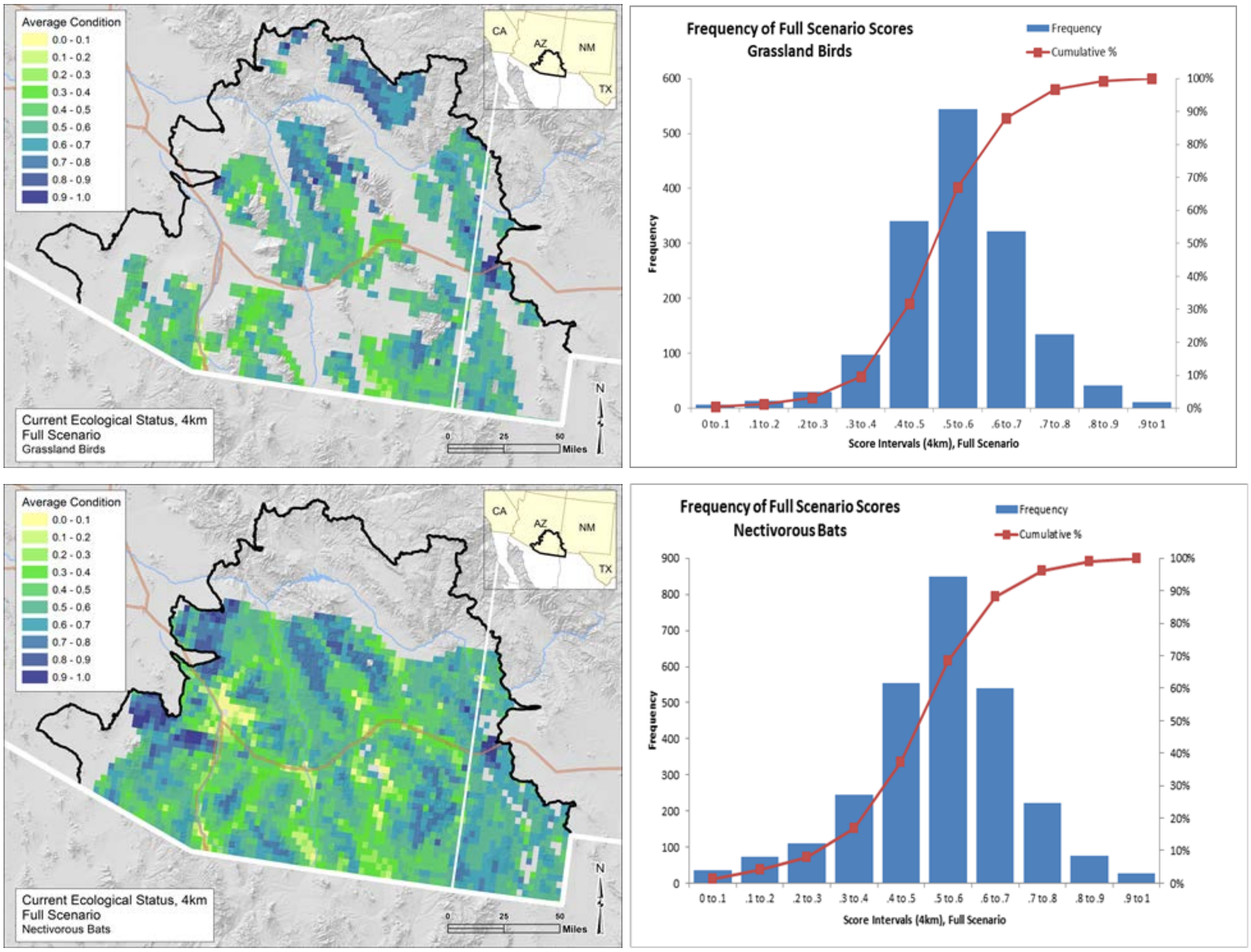


Figure 4-21. **Overall ecological status scores for the two species assemblage CEs illustrated in maps (left) and graphs of frequency distribution (right).** Maps show the ecological status scores **for each 4km reporting unit**, which is an average of status scores for all 30m pixels of the CE's distribution. Maps show only those reporting units containing habitat for these CEs. Companion graphs indicate the frequency distribution of ecological status scores for the CE. The x-axis represents the 0.1 increment scoring intervals, while the y-axis shows the number of grid cells in each interval (left) and the cumulative percentage of the grid cells for each interval (right).



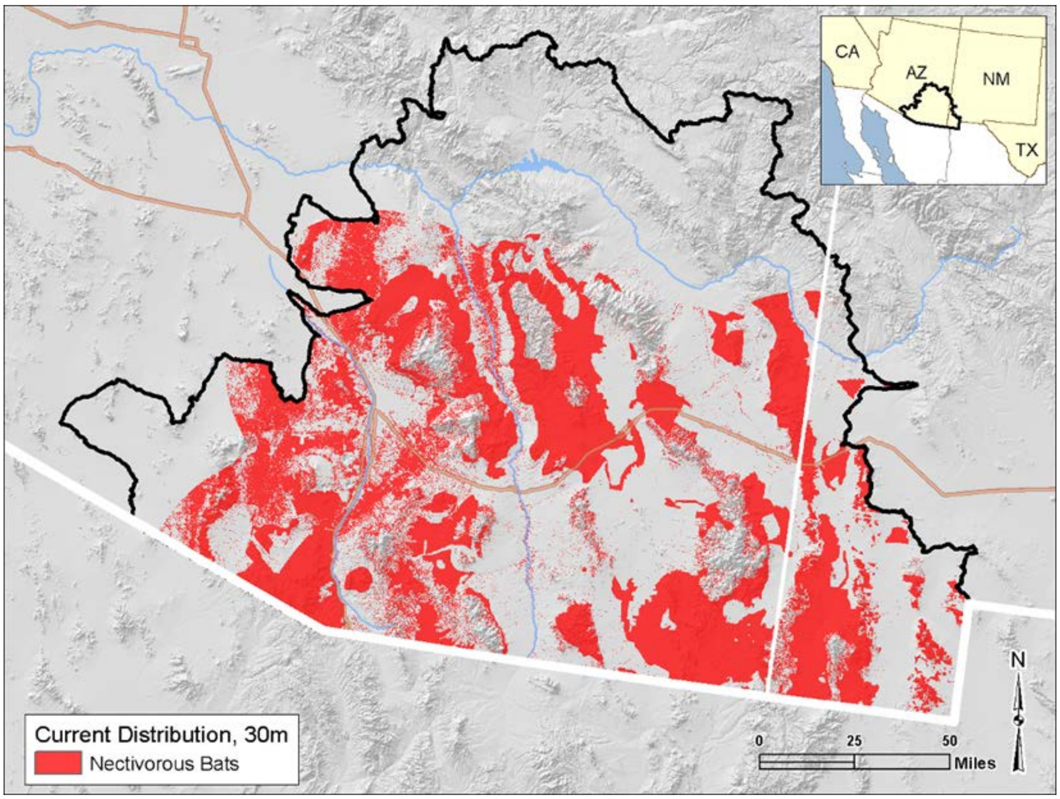
4.2.3.1 Species Case Study: Nectar-Feeding Bats

4.2.3.1.1 Description

Three species of nectar-feeding bats comprise this species assemblage: the lesser long-nosed bat (*Leptonycteris yerbabuenae*), the Mexican long-nosed bat (*Leptonycteris nivalis*), and the Mexican long-tongued bat (*Choeronycteris mexicana*). All three species are members of the family Phyllostomidae, which comprises mostly tropical species. Broadly, the geographic range of these species is centered in Mexico, extending north into parts of the extreme southwestern and western US along the US-Mexico border, and south into parts of Central America; the Madrean Archipelago ecoregion lies along the northerly portion of their range (AZGFD 2006, Arroyo-Cabrales et al. 1987, Cole and Wilson 2006, Frey 2004, Ortega and Arita 2005).

A map (Figure 4-22) of the combined potential distribution of these three species within the Madrean ecoregion was generated for this REA using documented roost sites as focal points. To estimate the foraging habitat of these species, all documented roost sites in Arizona and New Mexico were buffered based on proximity to habitat (vegetation types) and elevation, using a radius between 25 and 50 miles. (The radius was selected to take into account nightly foraging distances as summarized in USFWS 2013, but is provided as a range to mask the location of roost sites being buffered). These areas were then intersected with the distributions of five ecosystems[6] and limestone soils (an indicator of agave habitat), which are assumed to support suitable habitat, to identify their potential distribution (see Appendix C for a detailed description of the distribution modeling for this assemblage).

Figure 4-22. Current modeled distribution of the nectivorous bat assemblage within the MAR.



4.2.3.1.2 Ecology and Dynamics

Habitat for the lesser long-nosed bat in general includes tropical deciduous forest, as well as semi-deciduous thorn scrub, oak-pine, and cloud forests (Arita 2005). In Arizona, the species uses palo verde/saguaro, semi-desert grassland, and oak woodland (AZGFD 2011). In the northern part of the range in the United States and northern Mexico, Mexican long-nosed bat habitat includes desert scrub, open conifer-oak woodlands, and pine forests, generally in arid areas where agave plants are present (USFWS 1994). According to AZDGF (2006), "…roost sites of Mexican long-tongued bats [in the U.S.

[6] The five ecosystems are 1) MAR Apacherian-Chihuahuan Semi-Desert Grassland and Steppe, 2) MAR Madrean Encinal, 3) Sonoron Palo-Verde Mixed Cacti, 4) MAR North America Warm Desert Riparian Woodland and Shrubland Mesquite Bosque and Stream, and 5) MAR North America Warm Desert Lower Montane Riparian Woodland and Shrubland and Stream

portion of their range] are commonly associated with mesic areas in oak-conifer woodlands or semi-desert grasslands," as well as pine-fir forests at higher elevations; they also appear to be associated with surface water and riparian vegetation.

These species rely on nectar from agave species and columnar cacti as a primary food source, as well as pollen and fruit; all three species migrate seasonally, tracking "nectar corridors" of blossoming plants north from Mexico into the United States each spring (Fleming 2012). They roost in caves or mines near foraging habitat in spring, summer, and fall, as well as in trees or man-made structures such as barns or porches; lesser long-nosed and Mexican long-nosed bats generally hibernate in colonies in caves or mines during the winter.

All three species begin foraging after sunset, or later in the evening, and continue through parts of the night. They may frequently alternate between foraging and roosting. These bats spend most of their time in roosts, which fulfill many critical roles, including protection from weather; protection from predators; cheaper thermoregulation; reduced commuting costs to foraging sites; improved mating opportunities; improved maternal care; and competition avoidance, since few other vertebrates make use of most bat roost sites (Arita 1993, Harvey et al. 2011).

4.2.3.1.3 Change Agents

Numerous change agents can affect nectar-feeding bat populations and habitat. Specific change agents that may affect this species assemblage are described in relation to the key ecological attributes for the bat assemblage, primarily habitat availability and habitat quality. Climate change is another change agent that may affect this assemblage into the future, especially as it influences fire regimes and the spread of invasive species into bat forgaging habitat. Because a large portion of the life histories of all three bat species are dependent on available roost sites and foraging habitat in Mexico, as well as seasonal migration habitat (e.g. the nectar corridor they follow), management actions taken within the U.S. portion of the Madrean ecoregion may have a limited effect on overall population numbers unless management actions supporting their populations and habitat are taken in Mexico as well.

Development-related Effects on Habitat [Roost and Foraging] Availability. Disturbance, vandalism, and outright killing of bats in roosting sites have probably detrimentally affected all three nectar-feeding species (USFWS 1994). Intentional closing of caves and mines due to human safety concerns, including installation of incompatible gates, has eliminated or greatly degraded some roost sites and could eliminate additional sites in the future. Illegal border activities and associated enforcement actions along the U.S.-Mexico border may disturb or destroy bat roosts, and damage or destroy vegetation and increase the risk of fire in bat foraging habitat (USFWS 2007b). Development of agricultural fields, roads, highways and expanding urban or exurban populations contribute to the overall loss of foraging habitat for the bats. If foraging habitat close to roost sites has been removed or otherwise altered so as to not have the necessary nectar species, the bats will need to fly increased distance to obtain food.

Change Agent Effects on Composition of Foraging Habitat. Human harvesting of agave species, livestock grazing, expansion of invasive species and changes to fire regime all contribute to the loss of forage plants for nectar-feeding bats. Mesquite has replaced many areas of native grasslands which have agave species as a component (Gori et al. 2012) and may lead to the loss of agaves (see NRCS 2014, ecological site description in the grassland case study above and Appendix D). Invasive grasses, such as the lovegrasses (*Eragrostis* spp.) have also been shown to result in the loss of agave species (Lindsay et al. 2010).

Fire and Climate Change Effects on Habitat Condition. Increased fire frequency and intensity, in conjunction with drought, is of concern in nectar-feeding bat habitat. While the Madrean ecoregion typically experiences periods of drought, climate change modeling shows that droughts will occur with higher temperatures and greater frequency, thus becoming more severe (USGCRP 2009). Droughts deplete soil moisture, stress vegetation, increase vegetation susceptibility to insect and disease infestations and associated die-off, and can result in intensified fires and degraded wildlife habitat (SWCCN 2008). Droughts are projected to increase in frequency in this ecoregion (as well as Arizona as a whole) (Heinz Center 2011, AZ CCAG 2006). The effect of climate change-induced drought on ecosystems and species will be cumulative with other human-induced impacts such as land use changes, invasive species, and habitat fragmentation.

Madrean ecosystems have undergone the same historical fire suppression and overgrazing as other parts of the southwest and are predicted to experience more frequent and intense wildfires under altered climate regimes due to increased fuel loading and increases in flammable invasive species (USCCSP 2009). Increased fire frequency and intensity can also be linked to climate change effects, including rising temperatures, spring snowpack reductions, changes in precipitation patterns, decreased soil moisture, and insect outbreaks that weaken trees and other vegetation (Heinz Center 2011b).

It is assumed that the effects of increased drought and increased frequency and intensity of fire will impact the grassland, woodland and other ecological systems supporting bat foraging and roosting habitats.

4.2.3.1.4 Key Ecological Attributes

A key ecological attribute of an ecological resource is a characteristic of the resource’s biology, ecology, or physical environment that is critical to the resource’s persistence in the face of both natural and human-caused disturbance. Alteration of such a characteristic beyond some critical range of variation will lead to the degradation or loss of the resource within decades or less. For a deeper explanation of key ecological attributes, see Appendix B, and for more details about KEAs and indicators for the species CEs, see Appendix F. The KEAs identified for assessment for this conservation element (see Table 3-3 in the previous section) are described below:

1) Habitat Availability: development within the bats’ modeled habitat distribution is the indicator measured for habitat availability; development activities directly remove foraging habitat and human activities in general can disrupt or even remove roost sites. Development in the vicinity of roost sties may also increase the foraging distances for the bats. In addition, because greater amounts of human development correlate to higher levels of human activities on the landscape, the presence and degree of development also provides a qualitative evaluation of disruption of the bats’ foraging or roosting behavior.
2) Condition of Foraging Habitat: the composition of foraging habitat was assessed using the invasive species indicator, which includes the cover of mesquite. Mesquite has replaced many areas of native grasslands which have agave species as a component (Gori et al. 2012) and may lead to the loss of agaves (see NRCS 2014, ecological site description in the grassland case study above and Appendix D). Invasive grasses, such as the lovegrasses (*Eragrostis* spp.) have also been shown to result in the loss of agave species (Lindsay et al. 2010). The effects of livestock grazing were not assessed.
3) Fire Regime: Although fire regime is not a KEA for this assemblage, it is a KEA for the ecological systems such as grassland and encinal which comprise the bats’ foraging habitat. Departure from historical fire regime is an indicator of the loss of natural disturbance dynamics that maintains composition of plant species, vegetation structure, and sustains ecological processes such as nutrient cycling in bat foraging habitat; therefore, it provides some indication of the state of bat foraging habitat and nectar corridors.

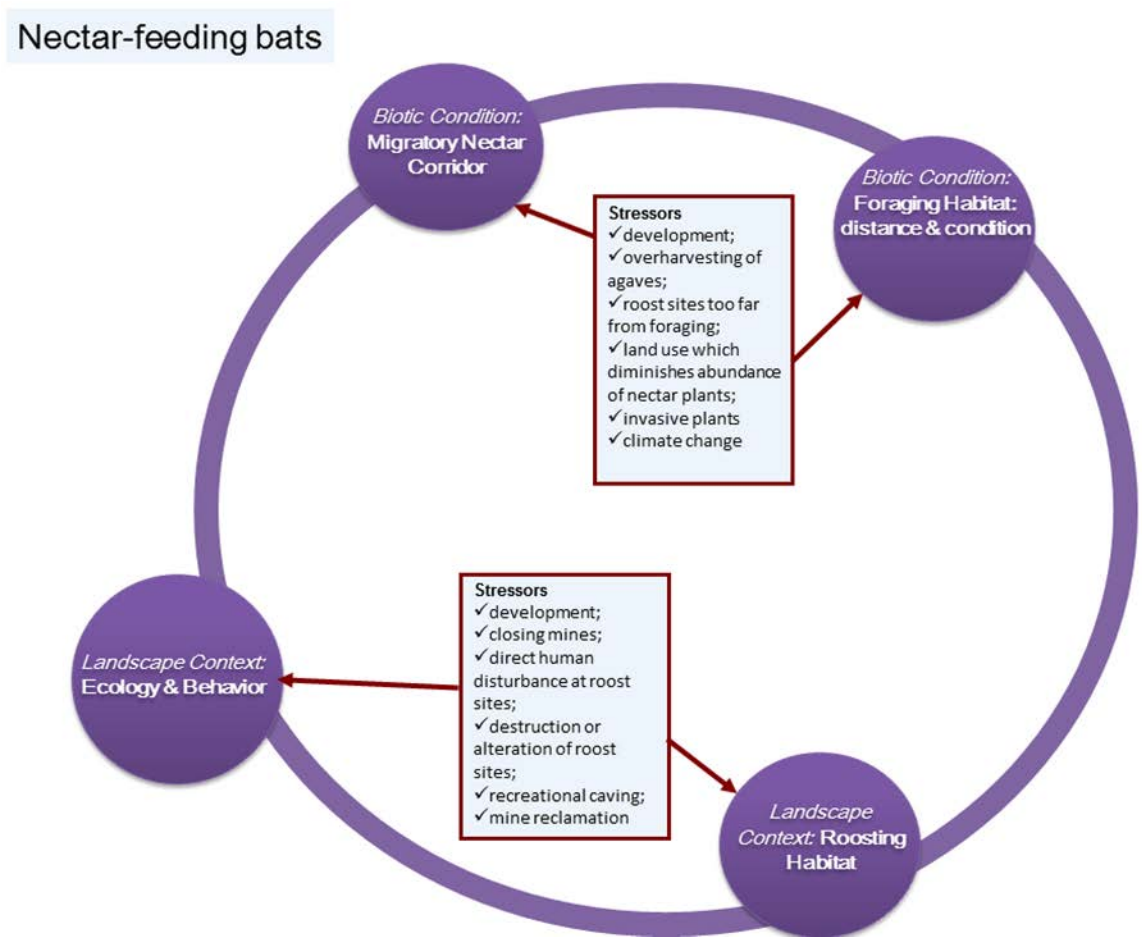
4.2.3.1.5 *Conceptual Model Illustration*

Below is the conceptual model diagram illustrating the relationships between the key ecological attributes of nectar-feeding bats and stressors that may affect their KEAs. The diagram indicates which of the key ecological attributes are affected by various stressors. For example, overharvesting of agaves is a source of stress since the bats are dependent on nectar corridors of agave and other plant species for foraging. This diagram is intended only as a general, conceptual overview and does not attempt to quantify these relationships.

Figure 4-23. Conceptual model diagram for nectar-feeding bats showing key ecological attributes (by KEA class) for these species, and stressors on the KEAs.

Inter-relationship between stressors and key ecological attributes

Key Ecological Attributes



4.2.3.1.6 *Individual Indicator Results*

As mentioned above, the status assessment for nectar-feeding bats focused on indicators of the KEAs for which adequate spatial data were available: 1) Development, 2) Invasives, and 3) Fire Regime Departure. All three indicators are indirect measures of ecological status.

Each of the three indicators is summarized separately, followed by a summary of overall ecological status, which integrates the results of all individual indicators assessed for this species assemblage. The results are presented using a common framework, in which the individual indicators, as well as the overall ecological status, are scored on a scale from 0.0 to 1.0, where 0.0 indicates a condition of complete replacement of reference ecological conditions due to the impacts of stressors, and 1.0 indicates a condition of no alteration of reference ecological conditions. The same yellow-to-blue color ramp is used for all results, with yellow representing low scores, green moderate scores, and dark blues high scores. The results of the assessments for the three individual indicators for the KEAs for the nectivorous bat assemblage are shown in the three maps in Figure 4-24 below.

Landscape Condition: Development Indicator

The development indicator results shown in the first map of Figure 4-24 reflect a number of discrete areas of development (yellows and greens on the map) across the bat assemblage's current distribution, particularly in the western portions of the distribution. These areas of lower scores for this indicator in part reflect a range of development features, including mines, municipalities, and other features. However, most of the bats' distribution in the MAR ecoregion is experiencing little or no impact (dark blue) from the development features reflected in this indicator. Where development is present, the primary impacts to bats include direct loss of grassland or other foraging habitat and potential increased disruption of roosting and other activities due to increased human presence. Transportation features are also visible in the map as networks of crisscrossing lines (yellows and greens) in otherwise blue areas on the map. These are important to note because of the potential for human access within bat habitat to be disruptive to bats. Grazing, as a land use, was not assessed.

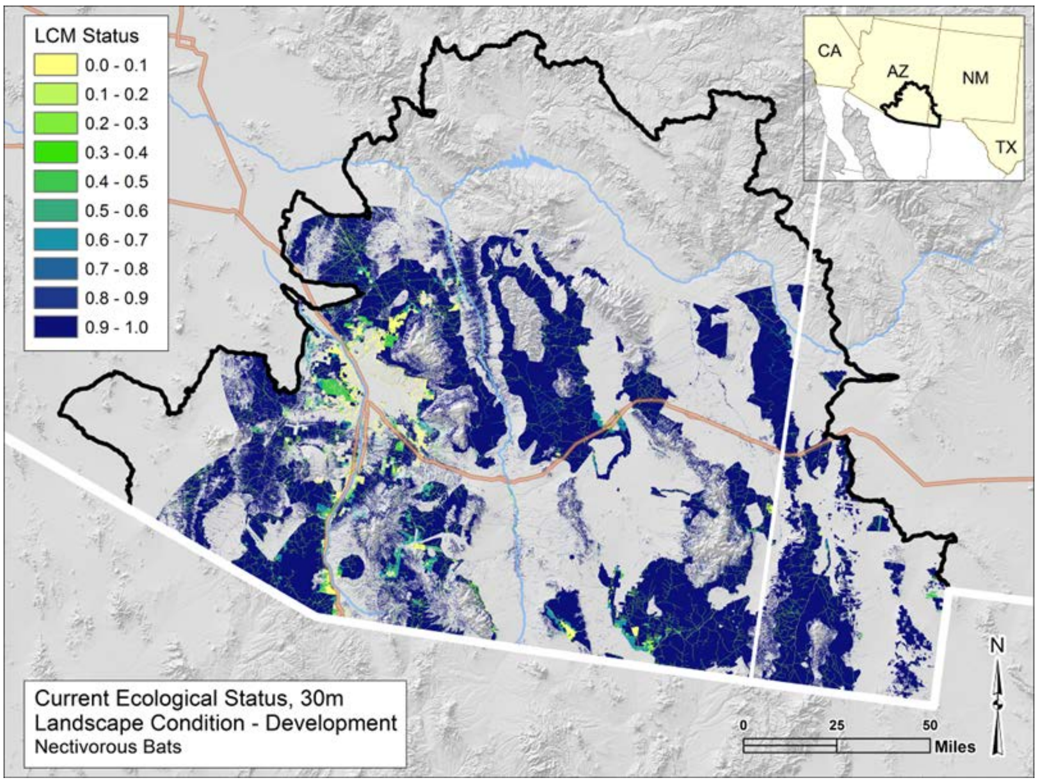
Fire Regime Departure Indicator

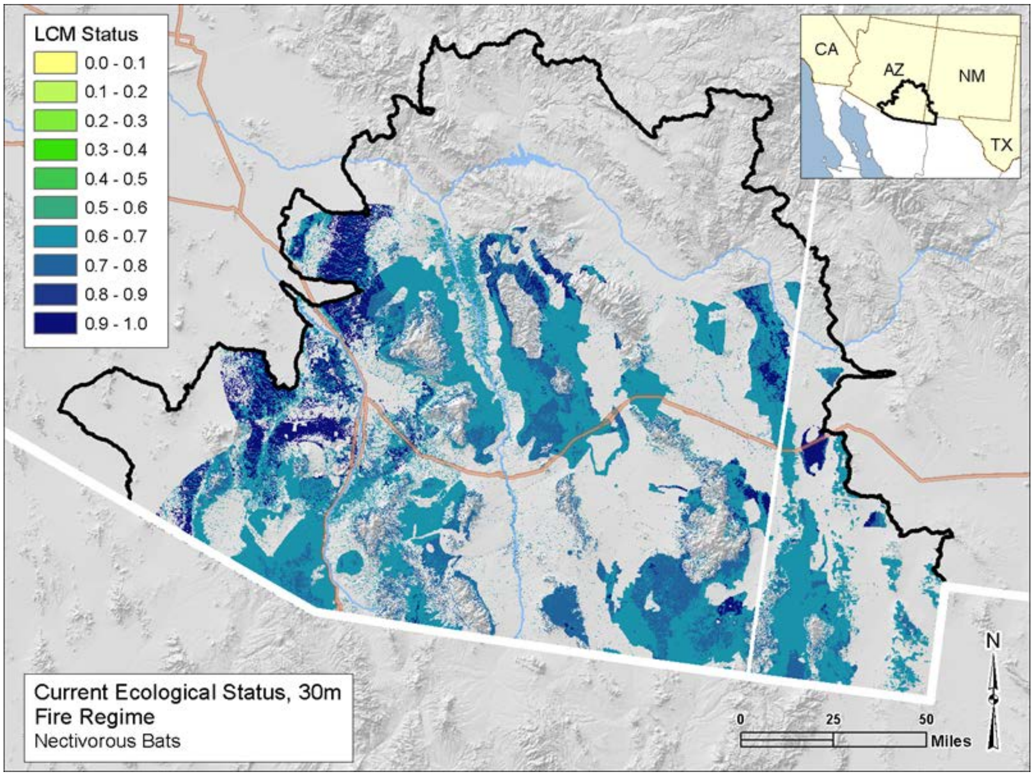
Fire is an important driver and key ecological attribute (KEA) for all of the ecological systems comprising foraging habitats utilized by this assemblage, and therefore the fire regime indicator was assessed in relation to the bat assemblage. It is based on the Vegetation Condition Class (VCC) dataset produced by Landfire, which was developed to compare historical reference conditions with current conditions for an individual ecological system type. The result of VCC is a ranking of departure from expected historical range of variability, which can be interpreted as "how has the disturbance regime [for the REA purposes and relevant to this ecoregion: fire regime] changed from its historical variability for this individual CE." Fire regime results, shown in the second map in Figure 4-24, indicate that fire regimes in the ecological systems present in the bat assemblage's distribution are largely split between severe ecological departure (scores of 0.65, shown in turquoise blue) and moderate ecological departure (scores of 0.75); very little of its distribution shows no departure in fire regimes. Alterations in floristic composition within the bat's distribution can occur due to fire. To the degree that fire is maintaining habitat supporting these species' nectar sources (*Agave* spp. and others), the altered fire regime is of concern for this assemblage. It may pose a threat of habitat destruction if unnaturally severe fires burn through the area.

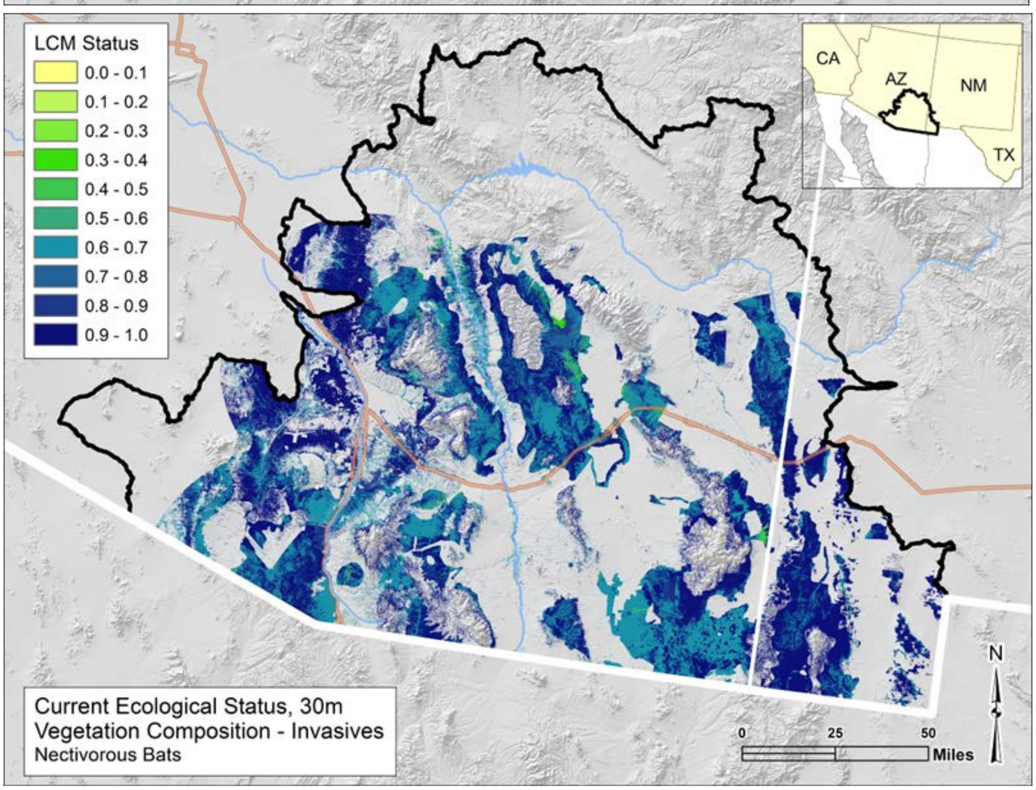
Invasive Species Indicator

The invasives results (third map in Figure 4-24) show that a fair amount of the bat assemblage distribution is impacted either by mesquite or by non-native grasses and forbs (turquoise blue color). In a few areas (greens), both groups of invasives are present at high cover. Most of the area showing invasive impacts has high cover of mesquite (rather than non-native grasses or forbs). Where grasslands that support agave and other forage species for the bats are experiencing significant mesquite encroachment or conversion to mesquite shrubland, there could be potential for loss of forage species.

Figure 4-24. Current scores for the three individual indicators for nectivorous bats: development (1st map), fire regime departure (2nd map), and invasive species (3rd map) for each 30m pixel. LCM Status = Landscape Condition Model Status of the indicator. Yellow (equivalent to 0) indicates high impacts from the CA, dark blue (equivalent to 1) indicates little to no impact from the CA. At the ecoregion scale, many development features are not readily visible (e.g., secondary roads or highways, railroads, small agricultural fields). Only 3 classes of fire regime condition are scored: no to little departure (dark blue), moderate departure and severe departure (lighter blues). For invasives, higher cover of mesquite or invasive exotics have scores between 0.4 and 0.6 (light greens), while lower cover has scores between 0.6 and 0.8 (light blues).




LCM Status
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
Current Ecological Status, 30m
Fire Regime
Nectivorous Bats
0
25
50
Miles
N

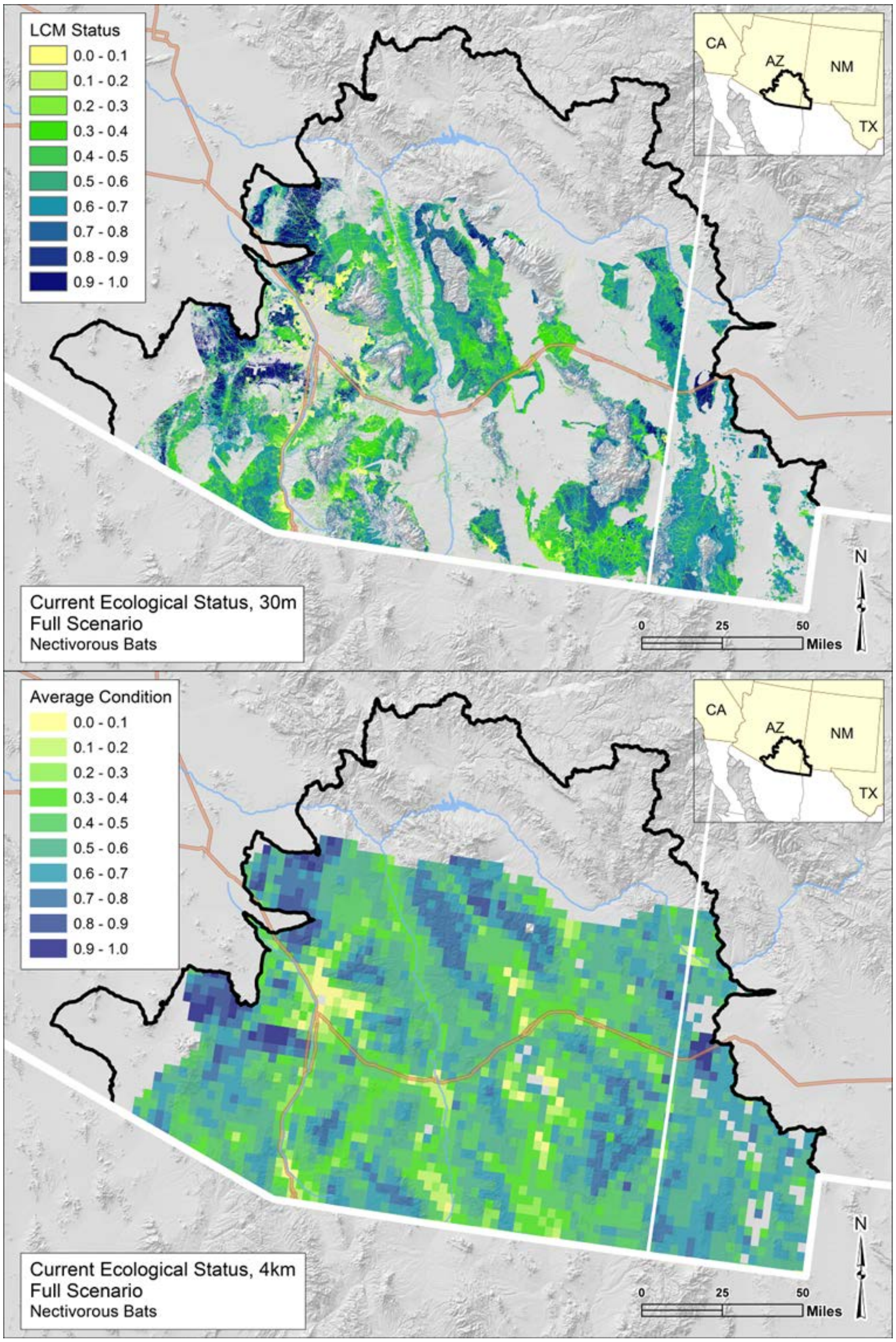

LCM Status
0.0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 0.9
0.9 - 1.0
CA
AZ
NM
TX
Current Ecological Status, 30m
Vegetation Composition - Invasives
Nectivorous Bats
0
25
50
Miles
N

4.2.3.1.7 Overall Ecological Status Assessment

The results of the three individual status indicators were combined for an overall ecological status score, per pixel of the CE's distribution, as shown in the first map of Figure 4-25 below. The overall ecological status scores for the CE were aggregated to 4 km reporting units by calculating the average of the CE pixel scores within each reporting unit, as shown in the second map of Figure 4-25 below.

When the three sets of indicator scores are aggregated to obtain the overall ecological status scores (as shown in the first map of Figure 4-25), much of the habitat for this species is in moderate condition, with values around 0.4, 0.5 and 0.6 in many areas, and some discrete areas as low as the 0.1 range (Figure 4-25). In visually comparing the maps of scores for the three individual indicators (Figure 4-24) to the map of the overall status scores (first map of Figure 4-25), the cumulative impacts of the change agents reflected by the indicators are clear. The altered fire regime and mesquite cover are both driving down scores in much of this CE's distribution, and scores drop even lower where development is also present. These same patterns are reflected when the overall status scores are averaged across each 4 km reporting unit, as shown in the second map of Figure 4-24 above. Based on the indicators assessed in this REA, changes in habitat quality from altered fire regime and encroachment by native woody increasers are having the most widespread effects on habitat quality for nectivorous bats. Development features are much more localized; depending on the type of development, the features may have contributed to direct habitat loss or degradation, as well as increased disruption of bat activities from increased human presence.

Figure 4-25. Current overall ecological status scores for the nectivorous bat assemblage for each 30m pixel (top) and 4km grid cells (bottom). LCM Status = Landscape Condition Model Status of the indicator. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs. In the second map, the score for each 4km cell is an average of the overall ecological status scores of the 30m pixels within the 4km cell that were scored for the CE. See Figure 4-21 for a histogram showing the frequency distribution of the 4km grid cell results.



4.2.3.1.8 Future Status and Risk

This CE was also assessed for ecological status for the 2025 timeframe, see section 4.4.1 2025 Risk Assessment below for those results. In addition, the distribution of this CE was compared to the climate change exposure index; those results are in section 4.3.5 Climate Trends and CEs. While climate change was not directly assessed for the bats assemblage, bioclimate envelope models projecting future climate change-induced stress were completed for two ecological systems very important to bat foraging habitat: the Apacherian-Chihuahuan Semi-desert Grassland and Steppe, and the Madrean Encinal (see section 4.3.6 Bioclimate Envelope Models below).

4.2.4 Ecoregion Ecological Integrity

Ecological integrity was assessed for five life zones: two for the aquatic realm (lowland and montane) and three for the uplands (desert, valley and montane). The desert scrub life zone has the largest amount of area within the MAR (Table 4-1), while the montane forest life zone is the smallest. An additional analysis looked at the change in extent of distribution for upland ecological systems, a comparison of historical distribution with current.

Table 4-1. Extent of the three upland life zones used for the MAR ecological integrity assessment. The area of the two aquatic life zones is not included, as those are based on the 5th-level watersheds and would add to 100% together. Any remaining area not included in these values for the uplands are developed area or agriculture, and very small in extent individual riparian or wetland ecological systems. Values calculated from the NatureServe (2013) map of terrestrial ecological systems.

Life Zone	Hectares	Acres	Percent of MAR
Desert Scrub Life Zone	**3,421,564**	**8,454,870**	**53.1%**
Valley Grassland Life Zone	**1,506,145**	**3,721,768**	**24.6%**
Montane Forest Life Zone	**880,471**	**2,175,692**	**14.0%**

For the five life zones, the results for the ecological integrity assessment of the ecoregion show similar patterns to those for the CEs. In general, the higher elevation regions have better ecological integrity, a result of less development and fewer invasive species, although fire regime departure is significant in all of the upland life zones. The Desert Scrub life zone has poor to moderate ecological integrity for much of its distribution, a result of fire regime alterations and proximity to heavily developed areas. In contrast, much of the Montane Forest life zone has moderate to good ecological integrity; there is much less development or invasives species at higher elevations. However, altered fire regimes are a real issue throughout much of the montane zone. The Valley Grassland life zone has low ecological integrity across much of its distribution. This life zone suffers from effects of all three indicators – substantial development impacts, problems with invasive species including mesquite, and moderately to severely altered fire regimes. Water use and development significantly reduce the ecological integrity of the Aquatic Lowland life zone, whereas the Aquatic Montane life zone has much better integrity based on this assessment.

4.2.4.1 Ecological Integrity for the Uplands of the Ecoregion

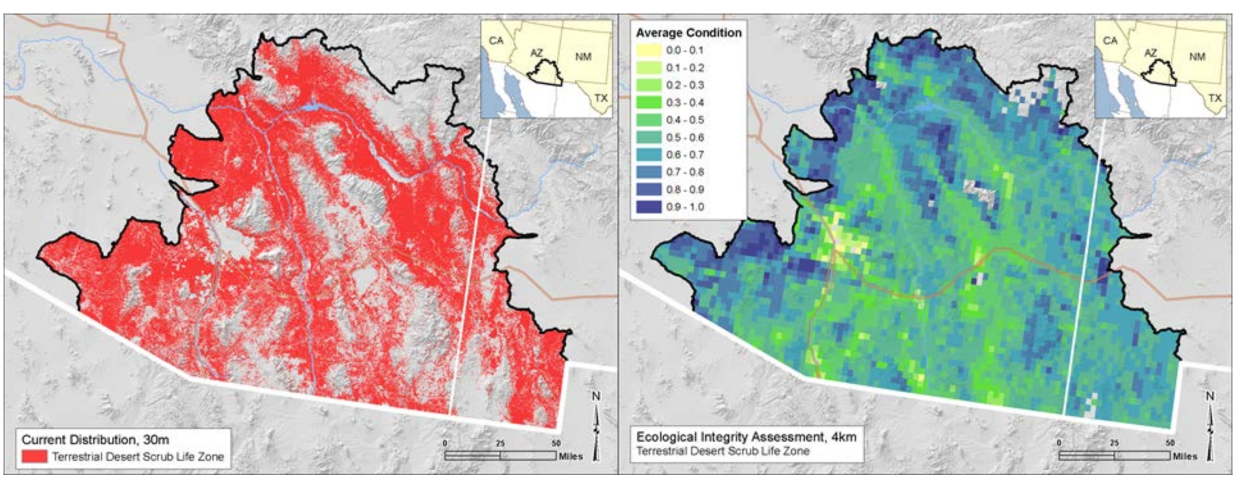
4.2.4.1.1 Terrestrial Desert Scrub Life Zone

The Terrestrial Desert Scrub life zone is composed of thirteen ecological systems and is dominated by three matrix systems: Apacherian-Chihuahuan Mesquite Upland Scrub, Chihuahuan Creosotebush Desert Scrub, and Sonoran Paloverde-Mixed Cacti Desert Scrub, which comprise over 40% of the Madrean Archipelago. The group of desert scrub ecological systems composing this life zone is adapted to the hot, dry climate, periodic drought, and poorly developed soils. Systems' stands occur on sand, saline or alkaline clays, gravelly loams, and rock outcrops, commonly at lower elevation sites, especially valleys and plains. The vegetation is typically open, with large spaces between shrubs and sparse herbaceous cover. The soil surface is mostly bare and sometimes a pebbly desert pavement may form. With such low vegetative cover, widespread fire was a relatively rare occurrence historically, and most of these communities are poorly adapted to fire. For example, one of the dominant plants, creosotebush (*Larrea tridentata*), is fire sensitive because of its highly flammable, resinous leaves and limited sprouting ability after burning, although it may survive lower intensity fires (Brown and Minnich 1986, Humphrey 1974, Marshall 1995, Paysen et al. 2000). Other plants, such as many of the cacti and other succulents, are eliminated by burning. A few shrubs such as mesquite (*Prosopis* spp.) sprout well following burning. Invasive species such as annual red brome (*Bromus rubens*) are often abundant following wet years and pose a fire hazard by creating a continuous fuel layer (Beatley 1966). The perennial invasive buffelgrass (*Pennisetum ciliare*) is expanding into desert scrub areas and drastically changing the fire regime (Brenner and Kanda 2013).

The distribution of the Terrestrial Desert Scrub life zone throughout the MAR is shown on the left in Figure 4-26 (see methods). The results of the integrity assessment for this life zone are shown on the right in Figure 4-26**,** summarized to the 4km^2 reporting unit. These are results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each reporting unit.

The results indicate that the degradation of the Terrestrial Desert Scrub life zone in the ecoregion is concentrated near larger urban areas, along major transportation and infrastructure routes, and in agricultural areas. However, much of this life zone is in moderate to poor overall condition. The integrity scores for this life zone are largely driven by the patterns of development in the desert scrub areas. There are areas having better ecological integrity, especially in the western extent and around the periphery of the ecoregion, a result of low levels of development, low or no cover of invasive species, and moderate fire regime departure.

Figure 4-26. Distribution (left) and integrity assessment results (right) of the Terrestrial Desert Scrub life zone in the Madrean Archipelago ecoregional assessment area. The map on the left shows the combined distributions of 13 terrestrial ecological systems which comprise the distribution of this life zone. The map on the right illustrates integrity results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each 4km^2 grid cell. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.

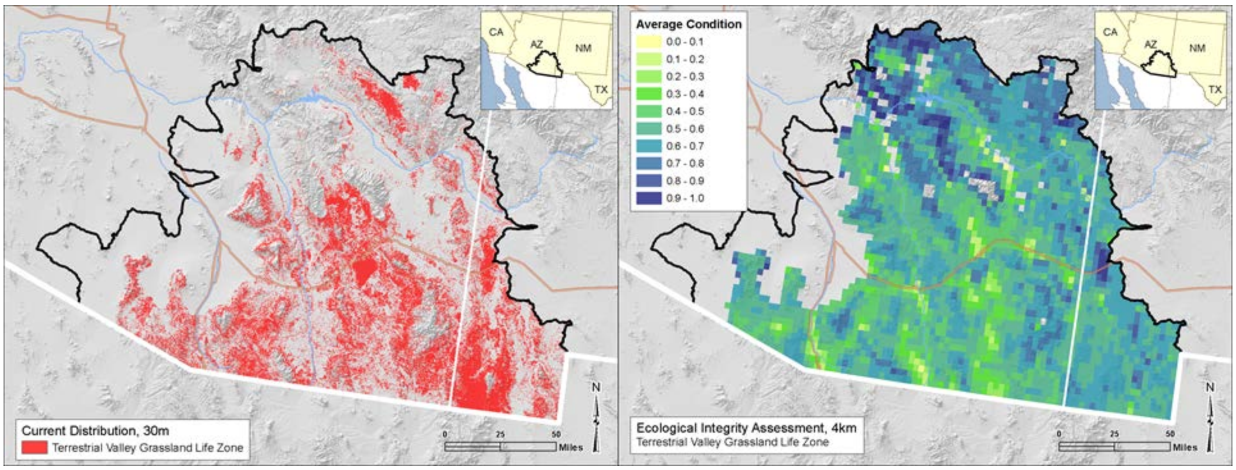


4.2.4.1.2 Terrestrial Valley Grassland Life Zone

The Terrestrial Valley Grassland life zone is composed of nine ecological systems and is dominated by the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe and Madrean Encinal, which comprise over 23% of the Madrean Archipelago. The semi-desert grassland, savanna, and shrub steppe ecological systems in this life zone are adapted to the hot, semi-arid clmate, and periodic drought. The vegetation is characterized by a moderate to dense perennial grass layer with or without scattered shrubs and trees. The life zone developed under a fire regime of frequent fires (McPherson 1995, Schussman 2006a, Schussman 2006b). These frequent fires (fire return intervals of 2.5 to 10 years) maintained these open grasslands with low shrub and tree cover (Brown and Archer 1999, McPherson 1995, Robinett 1994, Wright 1980). Active and passive fire suppression over the last century has excluded fire from much of this life zone (Gori and Enquist 2003, Schussman 2006a, Schussman 2006b). This fire exclusion has allowed increased woody species cover and resulted in an uncharacteristic fire regime in many stands (Barton 1999, Gori and Enquist 2003, Muldavin et al. 2002, Turner et al. 2003). This altered (uncharacteristic) fire regime greatly influences ecosystem processes, resulting in grasslands becoming dominated by woody vegetation and eventually converted to shrublands or woodlands. Conversion to juniper woodlands or mesquite or creosotebush shrublands is common when trees or shrubs exceed 15% cover (Gori and Enquist 2003).

The distribution of this life zone (Figure 4-27**,** left map) is concentrated mainly in the southern half of the ecoregion with two additional large areas northeast of the Gila Mountains. The results of the integrity assessment for this life zone are shown on the right in Figure 4-27**,** summarized to the 4km^2 reporting unit. These are results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each grid cell. The results indicate that degradation of the Terrestrial Valley Grassland life zone in the ecoregion is concentrated near agriculture and urban areas such as Sulfur Springs Valley near Willcox, Fort Huachuca/Sierra Vista area, Sonoita and San Bernardino Valley. The integrity scores for this life zone are largely driven by the development indicator, but the fire regime is severely departed across it range and there is some effect from invasives in the southern areas. The areas of better ecological conditions occur in the boot heel of New Mexico, the Animas Valley west of Lordsburg, the large stands northwest of the Gila Mountains and scattered smaller patches in the higher elevation, less disturbed foothill zone.

Figure 4-27. Distribution (left) and integrity assessment results (right) of the Terrestrial Valley Grassland life zone in the Madrean Archipelago ecoregional assessment area. The map on the left shows the distributions of 9 terrestrial ecological systems which were combined to create the the distribution of this life zone. The map on the right illustrates results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each 4km^2 grid cell. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.



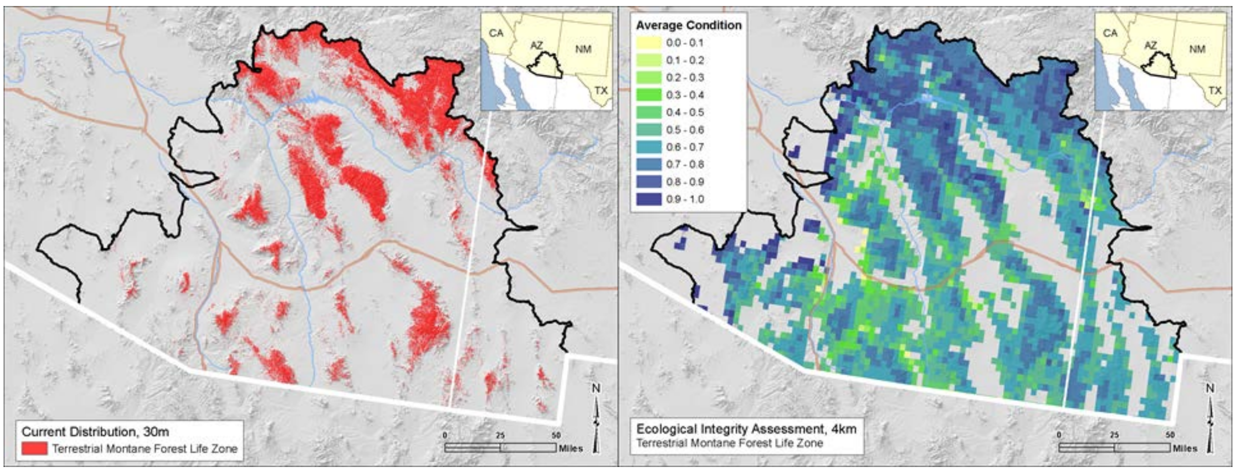
4.2.4.1.3 Terrestrial Montane Forest Life Zone

The Terrestrial Montane Forest life zone is composed of sixteen ecological systems and is dominated by two systems: Madrean Pinyon-Juniper Woodland and Mogollon Chaparral that comprise over 10% of the MAR. There are also significant amounts of Madrean Lower Montane Pine-Oak Forest and Woodland and Southern Rocky Mountain Ponderosa Pine Woodland. The remaining components tend to occur in small patches or are restricted to higher elevation mountains.

This montane life zone includes forest, woodland, shrubland, grassland, and sparsely-vegetated, substrate-driven ecological systems. The vegetation is characterized by open to dense tree and/or shrub layers with a variable perennial grass layer. Historic fire regimes for the systems in this life zone are variable. Mean fire return intervals range from 20-80 years for much of the systems with the more open pine savanna and oak-pine woodland types having more frequent low-severity surface fires that are carried by the herbaceous layer. Other montane systems, especially the sparsely-vegetated and higher elevation forests and chaparral types burned less frequently. Active and passive fire suppression over the last century has excluded fire from much of this life zone (Gori and Bate 2007). In the absence of disturbance such as fire, the woody component increased in density over time and subsequent fires became more severe (Gori and Bate 2007, Swetnam and Baisan 1996, Turner et al. 2003).

The distribution of this life zone (Figure 4-28**,** left map) is concentrated at upper elevation sites in the Sky Island ranges and the northern half of the MAR. The results of the integrity assessment for this life zone are shown on the right in Figure 4-28**,** summarized to the 4km^2 reporting unit. These are results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each reporting unit. The results (Figure 4-28) indicate a general degradation of the Terrestrial Montane Forest life zone in the southern portion of the MAR ecoregion primarily from severely altered fire regimes. There are local areas of severe degradation driven by poor landscape condition such as in the historic mining district of Bisbee in the Mule Mountains and development in the Santa Catalina Mountains north of Tucson. The mountains in the northern portion of the ecoregion including the northern sky island ranges (Galiuro, Gila and Pinaleno mountains) are in the best ecological condition with only moderate fire regime departure and apparently good landscape condition and low impacts from invasives.

Figure 4-28. Distribution (left) and integrity assessment results (right) of the Terrestrial Montane Forest life zone in the Madrean Archipelago ecoregional assessment area. The map on the left shows the distributions of 16 terrestrial ecological systems which were combined to create the the distribution of this life zone. The map on the right illustrates the results for all three indicators: development, fire regime departure, and invasive species, which were combined into a single ecological integrity score for each 4km^2 grid cell. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.



4.2.4.2 Change in Extent of the Uplands in MAR

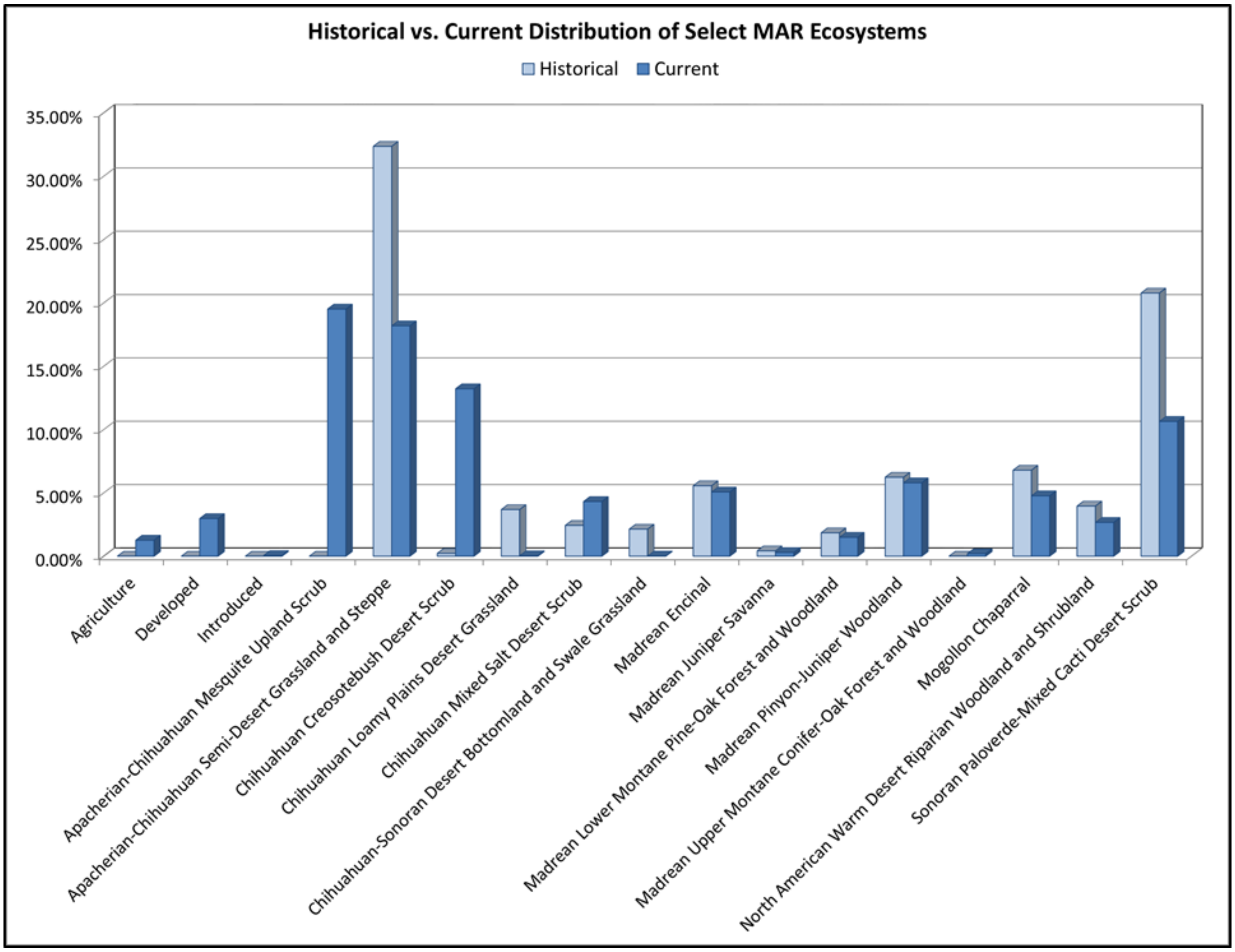
Change in extent was conducted for the uplands life zones; aquatic life zones were not included because the mapping of their historical distributions was not available. The results of the change in extent analysis from historical (pre-European settlement, as modeled by Landfire) to current (circa 2000) area of select terrestrial ecological systems for the ecoregion (Figure 4-29) show some conversion from natural vegetation due to increases in post-European settlement (as a proportion of the ecoregion area) such as agriculture (to 1.3%), development (to 3%) and introduced vegetation (to 0.5%). However these changes are a relatively small percentage in extent when compared to changes due to shifts in ecosystem composition. Historical distribution for one riparian ecological system (the North American Warm Desert Riparian Woodland and Shrubland) was available in the Landfire dataset, so it was included in this change analysis.

Overall, the major changes in extent have occurred due to substantial increases in Mesquite Upland Scrub (0% to 20%) and Chihuahuan Creosotebush Desert Scrub (0.5% to 13%) with corresponding large declines in Apacherian-Chihuahuan Semi-desert Grassland and Steppe (32% to 18%), Chihuahuan Loamy Plains Desert Grasslands (4% to nearly 0%), Chihuahuan Bottomland and Swale Grassland (2% to nearly 0%), and Sonoran Paloverde-Mixed Cacti Desert Scrub (21% to 11%). The desertification and conversion of semi-desert grasslands to desert scrub is well documented and has occurred over the last century (McPherson and Weltzin 2000, Wilson et al. 2001). The decline in Sonoran Paloverde-Mixed Cacti Desert Scrub is largely due to urban expansion from Tuscon and surrounding areas and conversion to other desert scrub systems. There has also been a small but notable increase in Chihuahuan Mixed Salt Desert

Scrub and substantial decreases in Madrean Encinal, Mogollon Chaparral and North American Warm Desert Riparian Woodland and Shrubland. The net change in other, less abundant ecosystems such as Madrean Pinyon-Juniper Woodland appear relatively minor, but there may have been significant changes locally.

See Appendix G for further details on methods and results for individual 4th level watersheds.

Figure 4-29. Historical vs. current abundance of select terrestrial ecological systems for the entire MAR ecoregion. The y-axis presents the percent of the MAR study area of the mapped historical or current extent of each ecological system or land cover type. Historical distribution was derived from the Landfire biophysical settings map and current distribution from the NatureServe terrestrial ecological systems map (2013). Historical distribution for one riparian ecological system was available in the Landfire dataset, so it was included in this change analysis.



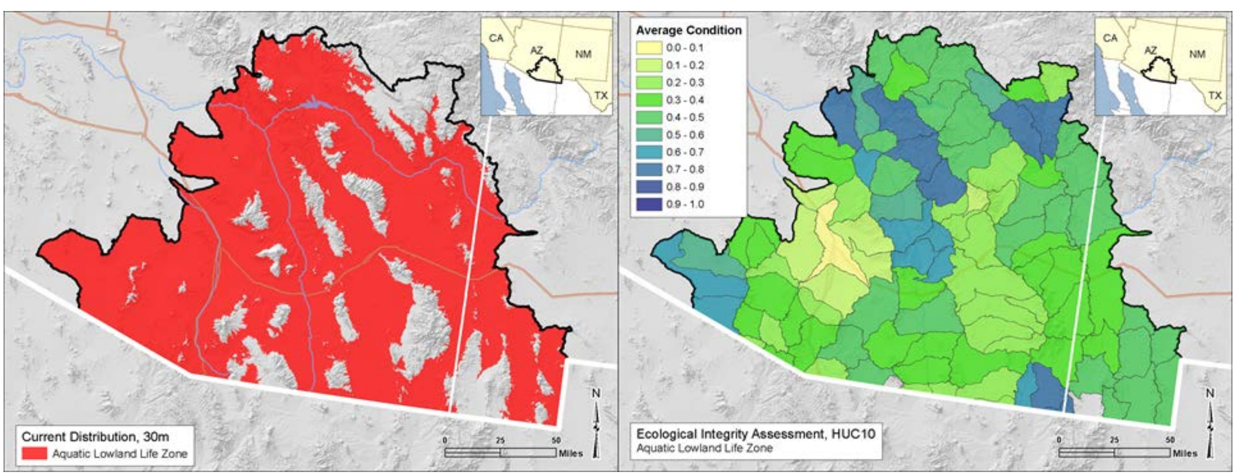
4.2.4.3 Ecological Integrity for the Aquatic and Wetland Resources of the Ecoregion

4.2.4.3.1 Aquatic Lowland Life Zone

The distribution of the Aquatic Lowland life zone (Figure 4-30, left) illustrates how much of the MAR ecoregion is at lower elevations (below 1,524 m or 5,000 ft). The ecological integrity scores for the Aquatic Lowland life zone are reported by the 5th-level watersheds (Figure 4-30, right) and take into account the stressor-based indicators of development, aquatic and terrestrial invasive species, and water use. The results show scores of 0.6 or less (on a 0.0-1.0 scale) for most of the watersheds; the majority of this lifezone is in moderate to poor condition.

Areas surrounding, and waters within, the Gila River downstream from the San Simon River confluence, most of the San Pedro River, and most of the Santa Cruz River south of Tucson show high levels of impact from development, water use, and invasive species. The most altered watersheds are located in the areas of of Safford, Willcox, and the Tucson metropolis, AZ. The least altered watersheds occur in the far west-southwestern corner of the ecoregion west and south of Sells, AZ; in the northern third of the lower San Pedro River basin; in the lower San Francisco River basin; and surrounding San Bernardino National Wildlife Refuge.

Figure 4-30. Distribution (left) and integrity assessment results (right) averaged by watershed of the Aquatic Lowland Life Zone in the Madrean Archipelago ecoregional assessment area. The distribution (left map, in red) shows areas below 1,524 m (5,000 ft) in elevation, and is intended to represent areas that contain any aquatic resource, such as rivers, riparian areas, ciénegas, washes, or marshes in this life zone. The results (right map) are for three indicators: development, invasive species and water use, combined into a single ecological integrity score for the low elevation portion of each 5th level watershed. While the entire watershed is displayed, only the low elevation portion of each watershed contributed to that watershed's score. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.

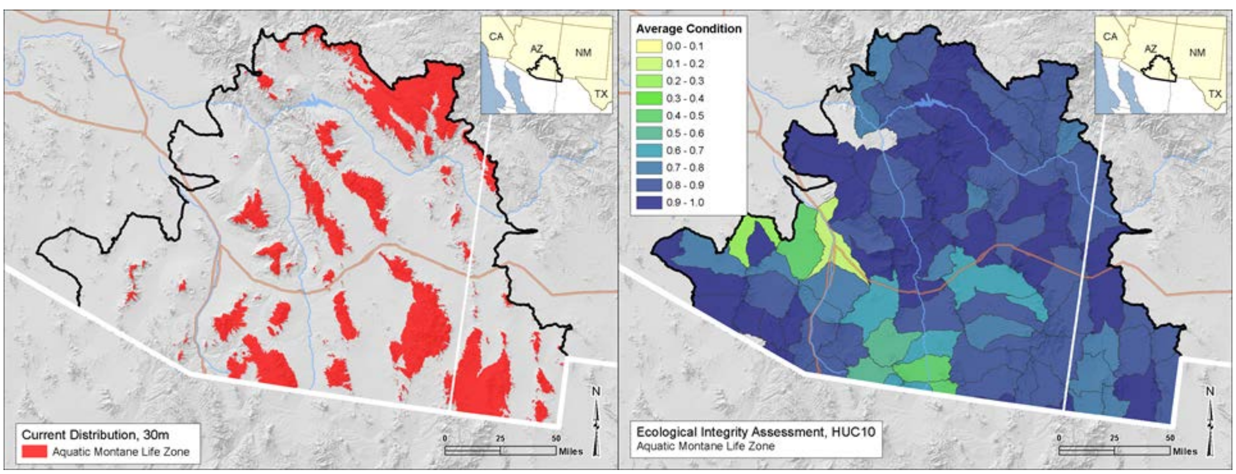


4.2.4.3.2 Aquatic Montane Life Zone

The distribution of the Aquatic Montane life zone (Figure 4-31, left) illustrates the areas of the MAR ecoregion at higher elevations (above 1524 m or 5,000 ft). The ecological integrity scores for the Aquatic Montane Life Zone are reported by the 5th-level watersheds (Figure 4-31**,** right) and take into account the stressor-based indicators for development and aquatic and terrestrial invasive species; the water use indicator was not assessed. While large areas of development are not found in this life zone, there are roads, mining, and associated dams and other water manipulation structures that play a role in the degradation of these habitats, along with invasive species. The two indicators used (landscape development) and invasive species (terrestrial plants, aquatic animals, and aquatic plants), when combined, show that the life zone integrity varies significantly across the ecoregion. This assessment illustrates that development is one of the most pervasive driving factors in the varying condition of the Aquatic Montane life zone across the ecoregion.

The southern central portion of the ecoregion has mining, transportation corridors, and towns (e.g. Warren, Bakerville, and Bisbee junction) that occur at similar elevations as this life zone. Compared to the lower elevation aquatic life zone (Figure 4-30**)**, the Aquatic Montane life zone is faring much better overall in the MAR, with more watersheds in better overall ecological integrity. These areas are not impacted by significant groundwater withdrawal and surface water diversions, nor are they as heavily exposed to development.

Figure 4-31. Distribution (left) and integrity assessment results (right) averaged by watershed of the Aquatic Montane life zone in the Madrean Archipelago ecoregional assessment area. The distribution (left map, in red) shows the areas above 1,524 m (5,000 ft) in elevation, and is intended to represent areas that contain any aquatic resource, such as such as headwater streams and tributaries, riparian areas, ciénegas, washes, or marshes in this life zone. The results (right map) are for two indicators: development and invasive species combined into a single ecological integrity score for the high elevation portion of each 5th level watershed. While the entire watershed is displayed, only the high elevation portion of each watershed contributed to that watershed's score. Yellow scores (equivalent to 0) indicate high impacts from the CAs, dark blue (equivalent to 1) indicate little to no impact from the CAs.



4.3 Climate Trends

4.3.1 Climate Change Exposure Index: Recent and Future

The recent and future climate change exposure indices combine the anomalies across all twelve months and all three core climate variables (minimum temperature, maximum temperature, and precipitation) presenting a spatially explicit measure of how much climate has recently deviated, and how much it is projected to deviate, from 20th century baseline conditions, including their observed range of variability.

According to recent trends (Figure 4-32), high elevations and mountainous areas are relatively stable; stability in minimum and maximum temperatures are contributing the most to these patterns. Decreases and increases in temperature have not deviated as much as low-lying areas when comparing the recent timeslice to the 80-year baseline. Precipitation is changing by a lesser magnitude than temperature and doesn't exhibit a clear spatial pattern.

Aggregated future trends show that mid-century climate is projected to be outside the range of historical variability across the entire MAR. The future climate change exposure index is more coarse (4km) than the recent trend analyses due to the spatial resolution of available future climate data. As a result, it does not capture the fine spatial patterns in microclimate that is reflected by the 800m recent trend analyses. However, relatively speaking, the northern MAR is projected to experience less overall climate change than the central and southern regions.

Figure 4-32. MAR current climate change exposure index (CCEI). This index combines the anomalies across all twelve months and all three core climate variables (minimum temperature, maximum temperature, and precipitation) presenting an overall measure of how much climate has recently deviated from historical variability. The CCEI is in units of standard deviation; yellow indicates areas of high exposure and blue areas indicate low to no exposure.

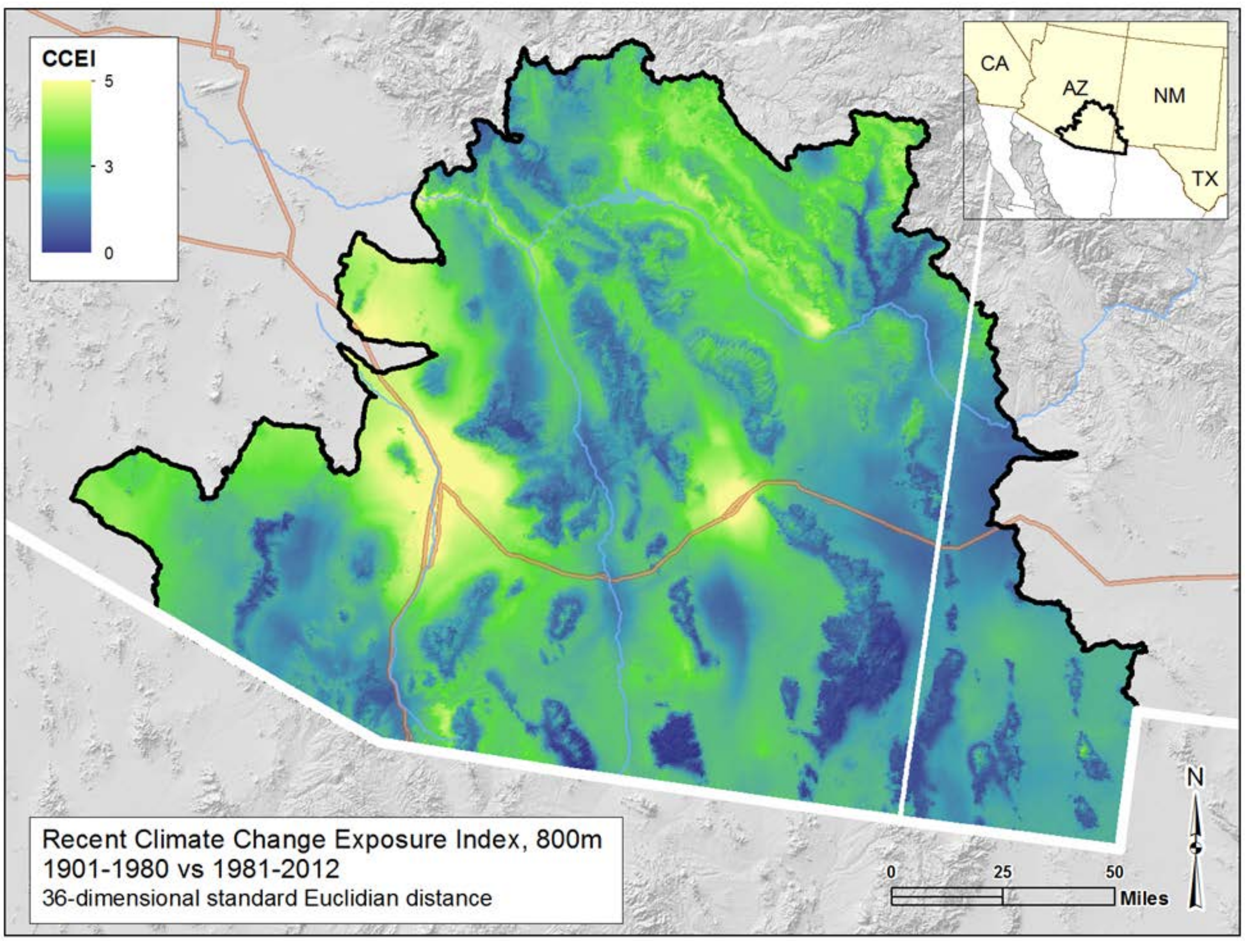


Figure 4-33. MAR projected future climate change exposure index, 1901-1980 vs. 2040-2069. This index combines the anomalies across all twelve months and all three core climate variables (minimum temperature, maximum temperature, and precipitation) presenting an overall measure of how much climate is projected to deviate in the future, from historical variablity. The CCEI is in units of standard deviation; yellow areas represent high exposure and blue areas represent low to no exposure. The scale for this figure is the same as the recent CCEI so comparisons can be made between them. For the future CCEI there are no blue areas, which indicate that by mid-century the entire region will experience notable climate departure.

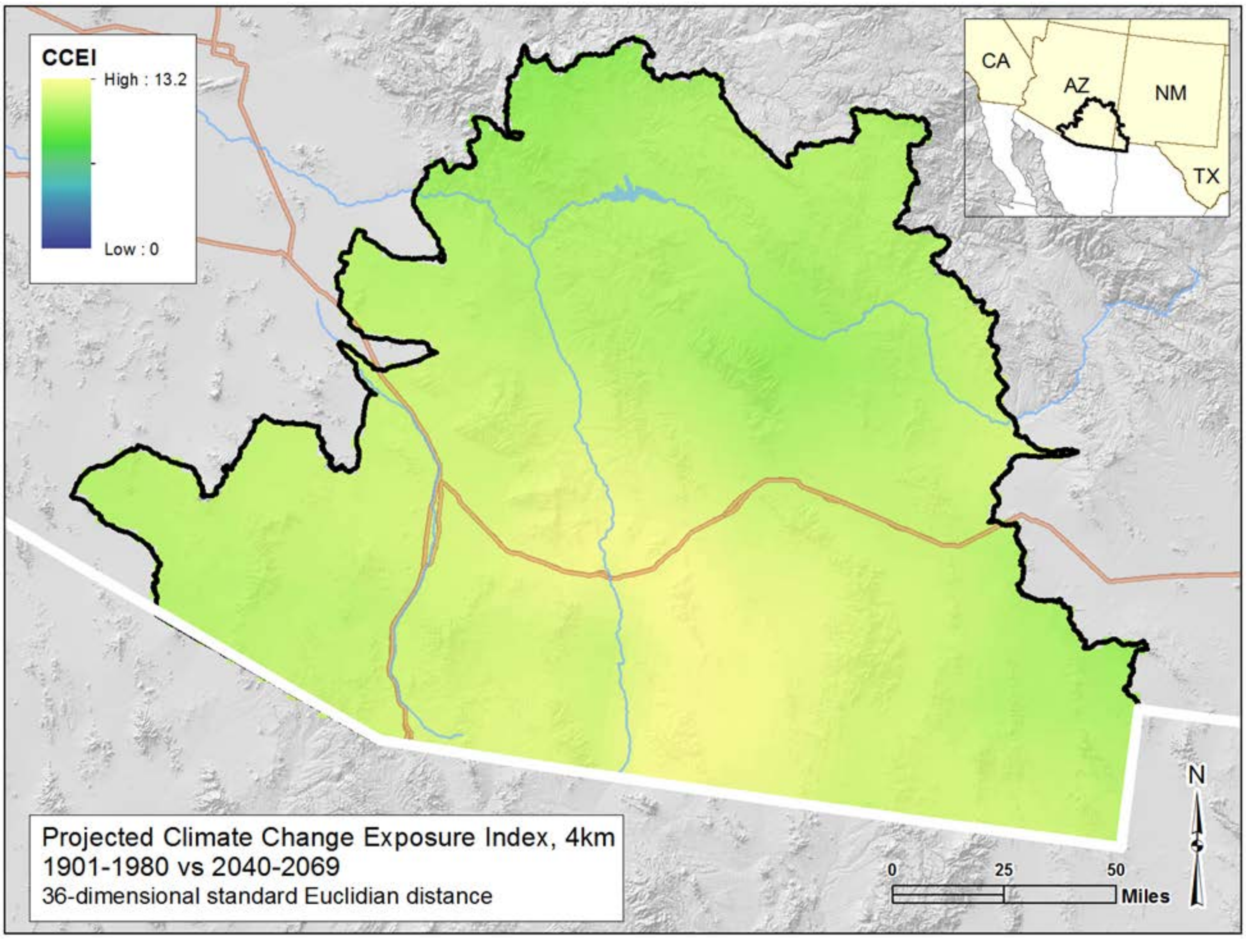
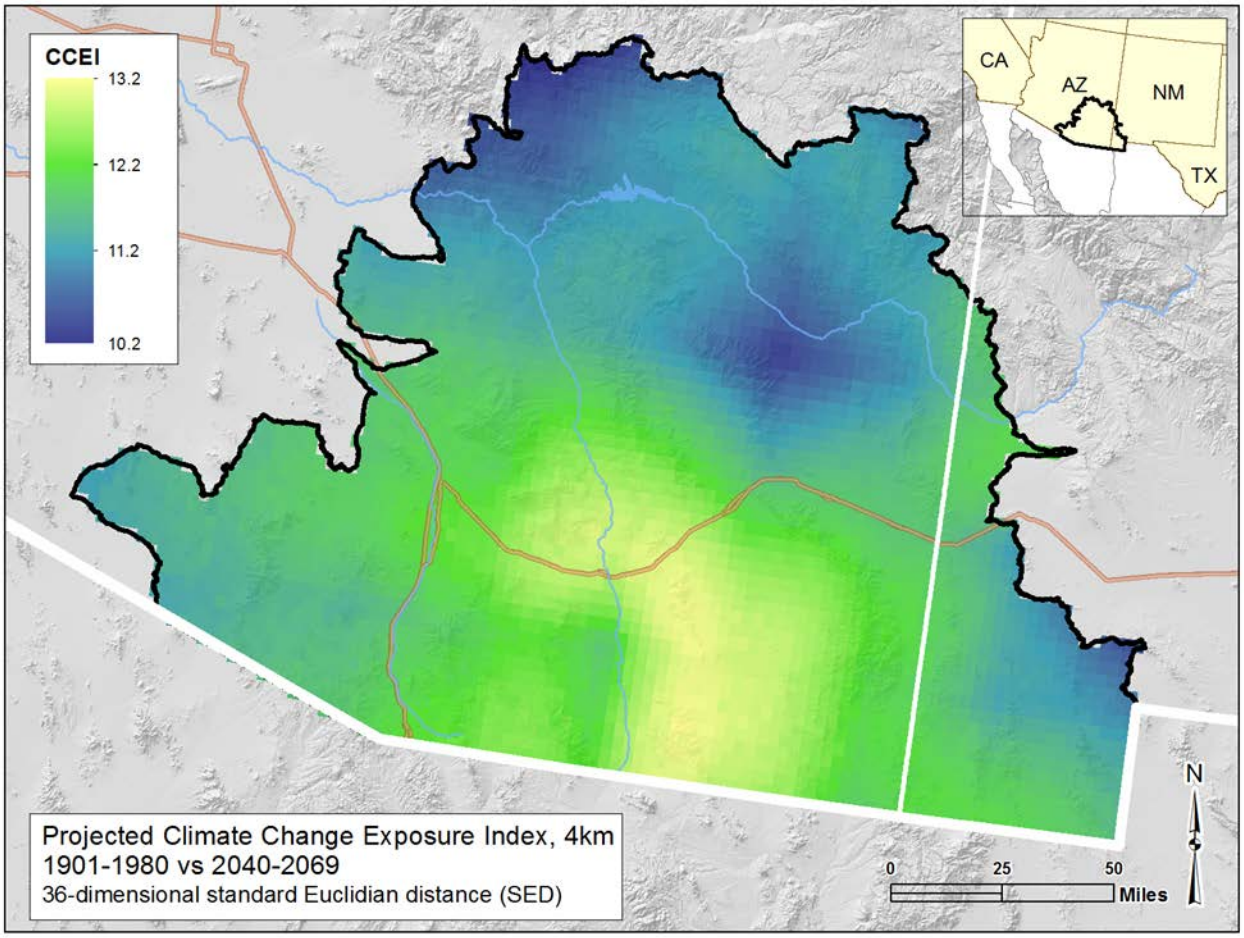


Figure 4-34. Climate Change Exposure Index (CCEI), observed values. This index is in units of standard deviation from the baseline mean. While possible values range from 0-13.2, all values for the future CCEI are greater than 10.2, representing significant changes across the entire ecoregion. In this map, only these observed values are shown, allowing for better visualization of differences across the ecoregion.



4.3.2 Recent Changes in Climate Compared to a 1901-1980 Baseline

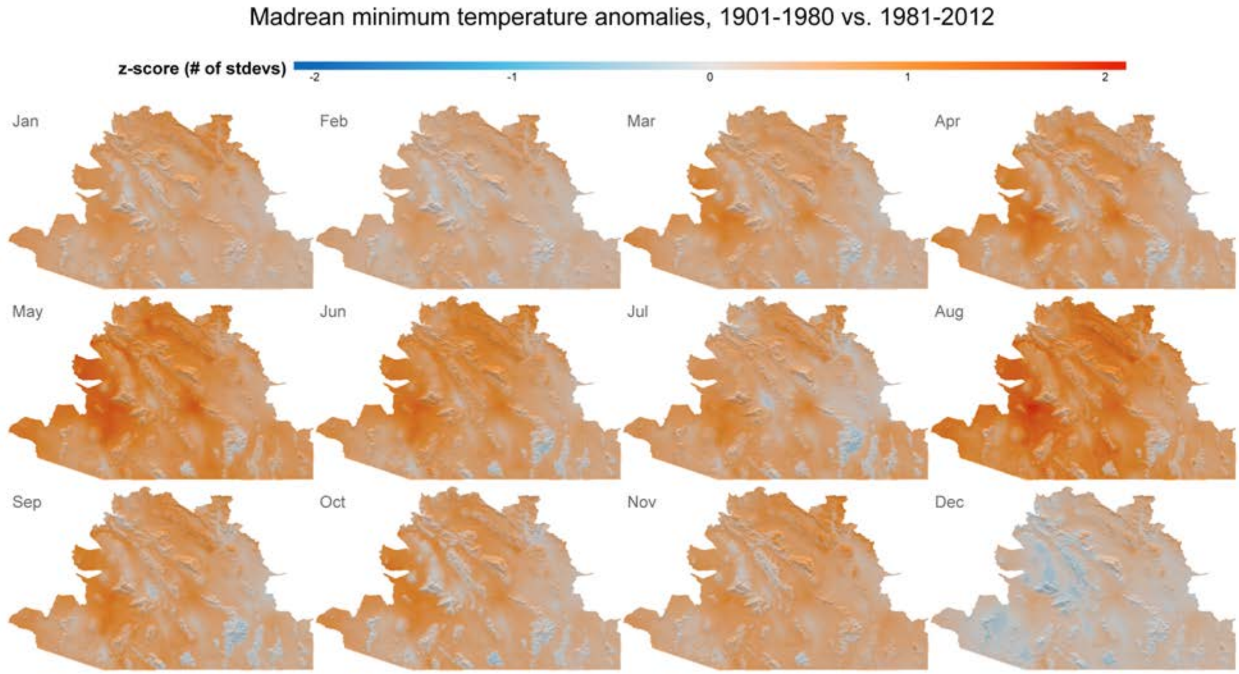
4.3.2.1 Precipitation

In the last 30 years, compared to the baseline, precipitation has varied in the direction of change spatially and seasonally, although the magnitude of change remains well within the range of historical variability. A majority of precipitation increases were in the east and southeast portion of the MAR, with the highest increase in May. The most marked decrease in precipitation was in June across the northwest portion of the MAR; however, values were modest in magnitude.

4.3.2.2 Minimum Temperature

Every month of the year exhibited minimum temperature increases across the majority of the ecoregion between the baseline and recent periods with values that were notable departures from baseline variability (Figure 4-35). The greatest increases approached 4 degrees Celsius (7 degrees Fahrenheit) and occurred during the spring months in low-lying western and northern parts of the MAR. These highest values occurring over the last 30 years are equivalent to the very most extreme (top 1%) of values that occurred in the 20th century baseline. However, for every month there were also pockets of minimum temperature stability in mountainous regions, indicating their importance in landscape resilience to significant climate changes that are already occurring.

Figure 4-35. Degree of departure over the last 30 years from 20th century baseline monthly minimum temperature values.



4.3.2.3 Maximum Temperature

Compared to minimum temperature, maximum temperature change between the baseline and recent time slices showed smaller increases and decreases that did not deviate more than one standard deviation from historical variability. Similar to the spatial patterns in minimum temperature, mountainous areas across the northern MAR showed either no change or slight decreases in maximum temperature.

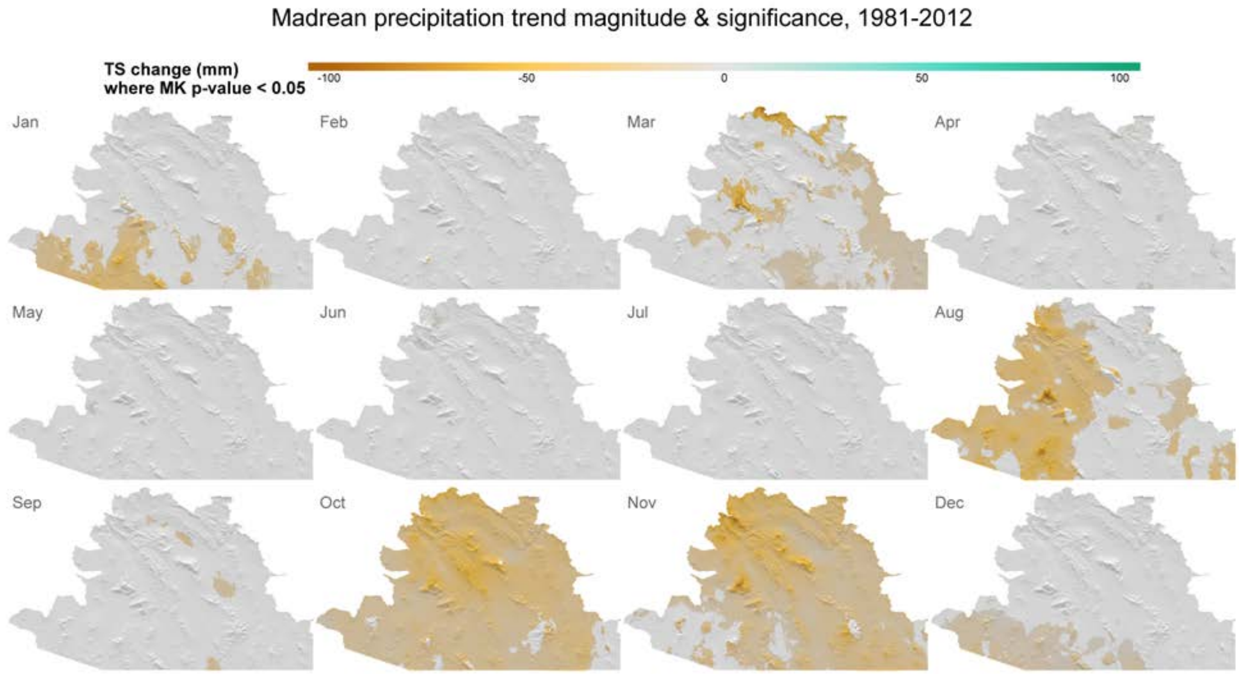
4.3.3 Trends within Recent Decades

This analysis addresses the magnitude and statistical significance of trends *within* the most recent 32-year timeslice, as opposed to the above analysis that measures recent change compared to the 80-year 20th century baseline. Instead of measuring change as a deviation from a historical mean climate and its variability, this analysis measures statistical significance (p-values <.05) and magnitude of trends based on the slope of a linear regression line. This analysis quantifies the direction of climate change in recent decades, and whether there is a statistically significant trend in change.

4.3.3.1 Precipitation

During the 32 years from 1981 to 2012, precipitation across the MAR had widespread statistically significant declines and no significant increases. Historically, July and August are the peak monsoon months accounting for the most precipitation; July saw no significant change, while August exhibited precipitation declines of roughly 30% across the western half of the MAR. The data suggest that October and November (months of intermediate overall precipitation levels), experienced the most spatially widespread and greatest percent decreases (Figure 4-36).

Figure 4-36. Quantification of monthly trends in precipitation in the MAR over the last 32 years. Areas in gray color are experiencing no statistically significant change over recent decades. Colored areas represent significant trends, with the color reflecting the amount (in mm) of change.



4.3.3.2 Minimum Temperature

Among the three variables analyzed, minimum temperature exhibited the most pervasive significant change during the years 1981 to 2012. Minimum temperature increases were most widespread across the ecoregion during summer months, but high elevations in the northwestern part of the ecoregion consistently experienced significant increases across all months. Most of these increases were in the 1 to 3 degree Celsius range (2 to 5 degrees Fahrenheit), but in some high-elevation locations in the northeastern corner of the MAR, minimum temperatures increased by more than 4 degrees C (7 degrees F).

4.3.3.3 Maximum Temperature

Statistically significant maximum temperature trends were less pervasive than minimum temperature, with the majority of the months exhibiting no widespread trends. November showed the most recent significant change with maximum temperatures increasing 2 to 4 degrees C (4 to 7 degrees F) across the MAR.

For a full explanation of recent trends with visualizations for each variable and month, please see Appendix I.

4.3.4 Projected Future Changes in Climate

4.3.4.1 Core Climate Variables

Precipitation

Similar to the recent trend results, MAR future projected precipitation change is variable in direction and magnitude across space and time. One commonality across 10 out of the 12 months is that the southwestern quadrant of the MAR is projected to become drier. The most notable change is a trend toward descreasing precipitation in April and May across the entire ecoregion, between -1 and -2 standard deviations beyond historical variability. The monsoonal months of July and August are also projected to decrease in precipitation in some areas by up to 20%, but these anomalies fall within the normal range of variability in 20th century precipitation.

Minimum Temperature

The GCM ensemble values for future climate used for this analysis predict that by mid-century, the average minimum temperature will increase by 1 to 4 degrees C (2 to 7 degrees F) throughout the MAR, across all months of the year. Compared to baseline variability, this change is the most extreme in July, August, and September, where temperatures are forecast to increase by 3 to 4 degrees C (5 to 7 degrees F) and exceed the baseline mean by between 4 and 5.5 standard deviations.

Maximum Temperature

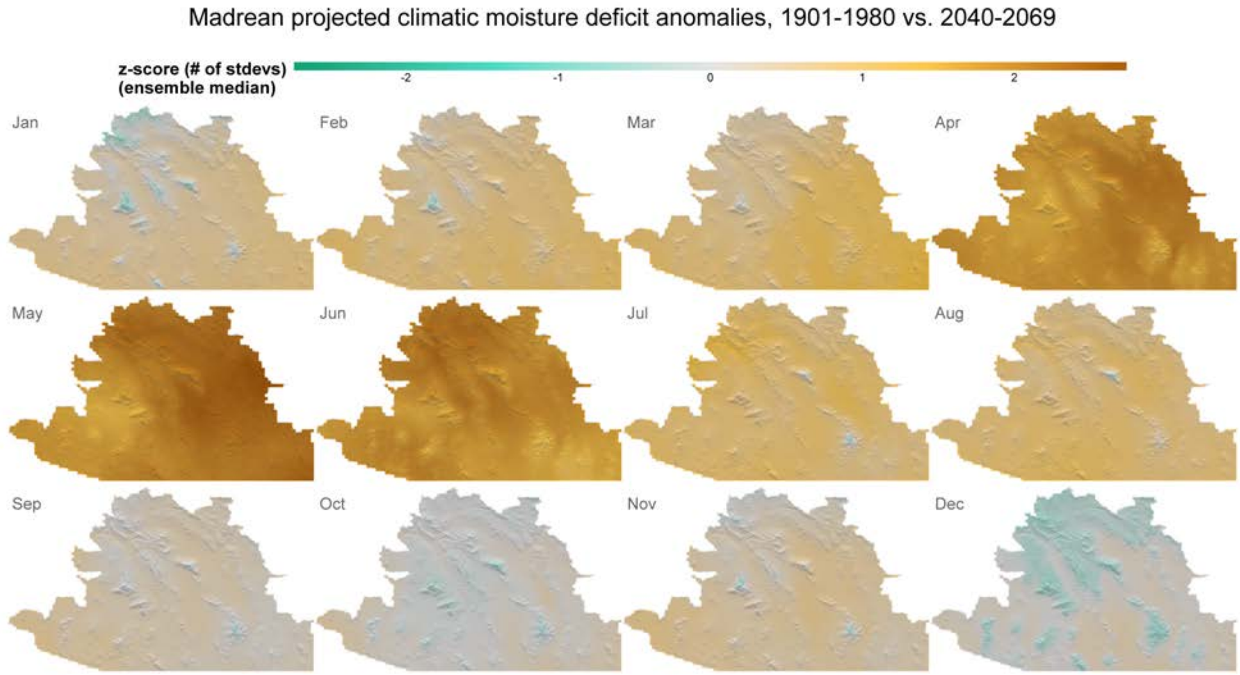
Maximum temperature is expected to increase by roughly similar values (1 to 4 degrees C; 2 to 7 degrees F) as minimum temperature, but when relating these changes to historical variability, they represent less dramatic shifts than the minimum temperature changes. Anomalies are most notable in July and August, where temperature increases are near 3 standard deviations beyond the baseline mean.

4.3.4.2 Derived Climate Variables

Climate Moisture Deficit

Climatic moisture deficit (CMD) is a measure of dryness derived from temperature and precipitation, and can serve as a useful indicator of drought stress, especially relevant to vegetation. Increasing CMD is associated with hotter and/or drier conditions, while decreasing CMD indicates greater moisture availability due to precipitation increases and/or temperature declines. The forecasted pattern of change in CMD is strongly influenced by topography (Figure 4-37). During fall and winter months, high-elevation areas are decreasing in CMD from -0.5 to -1 standard deviation from the baseline mean. Even in months such as July and August, where anomalies are increasing in CMD, isolated mountaintops in the Chiricahua and Pinaleno mountains are showing decreases in CMD. The months expected to experience the most moisture stress across the entire range compared to historical conditions are April, May, and June, which show projected anomalies of up to 3 standard deviations beyond the baseline mean, indicating that average future conditions of moisture stress during mid century will be equivalent to the very most extreme years in the 20th century baseline.

Figure 4-37. Comparison of future average monthly moisture deficit to baseline 20th century conditions. The z-score metric measures change in number of standard deviations of baseline values.



<u>Number of Frost-Free Days</u>

All months, other than summer months where there is historically little to no frost, are projected to see increases in NFFD. The greatest changes occur in the shoulder season months of April and November, where high elevations are projected to see up to 10 fewer nights of temperatures falling below 0 degrees C. From December through March, NFFD increases are forecast to occur throughout the MAR, with delta values approaching 8 days in some areas. These changes are projected to be roughly 2 standard deviations higher by mid-century than the frost conditions that occurred during the 20th century baseline.

<u>Frost-Free Period</u>

Frost-free period (FFP) is an annual variable that is the number of consecutive days between the last frost of the spring and the first frost of the fall, and essentially represents the length of the growing season. Climate models used for this study project that the average length of the warm season will increase dramatically in the MAR by the mid 21st century, with FFP increasing by 25 days (in the eastern MAR) to 55 days (in the west). These changes represent anomalies of 2 to 4 standard deviations from the baseline mean.

4.3.5 Climate Trends and CEs

The future climate change exposure index summarizes overall departure in all climate variables and for all months. The index is a quantification of relative overall departure of future climate conditions from the baseline conditions (Figure 4-34). By overlaying the current distribution of a given CE, the projected amount of climate stress across its geographic range can be visualized.

In the following figures, darker colors indicate fewer climate variables are significantly different, and lighter colors indicate many if not all of 36 climate variables are projected to be significantly different from the baseline period. Note that dark colors still indicate very significant climate change.

On top of the future CCEI shown in Figure 4-34, conservation element (CE) distributions are overlaid as a 4 km grid. Overlay maps were prepared for all CEs and the complete set of maps are found in Appendix I. Following are example maps for each of the three case study CEs (Figure 4-38 through Figure 4-40). In each figure, areas that do not include a conservation element (CE) distribution are masked in order to see the climate change index across the CE's distribution. Keep in mind that for all these figures, projected climate change exposure is significant (see Figure 4-33) and occurs across the entire ecoregion.

Figure 4-38. Apacherian-Chihuahuan Semi-Desert Grassland and Steppe distribution overlaid on projected climate change exposure index.

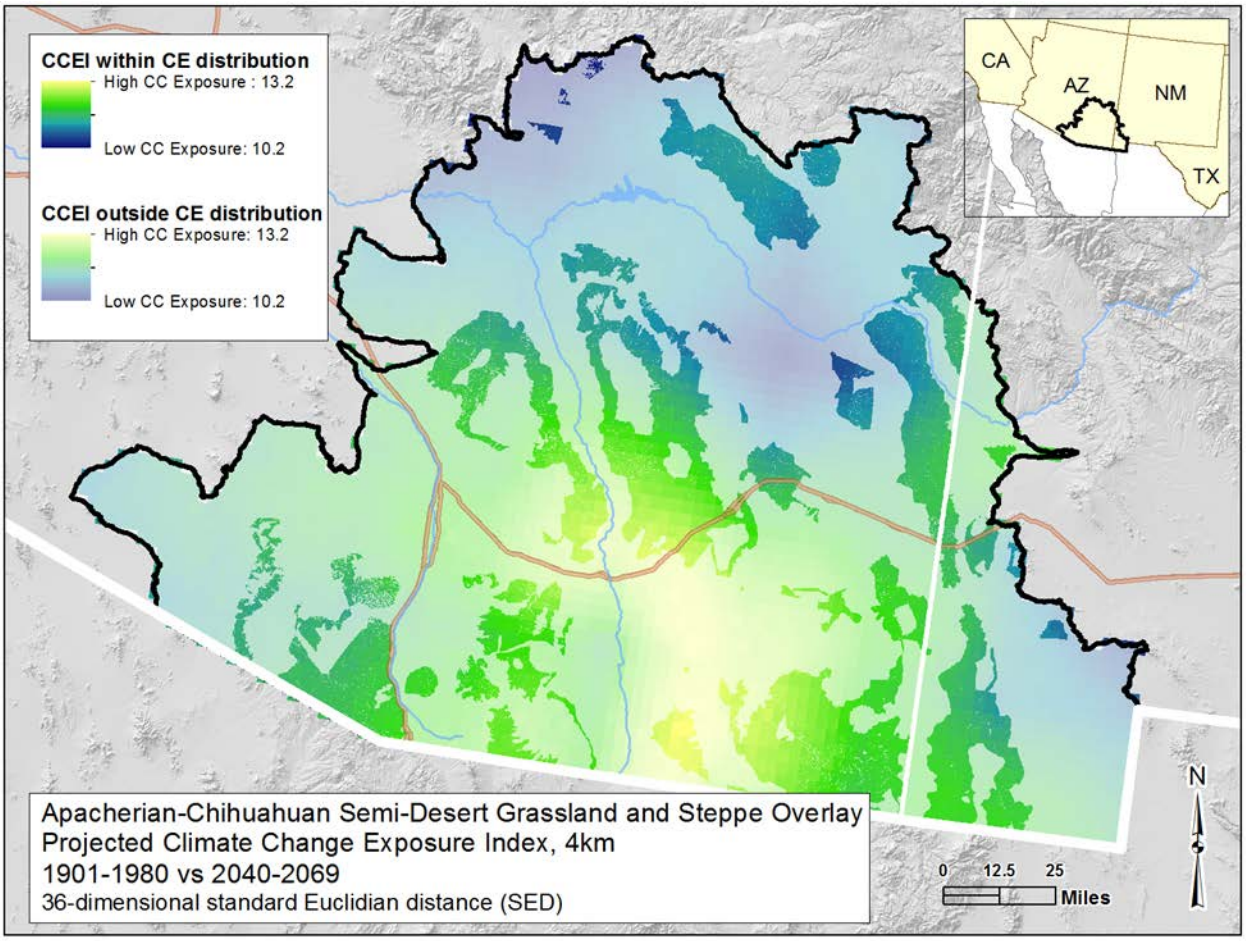


Figure 4-39. North American Warm Desert Riparian Woodland, Shrubland, Mesquite Bosque and Stream distribution overlaid on projected climate change exposure index.

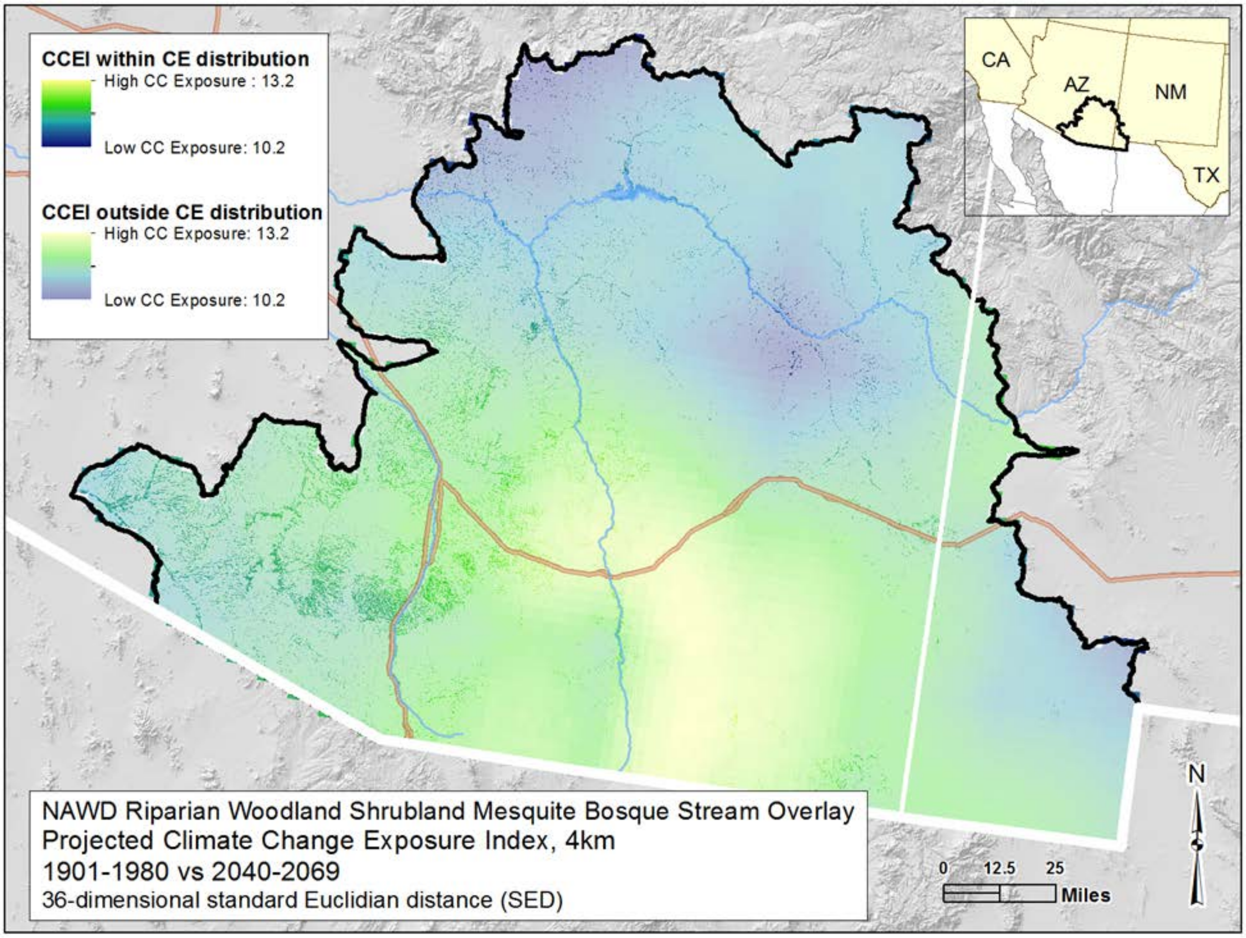
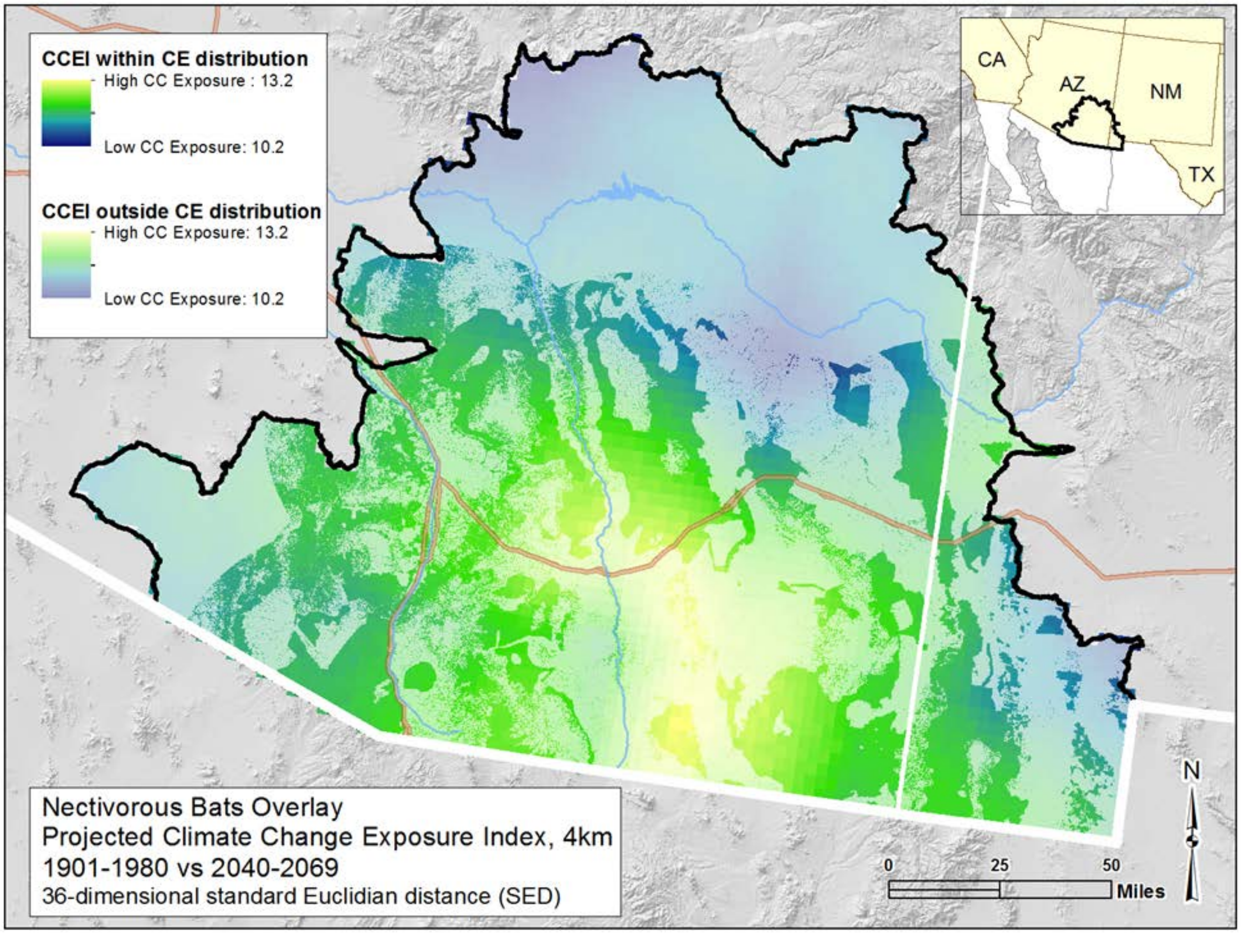


Figure 4-40. Nectivorous bats distribution overlaid on projected climate change exposure index.



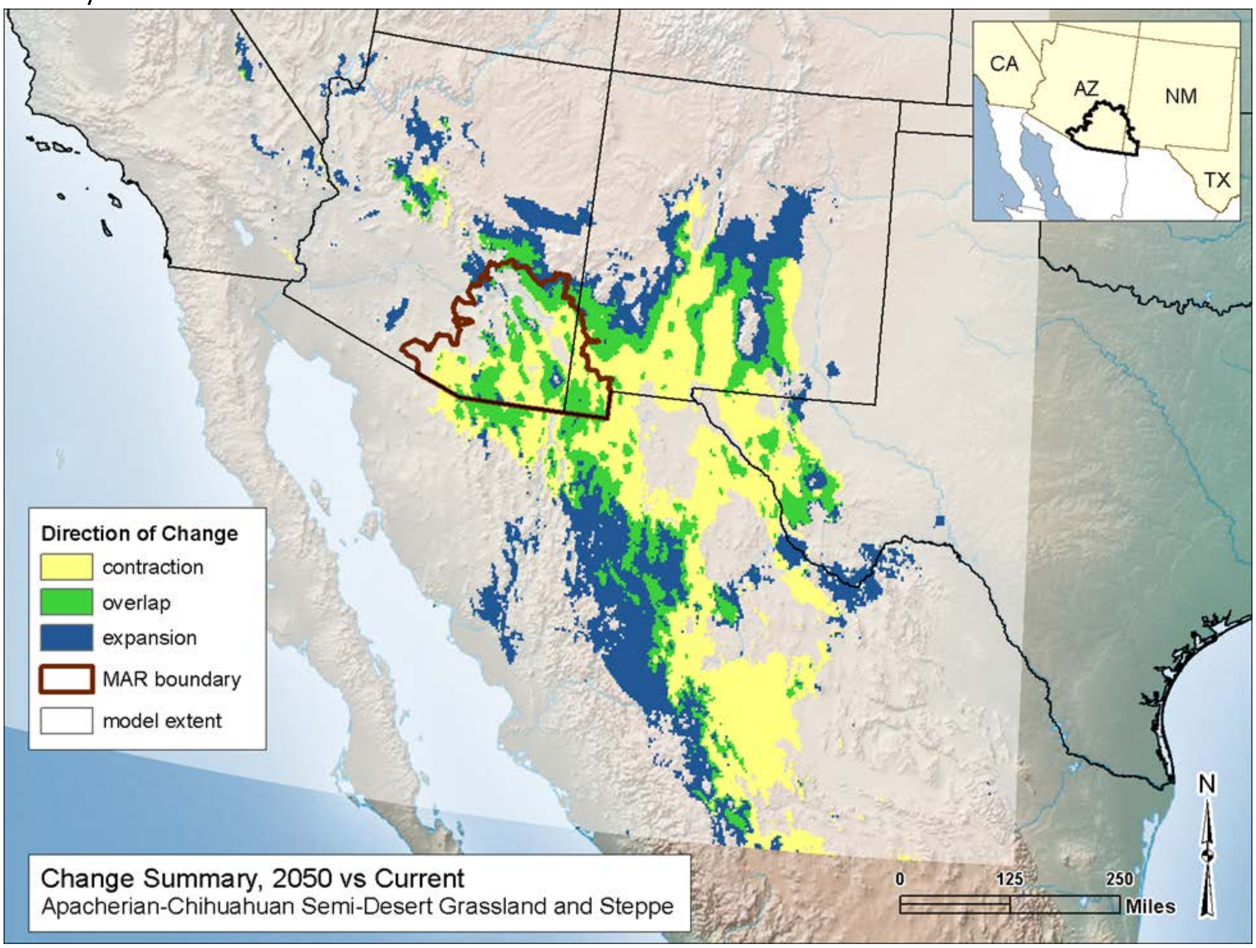
4.3.6 Bioclimate Envelope Models

Bioclimatic envelope modeling was used to help understand the potential impacts of climate change for CEs of interest by analyzing projected geographic shifts in suitable climate conditions. For each CE, the distribution of current and future climate suitability was modeled. The difference between the distribution and extent of current and future climate suitability suggests potential areas of contraction, expansion, and stability of areas of suitable climate. These models do not project shifts in species' actual distributions, but rather shifts in suitable climate conditions as defined by current observed localities where the CE is known to occur.

4.3.6.1 Apacherian-Chihuahuan Semi-Desert Grassland and Steppe

The bioclimatic envelope of the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe community is currently widely distributed across the southern and eastern MAR, but is projected to contract significantly by mid-century both within the MAR and throughout its entire distribution. Large regions of projected expansion also exist, but these fall almost entirely outside the MAR boundary. Of the four CE bioclimates modeled, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe was projected to have the largest area of contraction as a percentage of its total current distribution, with relatively little overlap between modeled current and future distributions of suitable bioclimate. Based on projected shifts, foothills and mid-elevation habitats may be the most stable areas as future climate conditions unfold.

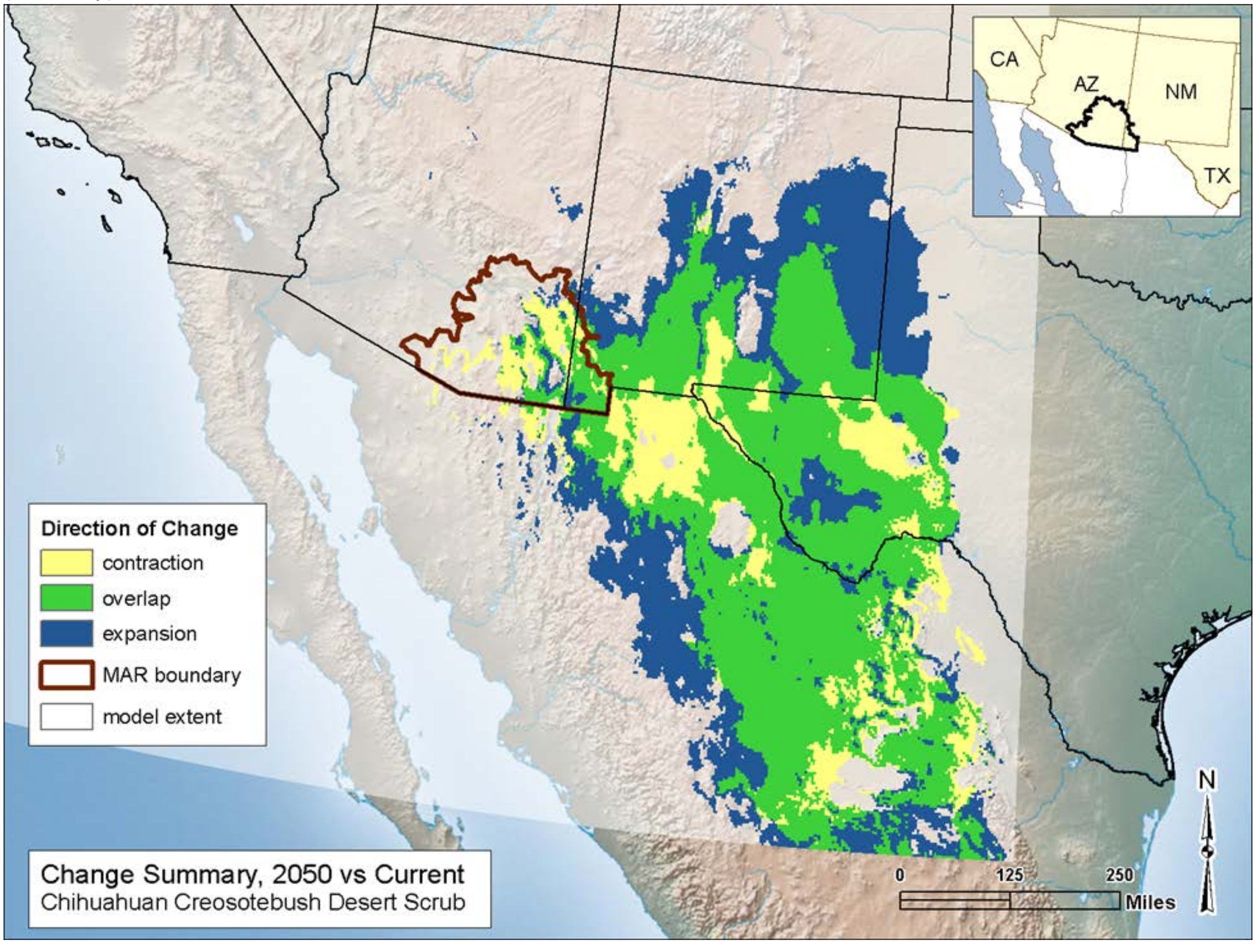
Figure 4-41. Mid-century projected change in suitable bioclimate for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe. This map depicts how current suitable bioclimate is projected to shift by showing areas of contraction, expansion, and overlap (stability). Projections indicate that there will be significant contraction of suitable conditions within the MAR, with some mid-elevation areas of stability.



4.3.6.2 Chihuahuan Creosotebush Desert Scrub

The MAR lies at the fringes of the modeled current Chihuahuan Creosotebush Desert Scrub bioclimate, and while this bioclimate is projected largely to remain stable or expand, it is projected to contract significantly within the MAR. Contraction is projected for central and northeastern parts of the MAR, while stability is projected for the southeastern MAR.

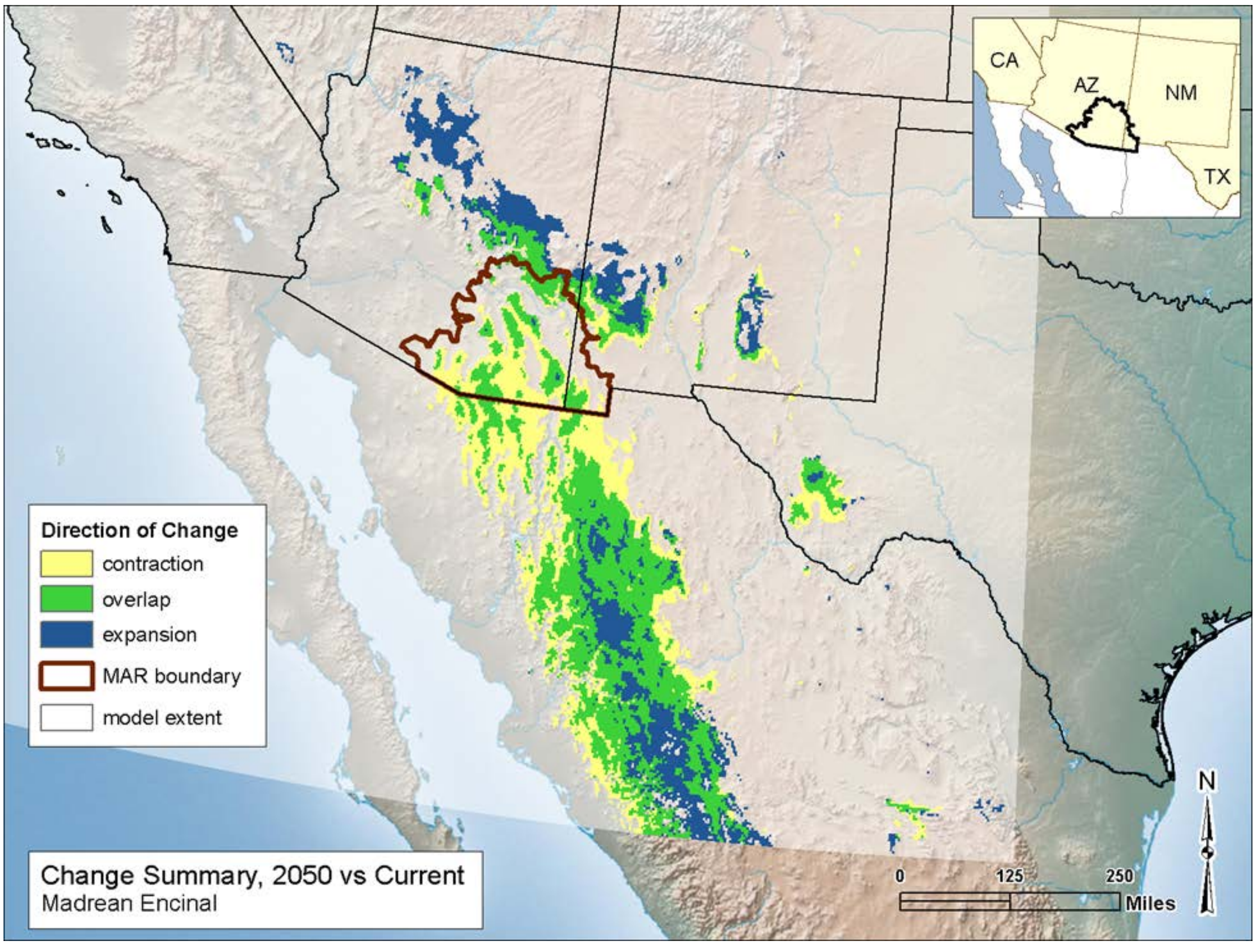
Figure 4-42. Mid-century future modeled suitable bioclimate for Chihuahuan Creosotebush Desert Scrub. This map depicts how current suitable bioclimate is projected to shift by showing areas of contraction, expansion, and overlap (stability).



4.3.6.3 Madrean Encinal

Across its entire current distribution, suitable bioclimate for the Madrean Encinal is projected to contract at lower elevations and move upslope, while mid-elevations are projected to remain stable. A majority of the area within the MAR boundary could contract (rather than remaining stable or expanding). High climate model agreement of future suitable conditions exists mainly at high elevations.

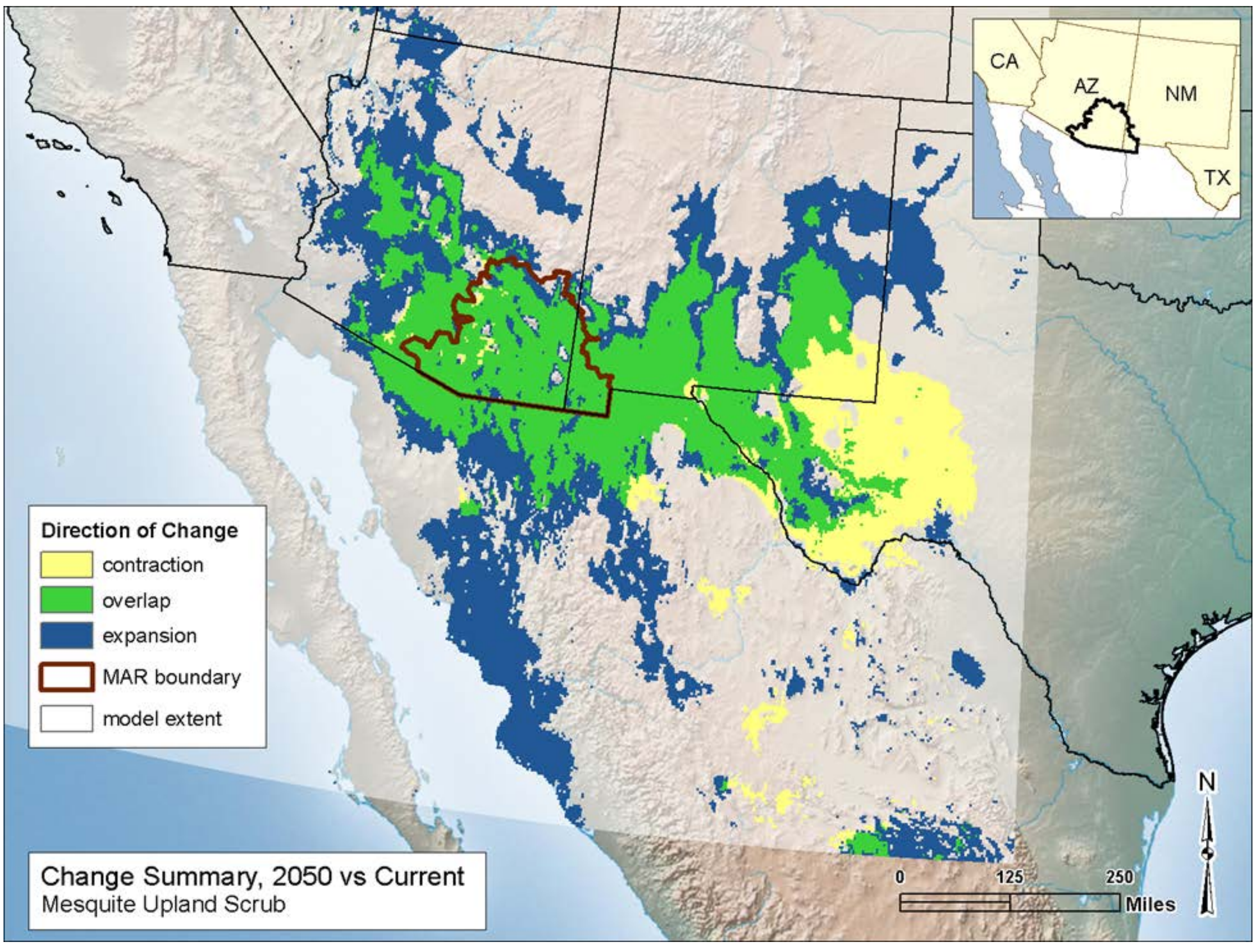
Figure 4-43. Mid-century projected change in suitable bioclimate for Madrean Encinal. This map depicts how current suitable bioclimate is projected to shift by showing areas of contraction, expansion, and overlap (stability). Future bioclimate is projected to shift upslope and middle elevations are potential areas of stability.



4.3.6.4 Apacherian-Chihuahuan Mesquite Upland Scrub

Bioclimate for the Apacherian-Chihuahuan Mesquite Upland Scrub is projected to persist and expand in every direction except some areas of contraction in Texas. Within the MAR boundary some small shifts toward higher elevations are projected. Bioclimate for mesquite upland shrub was projected to remain favorable in virtually all the MAR locations where Apacherian-Chihuahuan Semi-Desert Grassland and Steppe bioclimate was projected to contract, suggesting that mesquite may continue to invade desert grasslands in the future.

Figure 4-44. Mid-century projected change in suitable bioclimate for Apacherian-Chihuahuan Mesquite Upland Scrub. This map depicts how current suitable bioclimate is projected to shift by showing areas of contraction, expansion, and overlap (stability). The bioclimate for this vegetation assemblage is projected to remain stable and increase in some areas. Within the MAR boundary some pixels are highlighted as shifting upslope.



4.4 Other Assessments

4.4.1 2025 Risk Assessment

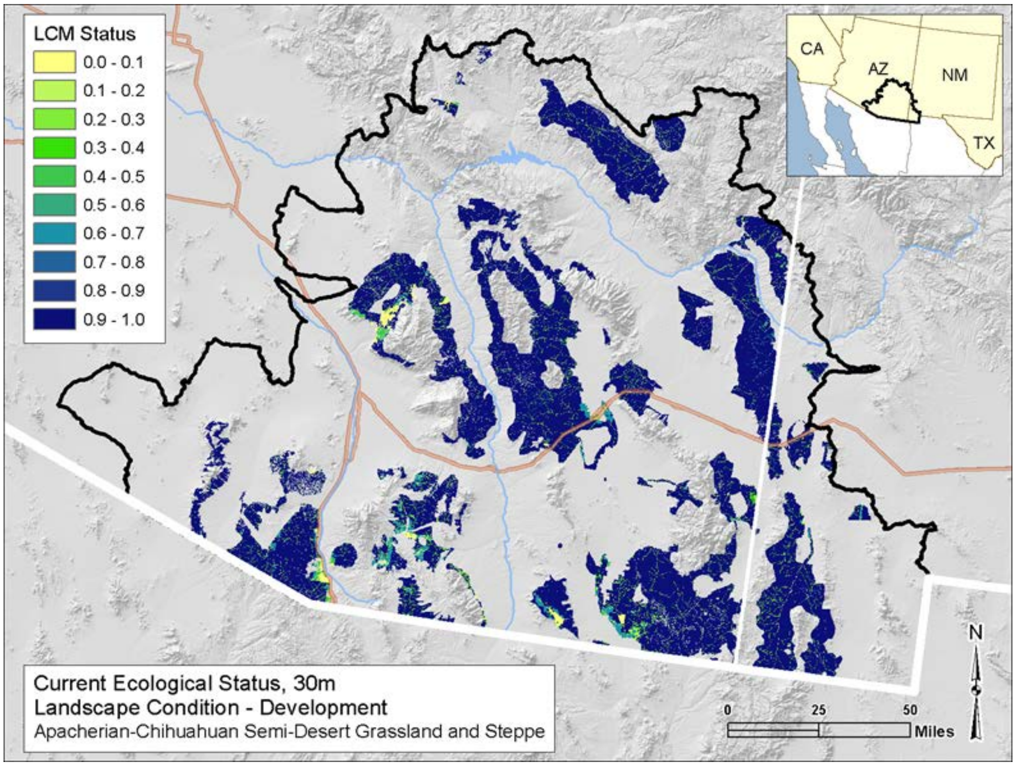
Inadequate data were available to conduct complete CE status assessments for the 2025 timeframe that are equivalent to those done for the current timeframe (2014). However, a variety of data representing potential areas of development change agents for near future timeframes were available to represent a 2025 landscape condition scenario. This allowed assessment of the development indicator for the 2025 timeframe for each of the three case study CEs (see Figure 4-45 through Figure 4-47) to provide a limited picture of potential ecological status in 2025. In addition, the three CEs were also overlaid with an urbanization risk map (Figure 4-48 through Figure 4-50). Solar energy potential maps are provided (Figure 4-51 and Figure 4-52) but not overlaid on the CE distributions because of their broad distribution, but they can be overlaid with any CE via BLM's GIS portal found at http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/dataportal.html. The overlay of the risk map is solely for visualization purposes in this report; the delivered products for these assessments include all source data and the three CE 2025 development status maps.

The landscape condition scenario for the 2025 status assessment includes the current development CAs, numerous footprints of proposed projects from the state of Arizona (confidential data that could not be delivered), and two major electrical transmission corridors. The corridors are the BLM-preferred proposed SunZia transmission line and the Southline corridor that cut across the center of the study area. Also of mention, but not included in the analysis is the Section 368 corridor comprised of small segments in the south and east of the region.

Comparing the development indicator scores for the current timeframe to the 2025 development-based ecological status scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe (Figure 4-45) and nectivorous bats (Figure 4-47), the differences are subtle at the ecoregion scale and are primarily driven by urban expansion in the central and southwest portions of the ecoregional assessment area and around Tucson. Footprints from a variety of proposed development projects in Arizona (new construction or expansion of existing infrastructure) impact the CEs' 2025 status (e.g. residential/commercial, roads, airports, mining, renewable and non-renewable energy, communication towers, water impoundments/dams/levees, etc.). The Arizona proposed development data is sensitive and restricted; therefore, details about specific sites and interpretations of potential impacts to specific sites cannot be identified in this report. For the aquatic ecosystem NAWD Riparian Woodland, Shrubland, Mesquite Bosque and Stream (Figure 4-46), the impacts due to the proposed development appear negligible.

The extent of future development currently planned, modeled, or with fairly high potential for action by 2025 is relatively small compared to the ecoregion extent. Therefore, separate assessments would need to be conducted to characterize localized effects of individual projects. The SunZia and Southline electrical transmission corridors bisect the entire ecoregion and numerous occurrences for several CEs but they are represented by a narrow 200 m corridor that is difficult to see at the ecoregion extent. No Solar Emphasis Zones were designated in the BLM Solar PEIS in the Madrean Archipelago Ecoregion, but there is some solar development on non-federal lands. There are extensive areas of federal lands delineated as variance areas where, through careful planning, facilities could be located on certain federal lands.

Figure 4-45. Future (2025) ecological status scores for Apacherian-Chihuahuan Semi-Desert Grassland and Steppe, based on the development indicator. Current ecological status is shown in the top map for comparison. LCM Status = Landscape Condition Model Status of the indicator. Status is generated for the development indicator for each 30m pixel.



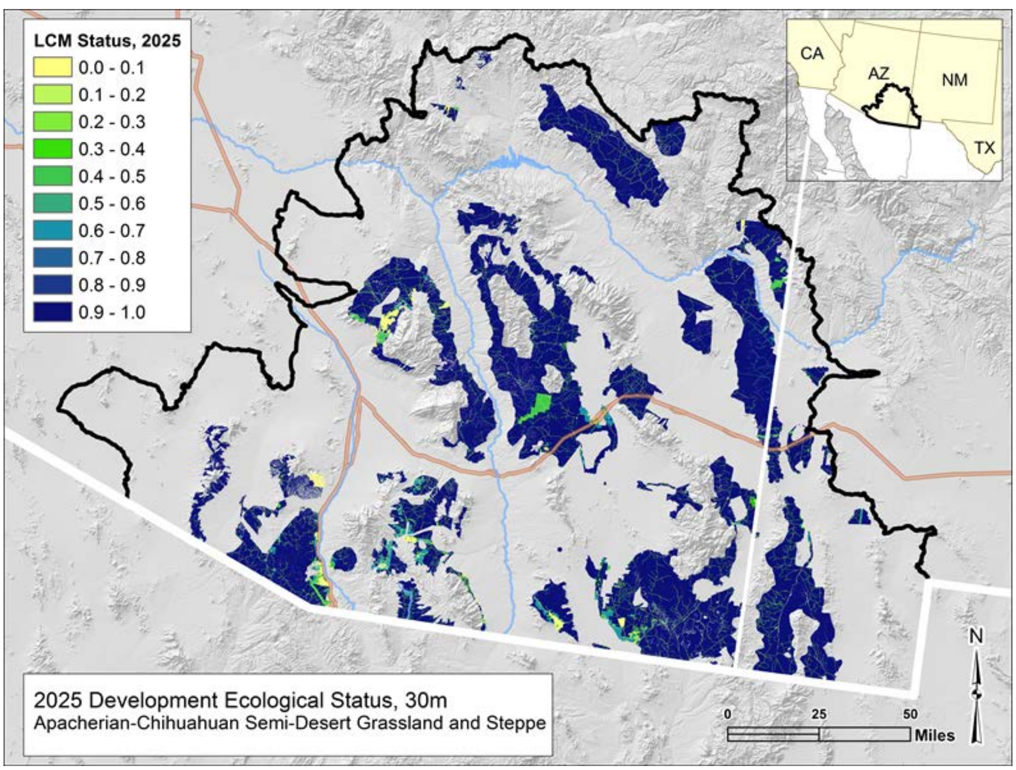


Figure 4-46. Future (2025) ecological status scores for NAWD Riparian Woodland, Shrubland, Mesquite Bosque and Stream, based on the development indicator. Current ecological status is shown in the top map for comparison. LCM Status = Landscape Condition Model Status of the indicator. Status is generated for the development indicator for each 30m pixel.

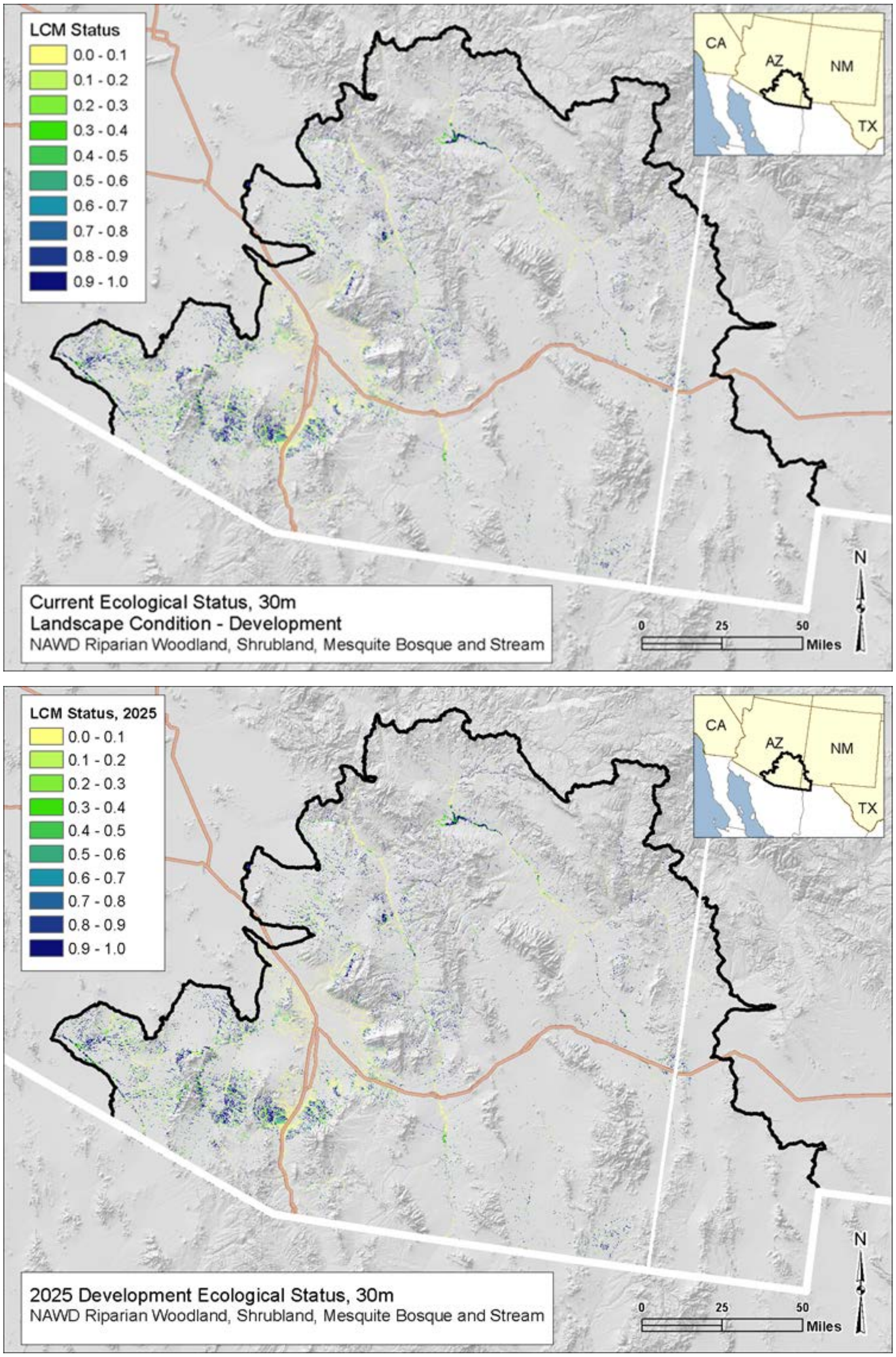
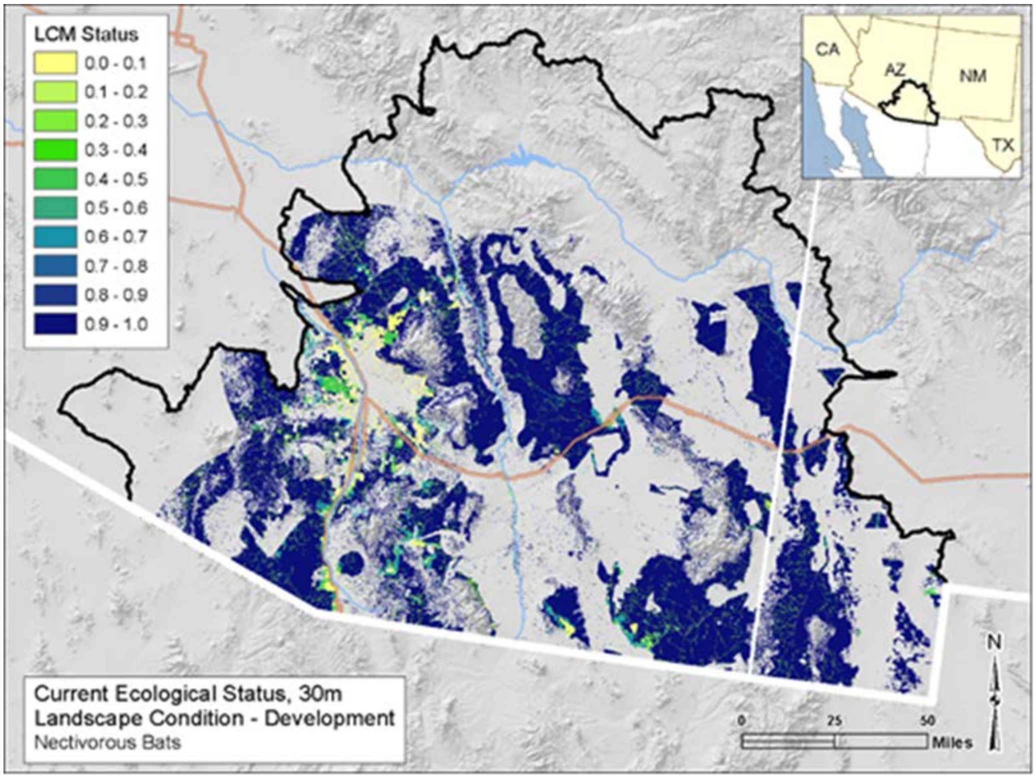
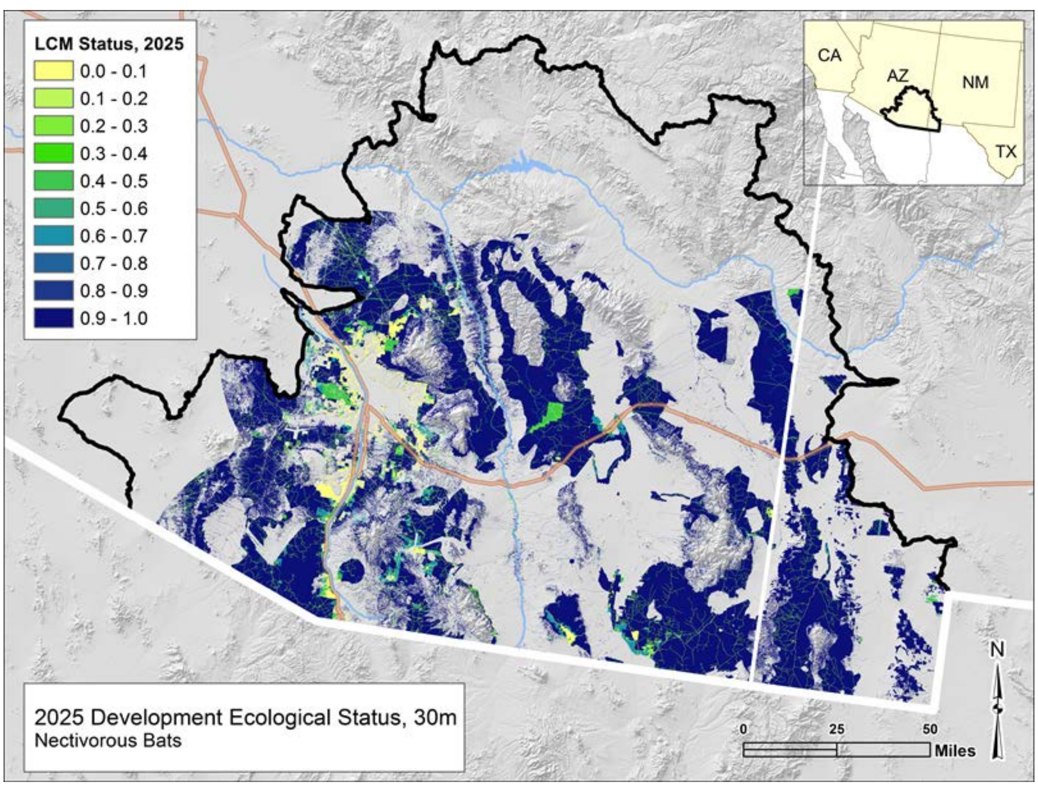


Figure 4-47. Future (2025) ecological status scores for nectivorous bats, based on the development indicator. Current status is is shown in the top map for comparison. LCM Status = Landscape Condition Model Status of the indicator. Status is generated for the development indicator for each 30m pixel.





4.4.1.1 Risk Maps: Overlays of Potential Future Development Footprints with CEs

This section illustrates additional risks to CEs from development-related CAs by overlaying a model of future urban growth (U.S. Environmental Protection Agency 2010) on the case study CE distributions (Figure 4-48 through Figure 4-50). The footprint of modeled expanded or intensified urbanization is small relative to the ecoregional assessment area; therefore, the maps are best viewed via the BLM REA GIS Portal to allow closer examination.

Figure 4-48. Future risk of urbanization for Apacherian-Chihuahuan Semi-Desert Grassland Steppe. Light pink areas represent a model of current urbanized areas already incorporated in the current status assessment; dark pink areas represent modeled potential urban expansion by 2030. SERGoM is the Spatially Explicit Regional Growth Model.

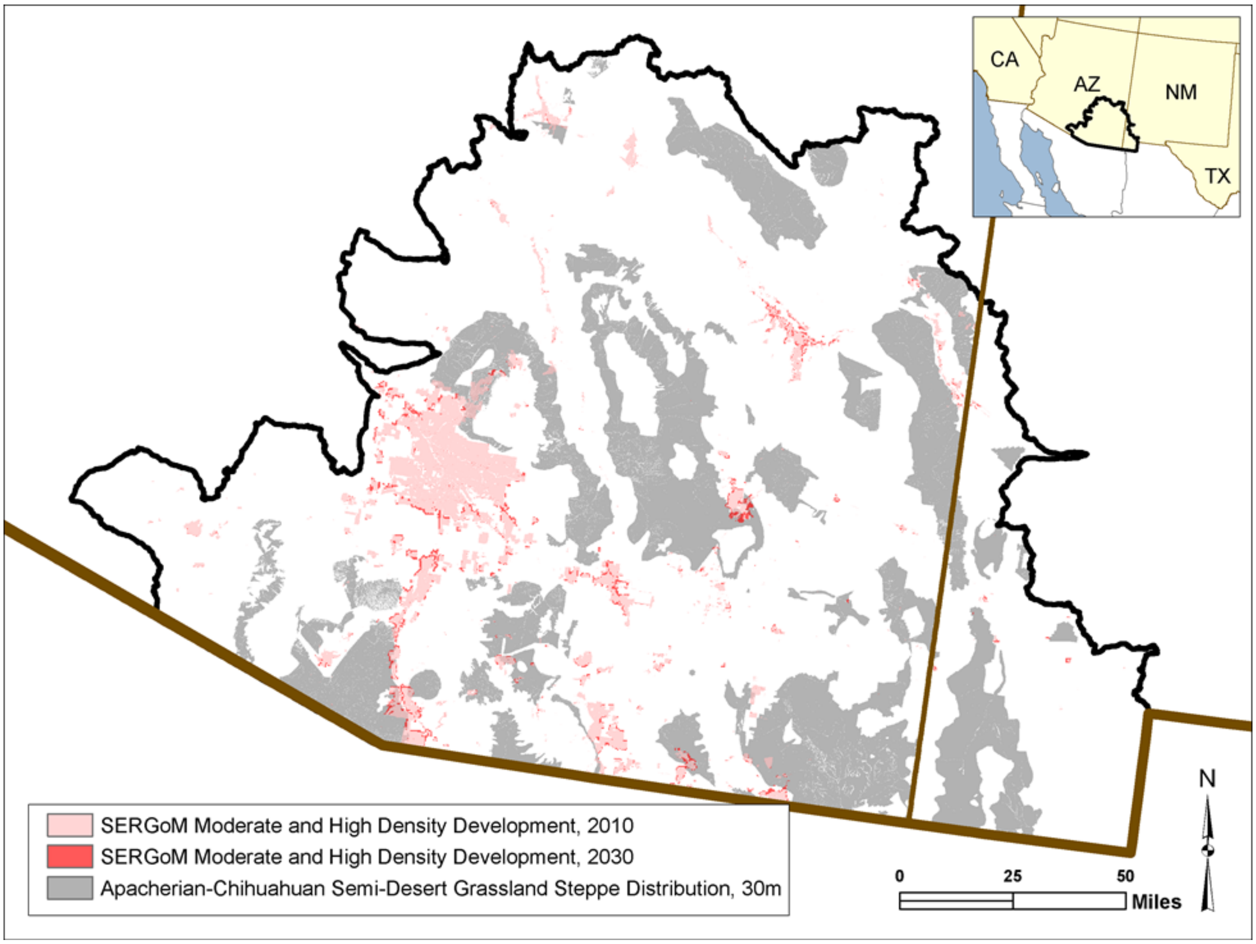


Figure 4-49. Future risk of urbanization for NAWD Riparian Woodland, Shrubland, Mesquite Bosque and Stream. Light pink areas represent a model of current urbanized areas already incorporated in the current status assessment; dark pink areas represent modeled potential urban expansion by 2030. SERGoM is the Spatially Explicit Regional Growth Model.

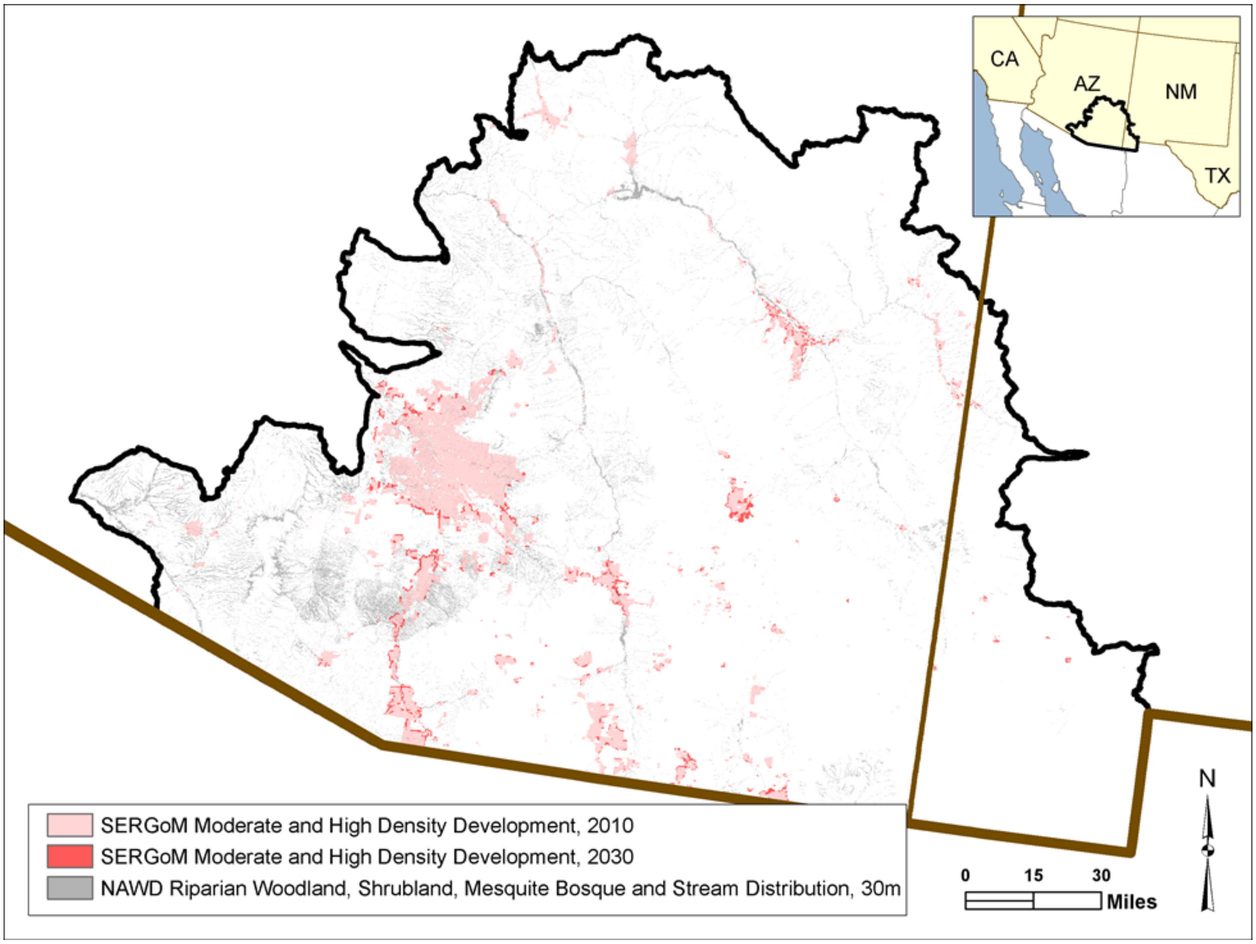
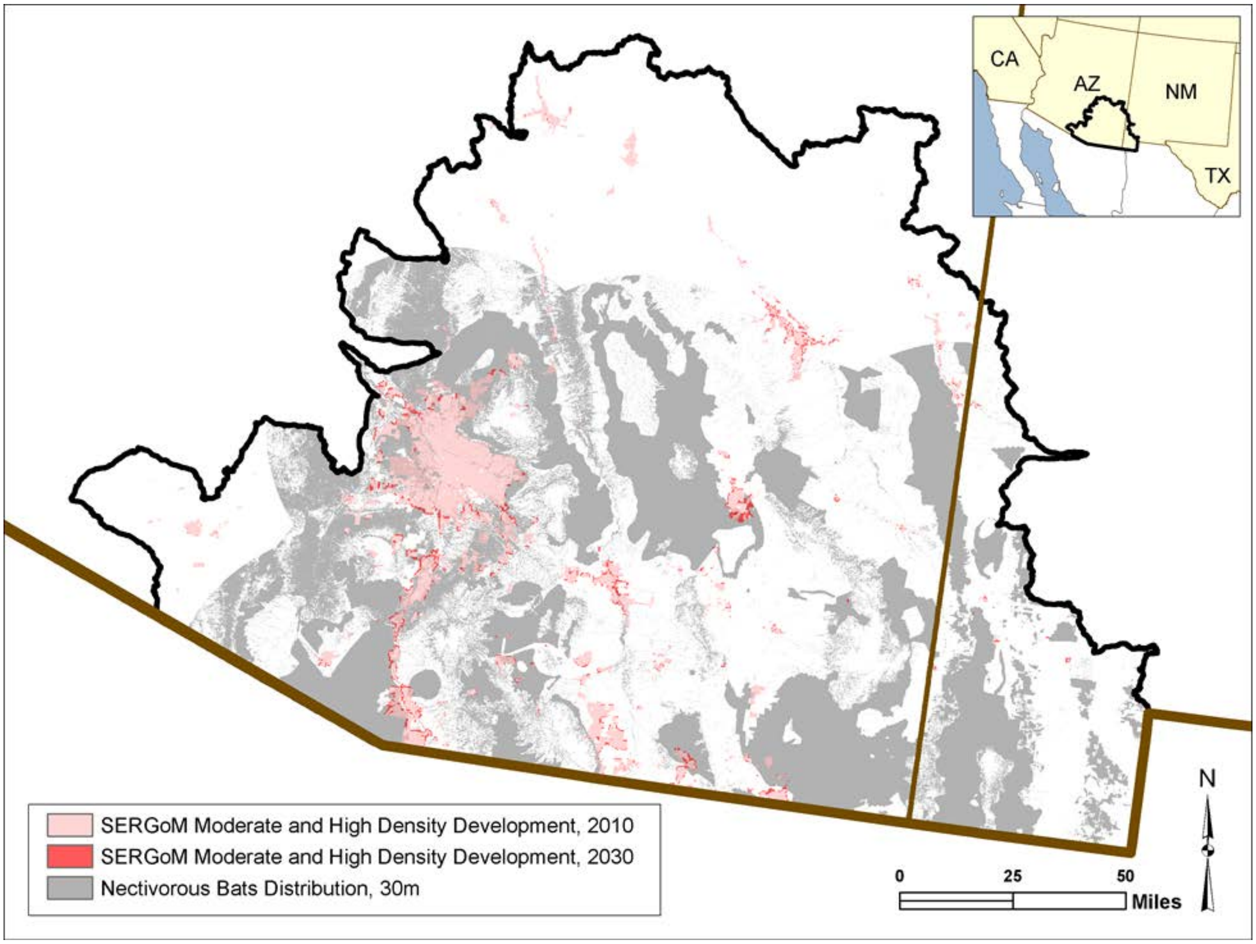


Figure 4-50. Future risk of urbanization for nectivorous bats. Light pink areas represent a model of current urbanized areas already incorporated in the current status assessment; dark pink areas represent modeled potential urban expansion by 2030. SERGoM is the Spatially Explicit Regional Growth Model.



4.4.1.2 Future Solar Potential

Solar potential maps were not overlaid on the case study CEs because of the broad coverage of solar potential in the ecoregion (although this can be done via the BLM REA GIS portal). Following are two maps from prior studies, the NREL solar potential within the ecoregion (Figure 4-51), and the areas of variance and exclusion on BLM lands (Figure 4-52). (Exclusion areas indicate where solar energy development would not be allowed; variance areas fall outside of preferred solar development zones but development may be permitted.) Note that no solar zones were established within the ecoregion via the programmatic EIS; therefore, the BLM opportunity areas for solar development fall within the variance areas.

Figure 4-51. Solar potential in the MAR. From the National Renewable Energy Laboratory Direct Normal Solar Insolation map (10km version, 1998-2009) filtered to slopes <5%. Units are Kwh/m^2 and represent very high levels of solar potential compared nationally. Unshaded areas are unsuitable because of excessive slope.

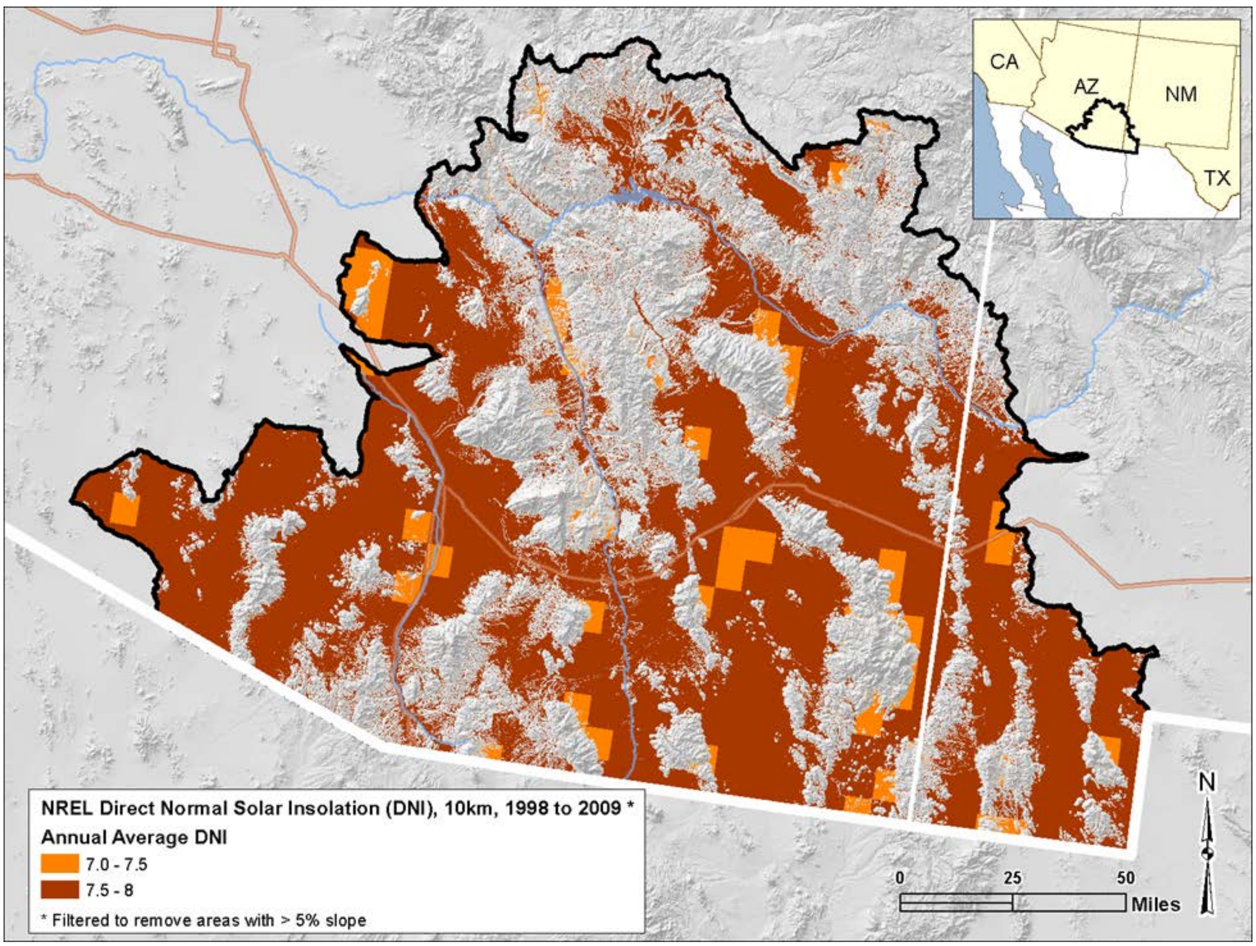
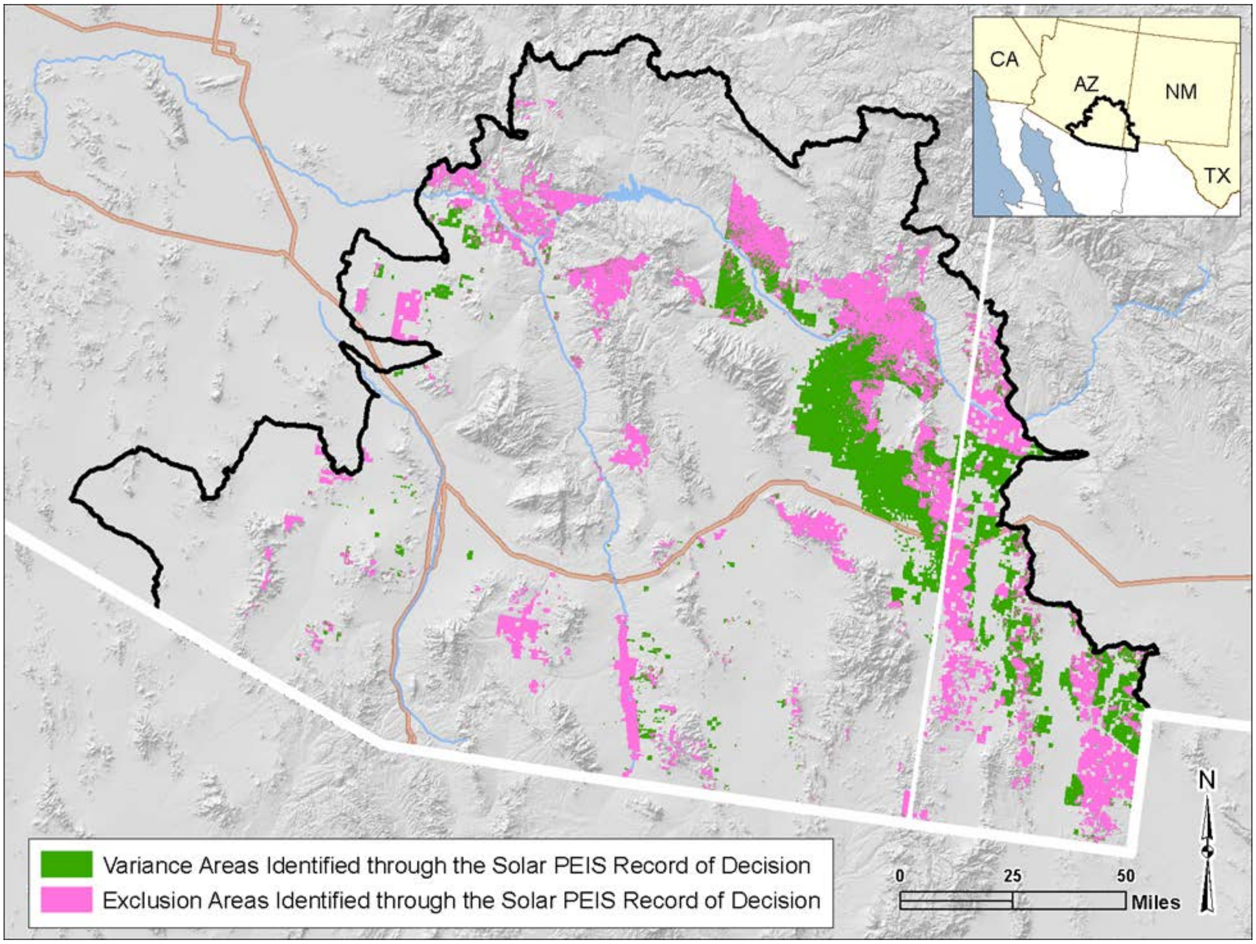


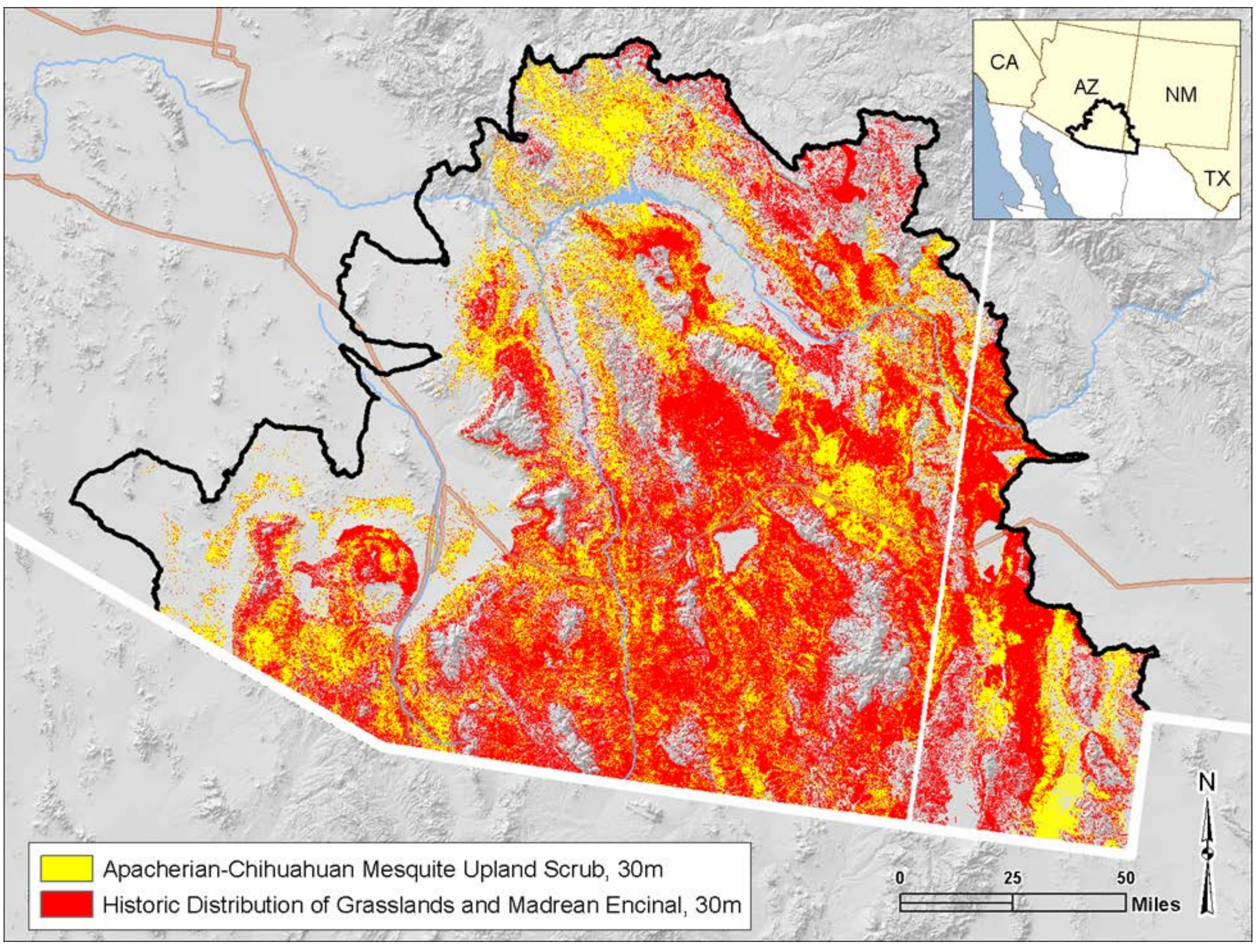
Figure 4-52. BLM Solar PEIS Exclusion and Variance Areas. Exclusion areas indicate where solar energy development would not be allowed. Variance areas fall outside of preferred solar development zones but may be permitted.



4.4.2 Mesquite Scrub Expansion: Restoration Opportunities

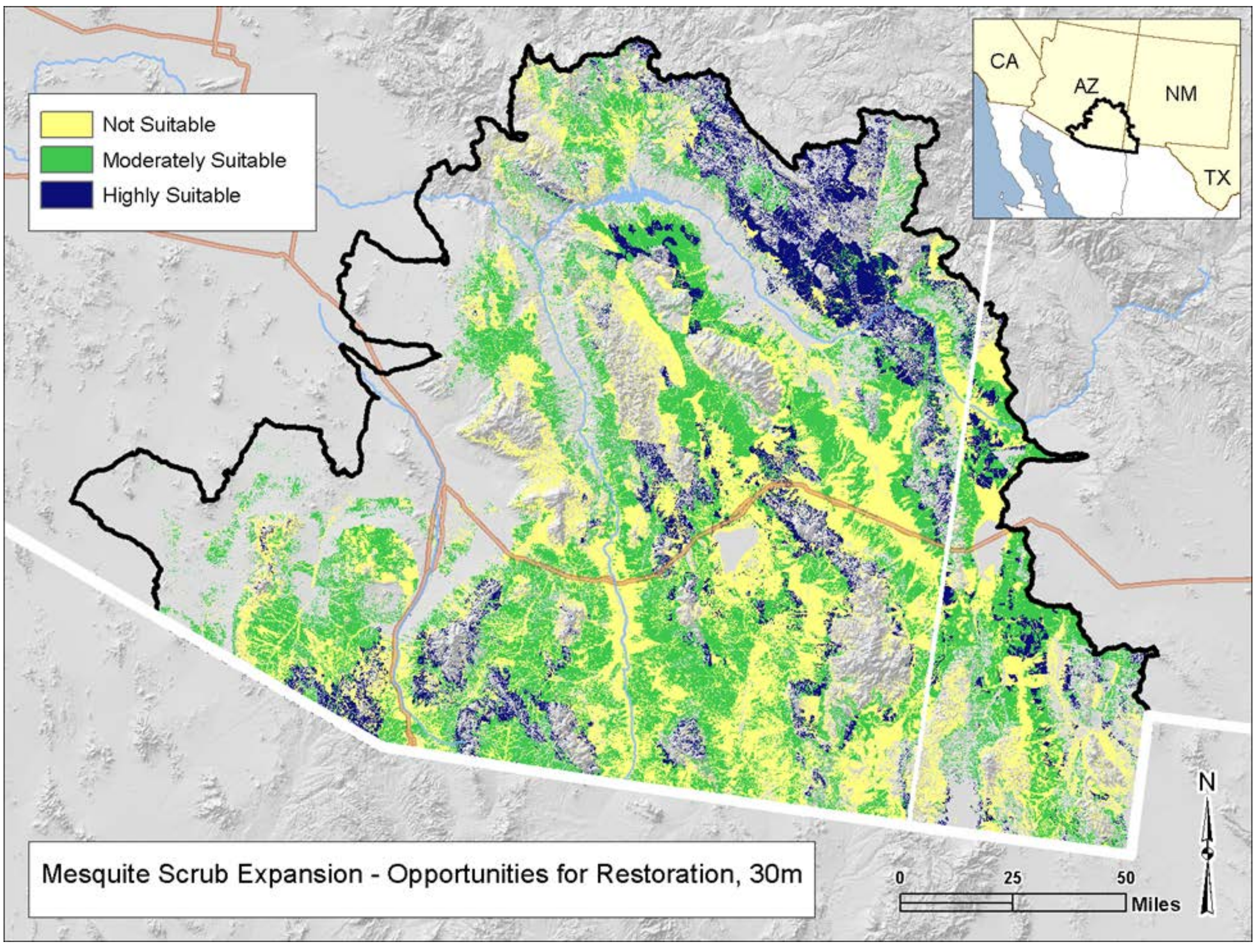
The area of distribution used in this assessment (Figure 4-53) was created by combining the distributions of Apacherian-Chihuahuan Mesquite Upland Scrub (from the NatureServe (2013) map of ecological systems), the historical distribution for Apacherian-Chihuahuan Semi-desert Grassland and Madrean Encinal (from LANDFIRE BpS), and the historical distribution of all grasslands as well as degraded grasslands from the TNC Grassland Assessment (Gori et al. 2012).

Figure 4-53. Assessment area for restoration of mesquite-invaded uplands. The assessment area is comprised of the current distribution of Apacherian-Chihuahuan Mesquite Upland Scrub (yellow), the distribution of degraded grasslands (red), and the historical distribution of Apacherian-Chihuahuan Semi-desert Grassland and Madrean Encinal (also red). The combined distribution dataset was delivered to BLM, but not with the attributes of the source dataset (some pixels had overlapping source data, e.g. mapped as mesquite and historical grassland in the same pixel). This map is to help visualize the different source data.



The results of the assessment for Mesquite Scrub Expansion: Restoration Opportunities are shown in Figure 4-54. The results are a combination of scores from three variables: development, percent cover of mesquite, and the suitability of soils for grassland restoration. The highly suitable areas for restoration (blue) mostly occur in the northern portion of the ecoregion around the Gila Mountains and in the Natanes Plateau. Highly suitable areas to the south occur in smaller patches and are restricted to the foothills, piedmont and alluvial plains around the higher elevation desert mountain ranges such as the Pajarito Mountains, Santa Rita Mountains, Patagonia Mountains, Canelo Hills, and Galiuro Mountains. These are areas where grasslands historically occurred on highly suitable Mollisol soils and likely still have some of the better condition remaining grasslands. Moderately suitable areas are found in the middle elevation plateaus, plains and valleys between some of the ranges. The not suitable areas (yellow) occur in transportation corridors such as from Tucson to Nogales, near some of the smaller urban areas, and in agricultural areas such as the San Simon Valley, Sulphur Springs Valley and Gila Valley below Safford.

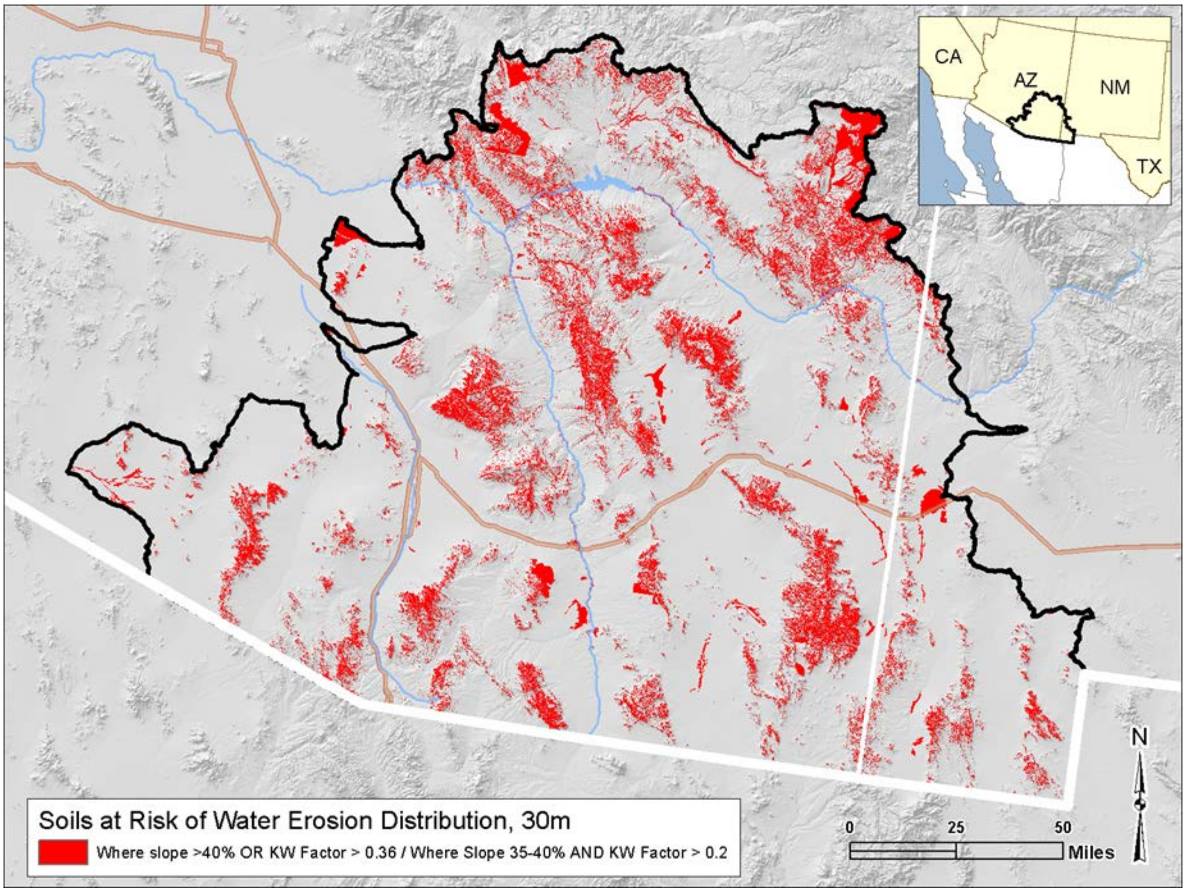
Figure 4-54. Suitability of restoration of mesquite-invaded uplands to grasslands or other native ecosystems. This map combines three variables: development, percent cover of mesquite, and the suitability of soils for grassland restoration. Yellow represents **not** suitable areas (due to intense development pressure, high cover of mesquite, or unsuitable soils).



4.4.3 Soil Erosion Potential

Soil erosion from extreme rainfall events interacting with other disturbances such as severe fires, can lead to significant sediment deposition into riparian or wetland areas and their associated aquatic habitats. Soil erosion can also lead to the loss of topsoil, downcutting of arroyos or washes and other undesirable effects. This assessment developed a map of soils susceptible to water erosion (Figure 4-55). The methods used to map these areas included both soils susceptible to erosion on steep slopes, as well as soils with a high erosion factor regardless of slope. The results indicate many of these erosion susceptible soils are in the higher elevation regions of the ecoregion, in and around the slopes of the sky islands. There are other areas of erodible soils not found on slopes, such as areas within some of the valley bottoms or in lower elevation basins.

Figure 4-55. Soils susceptible to water erosion; this map illustrates the result of combining soils with an erosion potential attribute and steep slopes.



5 Summary and Conclusions

5.1 Key Findings

5.1.1 Current Status, Integrity, and Recent Climate Trends

5.1.1.1 Current Ecological Status

Current ecological status was assessed for five terrestrial upland conservation elements (CEs), four aquatic CEs, five species and two species assemblage CEs. Generally across the three groups of CEs similar patterns were observed in the assessment results.

For the terrestrial uplands, the assessment shows that lower elevation CEs are the most impacted by the assessed change agents (CAs) within the ecoregion. Development and invasives CAs, the latter of which is often associated with development and human land use, are driving the degradation. This is most noticeable near urban and major transportation areas where there is a lot of infrastructure. The Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE and Madrean Encinal CE are greatly affected by both altered fire regime and invasives, with development also common in lower elevation stands. With fire exclusion, these CEs are vulnerable to increases in native shrub cover, especially invasive mesquite and juniper. The upper elevation CEs such as the pinyon-juniper woodlands and montane conifer forests are least impacted by development and more impacted by altered fire regimes. Some of these CEs show severe departure of the disturbance regime from its historical variability. The highest elevation stands are typically more departed because fragmentation of the landscape can impact the movement of fires that start in lower elevation savannas and woodlands and burn upslope into the montane zones.

For the aquatic CEs, the results are primarily driven by the stressor-based indicators (e.g. development, water use, invasive species), and suggest the majority of the lower elevation riparian areas are in much poorer condition than the higher elevations. This is because more development and higher water use occur along riparian corridors and alluvial fill found in the valley bottoms. These areas also generally contain the most developed part of the ecoregion, whereas the foothill and montane riparian areas have far less development and water use impacts. The Ciénega CE also shows a pattern of more impact closer to the heavily populated areas of the ecoregion. The playas have the most limited distribution in the ecoregion; these aquatic resources are also impacted by development, namely roads and railroad beds that cut across the face of playas and change the way water can move into and across the area.

Of the ungulates assessed in this REA, Coues white-tailed deer habitat has somewhat better ecological status than that of pronghorn or desert bighorn sheep. While invasives and altered fire regimes are affecting its habitat, the diversity of food plants deer can consume and the variety of habitat it utilizes suggest these factors may be somewhat tolerated by this species. Altered fire regimes and invasive species are the two factors affecting pronghorn status results; this is consistent with this species' reliance on healthy grassland habitat which in this ecoregion has been impacted by both change agents. Most of the desert bighorn sheep habitat is affected by severely altered fire regimes; studies in other parts of this species' range indicate fire suppression has altered density and composition of vegetation in desert bighorn habitat, resulting in loss of suitable habitat or herd declines (Cannings et al. 1999, Davidson 1991, Etchberger et al. 1989, Wakelyn 1987). Water use, recent burns, invasive species and development features are the main variables affecting the status of Chiricahua leopard frog habitat.

The results for both of the species assemblages, grassland birds and nectar-feeding bats, indicate that large portions of their habitat distributions are impacted by altered fire regimes and invasives species. As discussed earlier, invasive species whether exotic grasses or native mesquite, alter the composition and structure of the ecosystems upon which the animals in these two assemblages depend (Anable et al. 1992, Cable 1971, Gori and Enquist 2003, Gori et al. 2012, Muldavin et al. 2002, Turner et al. 2003). While the direct effects of these invasives could not be measured, the results do suggest generally areas where invasives are a serious issue, or alternatively may not be as abundant. There are known interactions between alterations of fire regime and the spread of invasive species, and their effects on the condition of grassland habitat. Mesquite has replaced many areas of native grasslands supporting the grassland birds. These grasslands also have agave species as a component (Gori et al. 2012) and mesquite invasion may lead to the loss of agaves upon which the bats feed (see NRCS 2014, ecological site description in the grassland case study above and Appendix D). Invasive grasses, such as the lovegrasses (*Eragrostis* spp.) have also been shown to result in the loss of agave species (Lindsay et al. 2010). The results are similar for the desert box turtle, with both altered fire regimes and invasives being the primary CAs affecting its habitat.

In summary, across the three groups of CEs, certain patterns can be discerned. First, while development activities can have major local scale impacts, it is generally a minor component of the results for the CEs found at higher elevations; most development occurs in, and hence has impacts upon, lower elevation areas including valley, floodplains, or in the foothill zones. Portions of CE distributions which are close to heavily populated or developed areas show the effects of the development, but this ecoregion has many small roads and highways which are pervasive through the area. They are hard to discern in the results when displayed at the ecoregion scale, but they do have local impacts on status. In addition, these local development features fragment the occurrences of the ecosystems (e.g. grasslands supporting bird assemblages or pronghorn herds) or species habitat. For example, corridors for pronghorn movement between or within separate herd home ranges are essential to maintaining gene flow and finding quality forage and water sources in summer and winter. Barriers to movement result from fragmentation and habitat loss caused by human development, in the form of fencing, mining, urban sprawl, and roads, railroads and highways, among others (AZGFD 2011).

Secondly, altered fire regimes are affecting most areas of the ecoregion. All of the terrestrial upland ecosystems have significant portions of their distribution with either moderate or severe departure from historical fire regimes. Most of the species also have poor ecological status across much of their distribution in relation to the fire regime indicator. For example, frequent stand replacing fire (fire return interval (FRI) of 2.5 to 10 years) was the fire regime characteristic of the Apacherian-Chihuahuan Semi-desert Grassland and Steppe CE historically before 1890 (Bahre 1985, Kaib et al. 1996, McPherson 1995, Wright 1980). During the century of fire suppression, widespread conversion of grasslands to shrublands occurred (McPherson 1995) and prescribed burning has been demonstrated to decrease shrub cover and increase native grass cover (Bock and Bock 1992, Robinett 1994). While fire regime and its alteration from the historical range of variability is not a direct measure for individual species, the habitat for all of the species CEs can be affected by the impacts of recent fires. For example increased sedimentation in Chiricahua leopard frog habitat due to erosion triggered by severe fires (USFWS 2007a) or shifts in vegetation structure due to fire suppression (increased density of shrubs) within the foraging range of bighorn sheep, which can lead to increased predation success (Etchberger et al. 1989).

Third, invasive species in both the uplands and the aquatic realm are a significant problem at the middle to lower elevations. The data for the invasives indicators was generally of poor to moderate quality, but the patterns are similar across all three groups of CEs. Lower elevations (i.e. not in the mountain ranges) are impacted by invasives, while the higher montane elevations are much less so. These results are not unanticipated; invasion by mesquite (*Prosopis* spp.), exotic grasses and forbs, tamarisk (*Tamarix* spp.) or Russian olive (*Elaeagnus angustifolia*) and exotic aquatic animal species, is well documented for this ecoregion and known to be a growing issue.

Lastly, water use is one of the greatest stressors affecting aquatic CEs in the Madrean Archipelago ecoregion, especially at lower elevations. While the water use data used in this assessment are spatially coarse, effects of high amounts of water use can be severe and cause stress to the plants and animals dependent upon the aquatic ecosystem and its associated riparian or wetland vegetation. The areas of high rates of water use are all basins in Arizona with either dense municipal development (Tucson AMA) or large areas of intensive irrigation (Pinal AMA, Douglas and Willcox basins). At least three of the species CEs are dependant upon surface waters and access to them: pronghorn, desert bighorn sheep and Chiricahua leopard frog. The conceptual models for all there of these discuss the importance of surface water for these species. For example, although bighorn are able to obtain much of the water that they need from their diet, the absence or reduction of succulent forage requires bighorn to seek out additional surface water. Decreased water resources and increased presence of predators at available water sites can expose bighorn to greater risk of mortality; in addition, warmer temperatures and lower precipitation may lead to increased water draw-downs by human populations (Heinz Center 2011, Southwest Climate Change Network 2008).

5.1.1.2 Ecological Integrity Assessment

Ecological integrity was assessed for five life zones: two for the aquatic realm (montane and lowland) and three for the uplands (montane, valley and desert). An additional analysis compared the change in extent of historical to the current distribution for upland ecological systems. For the five life zones, the results for the ecological integrity assessment of the ecoregion show similar patterns to those for the CEs. In general, the higher elevation regions have better ecological integrity, a result of less development and fewer invasive species, although fire regime departure is significant in all of the upland life zones. The Desert Scrub life zone has poor to moderate ecological integrity for much of its distribution, a result of fire regime alterations and proximity to heavily developed areas. In contrast, much of the Montane Forest life zone has moderate to good ecological integrity, although altered fire regimes are a real issue throughout much of the montane zone. The Valley Grassland life zone has low ecological integrity across much of its distribution. This life zone suffers from effects of all three indicators- substantial development impacts, problems with invasive species including mesquite, and moderately to severely altered fire regimes. Only a few areas in the northern portions of the ecoregion have good integrity.

The results of the change in extent analysis from historical to current area of terrestrial ecological systems show major changes in extent (as a percent of the ecoregion area) have occurred due to massive increases in Mesquite Upland Scrub (0% to 20%) and Chihuahuan Creosotebush Desert Scrub (0.5% to 13%) with subsequent large declines in all of the grassland ecological systems (Apacherian-Chihuahuan Semi-desert Grassland and Steppe (32% to 18%), Chihuahuan Loamy Plains Desert Grassland (4% to nearly 0%), Chihuahuan Bottomland and Swale Grassland (2% to nearly 0%)). In addition there has been a major decline in the extent of Sonoran Paloverde-Mixed Cacti Desert Scrub (21% to 11%), largely due to urban expansion from Tucson and surrounding areas and conversion to other desert scrub systems. There are only modest amounts of conversion from natural vegetation due to increases in post-European settlement (as a proportion of the ecoregion area) such as agriculture (to 1.3%) and development (to 3%).

Water use and development significantly reduce the ecological integrity of the Aquatic Lowland life zone, whereas the Aquatic Montane life zone has much better integrity based on this assessment. For the Lowland life zone, areas surrounding, and waters within, the Gila River downstream from the San

Simon River confluence, most of the San Pedro River, and most of the Santa Cruz River south of Tucson show high levels of impact from development, water use, and invasive species. The most altered watersheds are located in the areas of Safford, Willcox, and the Tucson metropolis, AZ. The least altered watersheds occur in the far west-southwestern corner of the ecoregion west and south of Sells, AZ; in the northern third of the lower San Pedro River basin; in the lower San Francisco River basin; and surrounding San Bernardino National Wildlife Refuge. The Aquatic Montane life zone occurs in areas that are generally not impacted by significant groundwater withdrawal and surface water diversions, nor are they as heavily exposed to development.

5.1.1.3 Recent Climate Trends

Statistically significant climate change is already occurring in the Madrean ecoregion, and these changes have a distinct spatial and temporal character. The increase in minimum monthly temperatures is the change that most frequently exceeds 20th century conditions across the largest area of the Madrean. In the months of May-August, average monthly minimum temperature values in recent decades exceed the vast majority of 20th century observed minimum temperatures over much of the ecoregion, with the most dramatic increases occurring in the lowest elevations. Recent increases in monthly maximum temperatures are less dramatic, yet still statistically significant, principally in late spring and early summer, and again primarily distributed in lower elevation areas. The nature of these changes has resulted in an overall reduction in the diurnal temperature range, as minimum temperatures are increasing more than maximum temperatures. An effort to analyze daily climate trends, rather than monthly averages, could further characterize the nature of this observed trend in climate change.

Recent changes in precipitation are more complicated to interpret, due in part to the natural variability of precipitation patterns in this region. For most months, there are regions of drying trends (generally in northern and western portions of the MAR) and regions of increasing precipitation (generally in eastern half of the MAR and at higher elevations). While trends comparing the most recent three decades to the 20th century baseline show many months and regions of increasing precipitation, trends *within* just the last 30 years show either no significant change (April-July) or a trend toward drying (August-November). Over the last 30 years, the strongest drying trend has occurred in October and November. These observations conflict with global climate model projections, which suggest an increase in precipitation in early fall (see below).

5.1.2 Future Near-Term Risk

This assessment was limited to assessing future development impacts for the 2025 timeframe using the development indicator and associated landscape condition scenario for the case study CEs and generating graphic overlays of potential urban expansion on these CE distributions. Additionally, separate maps of solar energy development potential are provided. The extent of likely future development (by 2025) is relatively small in the ecoregion; expected potential for expansion is centered around existing urban areas. Major new electrical transmission corridors (SunZia and Southline) are planned which will bisect the entire ecoregion and may affect a large number of CEs. They are the subject of an existing EIS process. The potential for solar energy development is extensive but no BLM solar energy zones exist in the ecoregion, therefore, specific impacts cannot be anticipated at this time. The more widespread risks are likely in the form of climate change (see below) and associated broad landscape change agents such as invasive species and fire.

5.1.3 Future Climate Trends and Implications

Based on the climate values projected by an average of six global climate models run under a moderately aggressive greenhouse gas emissions scenario, mid-century climate is projected to be well outside the range of 20th century climate patterns across the entire MAR. Relatively speaking, the northern MAR is projected to experience less overall climate change than the central and southern regions.

Consistent with recent temperature trends, climate models project substantial increases in maximum and minimum temperatures by mid-century. Also consistent with recent trends, minimum temperature changes are projected to be the most severe, with summer months experiencing greater minimum temperature increases than other seasons. Future summer minimum temperatures are projected to far exceed even the most extreme values experienced during the 20th century baseline. Maximum temperature increases are also projected to be most intense in the summer months, but not as extreme as minimum temperature increases.

Global climate model projections for moisture indices such as precipitation and CMD show a general drying trend across the ecoregion during the months of April through August, with much less change over the remaining months and even slight precipitation increases projected for some fall and winter months. The month with the largest projected increase is October, with a lesser but still significant increase in moisture indices for September. Moisture stress is projected to be most severe in late spring and early summer, with the average mid-century moisture deficit for April through June falling in the range of the most extreme 5% of 20th century baseline values across most of the region. It is difficult to project future monsoon patterns, as there is inconsistency between climate model precipitation projections and actual observed recent precipitation trends.

The average length of the growing season (frost-free period) is projected to increase dramatically in the MAR by the middle of the 21st century, with the frost-free period increasing by anywhere between 25 days (in the eastern MAR) and 55 days (in the west). These projected changes represent the most extreme values of the 20th century, and will be a notable departure from conditions of frost to which species and ecosystems in the region are adapted. Although a longer growing period may benefit some species, the combination of a longer warm period with decreased moisture availability and higher temperatures may significantly stress some species.

Of the four CE bioclimates modeled, the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe was projected to have the largest area of contraction as a percentage of its total current distribution, with relatively little overlap between modeled current and future distributions of suitable bioclimate. Based on projected shifts, foothills and mid-elevation habitats may be the most stable areas as future climate conditions unfold. The Madrean Encinal is projected to lose much of its current bioclimate in the future particularly in its Mexico distribution. Both of these suggest potential major shifts in the vegetation assemblages of the MAR in the grassland zone and hence potentially affecting habitat for pronghorn, grassland birds and the nectar-feeding bats.

5.2 Key Gaps and Limitations

A rapid assessment is, by nature, going to be limited to the use of available data, a short project timeframe, and resource limitations. This section highlights key gaps and limitations of the overall assessment; specific detailed information can be found in the appendices as well as a data quality assessment spreadsheet delivered to BLM. One of the major data gaps and limitations is that the Mexico portion of the ecoregion was not included in any of the data discovery steps or spatial analyses, other than for the bioclimate envelope modeling.

Following are gaps and limitations summarized for CEs, CAs, Climate Change Data, and Modeling Methods. Additional limitations on application of the products are covered in section 5.3.

5.2.1 Conservation Element Distributions

The distributions for all but one of the upland ecological systems use vegetation distributions derived from remote sensing data and ancillary predictive environmental data, which in turn incorporate rigorous methods for quality assurance and quality control. As with all land cover mapping, limitations pertain to the age of the satellite imagery used for the mapping (ca. 1999 to 2001), the scale (1 acre minimum mapping unit), and both spatial and thematic resolution of the mapping. The distribution for the Apacherian-Chihuahuan Semi-Desert Grassland and Steppe CE was derived from a different dataset, The Nature Conservancy's (TNC) mapping of grasslands throughout the MAR (Gori and Enquist 2007, Gori et al. 2012). This was used because it was completed more recently than the NatureServe (2013) map (which is based on 1999-2001 imagery), included many field-verified locations, and in addition has much value added because of the work to assign current condition classes to the mapped areas of grassland. Because the TNC data is spatially represented as large polygons of grasslands in different conditions (including areas of historic grasslands), the grassland polygons represent general areas of grasslands, and within those there are undoubtedly areas of woodlands, shrublands, bare ground, or even human development. This is one area of recommended improvements that could be done utilizing range assessments or other field based validations (for both the NatureServe-based and TNC-based distributions).

The estimated distributions of the riparian/stream and playa CEs in the Madrean Archipelago ecoregion rest on vegetation distributions derived from remote sensing data and national hydrography data, which in turn incorporate rigorous methods for quality assurance and quality control. However, hydrographic data on perennial, intermittent, or ephemeral flow characteristics, and how much of a playa depression may be wetted, does not capture the entire range of variability due to variation in weather and human water use. The estimated distribution of ciénegas in the ecoregion derives from Hendrickson and Minckley (1984) and extensive additional data mining carried out subsequent to this publication by TNC, which ground-checked individual sites with the cooperation of from numerous private landowners. Because point locations of cienegas on private lands are sensitive information, TNC made their dataset available to this assessment with the stipulation that cienega locations be represented on maps only by 6^{th}-level (HUC 12) watersheds (see Appendix B).

The distributions for the species conservation elements were derived from a variety of sources which in turn were developed with a variety of methods, from actual known herd locations for the ungulates, a predicted habitat distribution model for the desert box turtle, and utilizing mapped area of ecological systems for both of the assemblages. The Chiricahua leopard frog distribution is represented by small-scale watersheds (6^{th}-level/HUC 12s) within which it may or may not occur. Another key consideration with some species CE distributions is that they incorporate areas of non-habitat (e.g., areas already removed by highways) which affects the status assessment results by indicating impacted habitat where none currently exists. Recommended improvements include such things as field-inventories for desert box turtle populations allowing improvement of the habitat model for that CE; further reconciliation of ungulate distributions across state boundaries; and further work with the US Fish and Wildlife Service and state fish and game agencies on the consolidation and improvement of distribution data for Chiricahua leopard frog. Grassland birds are of particular interest and concern in this ecoregion. Treating the diverse suite of grassland birds as a single CE assemblage has limitations. Each of the species found in this assemblage has very different characteristics and needs, and an assessment that is pertinent to them all within the constraints of available data and a rapid assessment, necessarily results in generalized findings that will not shed light on the status of any individual bird species. In addition to different habitat needs (e.g., grass height, structure, grass species composition, amount of bare ground, etc.) some of these species are resident species, while others are migrants here only in the winter, and others migrants here only in the breeding season. Even at the general levels for this assessment, the species in the assemblage do not respond the same way to development or other human disturbances, fire, or non-native or invasive grasses/forbs or shrubs.

5.2.2 Change Agent Distributions

The CA data are of varying spatial resolutions and file format types (i.e., point, line, polygon and raster), and some of the CA datasets are modeled data (e.g. fire, mining footprints, etc.). Development is the most comprehensive and complete indicator used in the MAR assessment. It represents fairly accurately the locations of intensive agriculture, roads (both dirt and paved), rural and urban development, mines and related infrastructure, dams, canals, water diversions, power lines and pipelines. A key data gap, as in other REAs, is the absence of grazing data and thus this CA was not included in the assessment. Inaccuracies come from the categorization of the urban density and road type and some agricultural areas may be miss-classified as natural vegetation such as hay meadows that are no longer mowed or fallow fields filled with weeds.

No systematic, ecoregion-wide survey for aquatic invasive species has been conducted; data sets used for this assessment include intensive surveys, casual observations and plot-based data. While these data are highly accurate, they are by no means systematic across the entire ecoregion and certainly omit occurrences. Invasive plant species in the uplands is another major data gap. Although the Integrated Landscape Assessment Project (ILAP) had modeled data for percent cover of exotic invasive herbs, the ILAP team notes that it is a model with moderately high uncertainty due to the lack of field-based input data for known locations (and cover) of invasive plants. In addition it includes very few locations for some of the more invasive and ecologically disruptive species such as the lovegrasses (e.g. *Eragrostis lehmanniana*) and buffelgrass (*Pennisetum ciliare*). The ILAP model for mesquite density/cover is a better model than that for invasive exotic herbs, as there are more field-based locations for known occurrences of mesquite; and the input data were vegetation sampling plots, which include percent cover estimates and not just presence/absence. But both of these datasets are modeled “predicted” distributions of the 2 types of invasives, not actual mapped distribution of them that has been field-verified. Outside of the ILAP data, there is a lack of comprehensive (MAR-wide) current distribution or risk of occurrence data for exotic invasive plants. An additional limitation is that the analysis of status relevant to the invasives combined both the cover of exotic herbaceous plants and mesquite. The results for the invasives indicator hence need to be interpreted with caution, and substantiated by on-the-ground surveys. Consolidation and improvement of datasets for all types of invasives species is a much needed effort for the MAR, indeed for the entire western U.S.

Fire regimes are complex, and while a substantial body of work documenting current and past fire regimes across the southwest exists, many of these studies are local in nature. The efforts of LANDFIRE to model disturbance regimes, and their departure from reference or historic conditions, remains one of the only regional or national datasets available that spatially represents fire (or disturbance) regime departure. The LANDFIRE Vegetation Condition Class (VCC) dataset is not a direct measure of fire risk or fire regime departure from expected historic range of variability. It is calculated based on changes to species composition, structural stage, and canopy closure, and derived by comparing expected (historic) proportions of structural stages with current proportions (Rollins et al. 2007) within large enough summary landscape units to adequately represent the historic conditions versus current conditions. Hence the results from this indicator should not be over-interpreted relevant to current fire regime conditions; rather it provides a useful overview of where disturbance regimes in general are different from the expected historical regimes. Those differences can be due to a number of factors, such as impacts of drought and warmer temperatures over the past 20 to 30 years, increases in invasive grasses that introduce a regime of frequent fires to desert scrub ecosystems, the invasion of mesquite into upland grasslands due to the effects of many decades of land use practices, or effects of grazing or other activities that might alter the structural and compositional characteristics of the ecosystem. This indicator does provide an overview of general areas of fire regime alterations, and consultation of one of the many local studies can provide the more local context for interpreting the results related to local management needs.

Water use is one of the greatest stressors affecting aquatic CEs in the Madrean Archipelago ecoregion. However, estimates of water use for the ecoregion are spatially very coarse, and so do not support any discrimination of impacts at the scale of individual CE occurrences. Spatially more precise data do exist on water use – or at least on points of water extraction – but they are notoriously difficult to analyze because they typically catalog capacities and rights to extract or divert water, not actual rates of water use. Data on stream discharge and groundwater depths also exist, but from very sparsely distributed monitoring stations and/or for very short time periods. Further, even with point data on water diversions and withdrawals – or water consumption – it is not possible to determine where and with what severity the ecological effects of those uses will take place in desert ecosystems without hydrogeologic modeling. The effects mostly occur downstream in drainage basins and also down-gradient within groundwater systems. Determining these spatial relationships in desert ecosystems requires enormous amounts of spatially precise data and models of how water moves within the surface flow network, the groundwater system, and between the two at different scales of time and space (e.g., Baird et al. 2005). Further, desert aquatic ecosystems are affected by even small changes in water table depth and/or water inflows, representation of which may be outside the spatial and temporal resolution, data precision, and capability of most hydrogeologic models. Surface-groundwater models do exist for portions of the Madrean Archipelago ecoregion, but only for small portions of the ecoregion, with varying levels of spatial and temporal resolution, and varying capabilities to represent surface-groundwater interactions, e.g., for the Upper San Pedro River Basin (Lacher 2011) and Cienega Creek watershed (Bota and Maddock 1996) in Arizona, and the Lower Animas and Lordsburg Basins in New Mexico (Johnson and Rappuhn 2002).

The assessment of status for aquatic CEs incorporated data on actual conservation element condition. These were spatially very sparsely distributed and/or cover very short periods of observation. These data applied only to the riparian/stream conservation elements, and included data on biotic condition (integrity of fish, endangered species and stream macroinvertebrate assemblages) and geomorphic habitat condition. The BLM has collected extensive, standardized data on riparian-stream habitat condition using its Proper Functioning Condition protocol. However these data were not readily available in digital format for the entire ecoregion. Clearly the integration of the BLM data on riparian / stream habitat condition and bird data from numerous bird surveys (amateur and professional) would add substantially to the REA assessment results. The assessment also faced a large gap in knowledge of biotic conditions in the playas within the ecoregion, which have not been systematically surveyed. Databases exist on bird observations in the ecoregion, but these would have required experimentation to develop appropriate means for data mining and analysis, which is outside the scope of an REA.

Change agent data to represent the expected 2025 conditions was severely lacking. Adequate data was obtained to represent the development change agents but much of that is secure data that could be used in the assessment but not shared. Data gaps exist for invasive species and fire for 2025 that prevented the generation of a complete 2025 CE status assessment or ecoregion ecological integrity assessment.

5.2.2.1 Climate Change Data

Interpolation

Every gridded climate dataset involves interpolation, which contains an inherent degree of uncertainty. Interpolation is the estimation of unknown values based on surrounding data points. In the case of interpolated climate surfaces, historical and recent climate data from observations is restricted to scattered weather stations, whose density patterns generally reflect patterns of human settlement and are inherently biased towards easily accessible, low elevation sites. While temperature interacts with topography in a relatively predictable manner, the interpolation of precipitation, particularly over topographically complex regions, is a weakness of all gridded climate datasets. Therefore results of spatial and temporal precipitation analyses from gridded climate data are less certain than those for temperature, particularly over mountainous terrain. Observational uncertainty of current climate surfaces also limits the accuracy of future gridded climate surfaces because interpolated 20th century observations are used in the delta downscaling method.

Global Circulation Model Uncertainty

Any effort to understand the impacts of future climate change on biodiversity requires outputs from global circulation models (GCMs). GCMs attempt to capture the patterns, forcings, and feedbacks of the entire global climate system over time, and therefore are relatively limited in their direct applications to regional scale questions. GCMs often disagree in magnitude of change in climate and even disagree in the direction of future precipitation trends. One approach, supported by the climate modeling community to incorporate this kind of uncertainty, is to use multi-model ensembles in ecological forecasting analysis (Tebaldi and Knutti 2007). For the MAR climate trend analysis and bioclimatic envelope modeling, an ensemble of multiple GCMs is used (for example, taking the median value across GCMs for a climate trend or looking at the degree of model agreement for a bioclimatic envelope model).

Downscaling Limitations

The process of climate model downscaling allows the use of GCM outputs at much finer spatial resolution for regional scale impact analysis and planning. However, there are sources of uncertainty in the downscaling process itself in addition to the raw GCM outputs. For analysis of future trends for this REA, the future dataset was downscaled using the delta approach or change-factor approach. This approach has limiting assumptions; one being that the relationship between macro and microclimates remains constant over time (Tabor and Williams 2010). Although effects such as local interactions between land-surfaces and climate can change spatially and temporally, the delta method does not capture these effects because the process of downscaling takes a 20th century observational baseline and projects that climate to a future time period.

5.2.3 Modeling Methods

The primary limitation in the modeling methods used to conduct the status assesments is the ability to link the effect of remotely mapped (for the most part) CAs on individual CEs. The site intensity and distance values assigned in the CE response models (used in the status assessments) reflect expert judgment from the contractor team based on the conceptual models. As understanding of CA effects on CEs evolves, the site intensity and distance values can be updated and results refreshed.

Geospatial modeling always introduces assumptions and abstractions of actual ecosystem processes and CA effects. The many factors that can be observed and measured in the field cannot be fully captured with existing data and geospatial modeling. While the geospatial results can be field tested to some degree and calibrated to field observations, there will not be a one-to-one comparability between the

KEAs & indicators identified in the CE conceptual models and what can be assessed with existing data. This methodology also does not model interactions between CAs, for example to calculate an increase in the distribution or intensity of one CA based on the presence or effects of another CA. However, in some cases the inputs used for the MAR (e.g., fire regime) are based on more complex models that do incorporate such interactions. Some CAs reflect potential for impacts on CEs, rather than known impacts. For example, the invasive species data from ILAP predict likelihood of invasive species presence, rather than actual mapped distribution of them.

There are limited data on individual indicators and the ways in which they may have varied over time and space prior to significant human alteration. In addition, there is limited knowledge of the extent of past human activity and the ways in which it could have altered an ecosystem. This is important because the modeling approach used in this REA assumes the status of a CE is perfect in the absence of CA data and a negative CE response to a CA. Looking to the future, there is very limited knowledge of the possible effects of future climate change.

Identifying the "critical ranges of variation" for some KEAs – and, therefore, for some of their indicators, is often difficult, and hence ranges of variation may not be defined by natural thresholds. That is, there may not be a naturally discrete range of variation within which one would describe the status as "good" and outside of which one would describe the status as "not good." Instead, there may only be a gradient of conditions supporting more or less biological diversity, productivity, and ecological functional complexity (e.g., USEPA 2005; Davies and Jackson 2006).

5.2.3.1 Climate Change: Bioclimatic Envelope Modeling

There are many additional factors that can affect the performance of niche models, including the quality of the species locality data, the quality and choice of inputs for climate and/or environmental variables (see section 5.2.2.1 above), and the degree to which the chosen variables actually influence the target species. Niche models make several simplifying assumptions: they do not account for the varying dispersal ability of different taxa, they do not consider genetic or evolutionary adaptive potential across individuals or populations, and they do not account for the influence of biotic interactions. This is why results of bioclimatic envelope modeling should not be interpreted as shifts in CE distributions, but rather potential shifts in estimated suitable climate conditions defined by the CEs' locality data.

5.3 Potential Applications and Decision Support

The extensive source data and analytical results created in this REA can support innumerable applications in assessment and planning; the BLM REA portal provides an opportunity to explore the actual data through panning, zooming, querying, and overlays with other data sets. Scale of application and appropriateness of the data to specific management questions must be handled with care. In general, the results of the analyses are intended to be applied to landscape/watershed scale questions where the status of conservation elements and general patterns are informative. Because source data used in the REA had many different spatial resolutions, the 30 meter resolution of the modeled results implies greater precision than the scale at which it is appropriate to use the assessed data. Assessment results should not be used at a site-specific level: assessed results may be different between pixels, but users should review broad patterns, not small groups of pixels. In addition, modeling results may be limited because some data may not include complete distributions of the CEs or CAs or was a data gap and not included in the assessment. Questions that seek to establish firm boundaries on the ground or apply management actions will often require the use of supplemental, local data and on-site assessment and confirmation prior to completing decisions. Further, this REA, like all REAs did not systematically treat all biodiversity. In particular, many rare, imperiled, or legally protected species are considered “local species” that are not typically treated in REAs so the MAR REA results should not be used to screen projects for potential conflicts with such species.

This REA was largely conducted using the NatureServe Vista ArcGIS extension for ArcMap. The decision support project (.mxd and all associated data, database, and parameters) were delivered to BLM to facilitate a number of applications such as:

- Easily refreshing analyses with updated inputs (data or model parameters)
- Running analyses with different inputs or assumptions such as different reporting units or different parameters for the landscape condition model that computes CE status
- Incorporating other data to expand the analyses (e.g., other CEs, other scenario inputs or different scenarios)
- Assessing proposals for projects or actions such as large infrastructure or resource extraction projects, land management actions such as invasive species control, etc.
- Assisting development of Resource Management Plans or other landscape plans such as county comprehensive plans by assessing the current condition, and developing and assessing various alternatives

Currently NatureServe Vista can be downloaded for free from www.natureserve.org/vista. As noted in Appendix C, some proprietary/secure data sets had to be removed from the delivered version of the Vista MAR REA project which will prevent replicating a few of the analyses such as the 2025 development status for case study CEs. As of this writing, BLM was working to obtain permission to receive all confidential/sensitive data.

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7 Glossary

Analysis unit: An analysis unit is the spatial unit of analysis for ecoregional assessment and is the smallest area analyzed and used for regional planning purposes. The analysis units for ecoregional analysis may be a regular size and shape (e.g., square, hexagon) but also may be defined by a particular level of hydrologic unit or similar geographic feature.

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 historical, cultural, or scenic values, fish and wildlife resources or other natural systems or processes, or to protect life and safety from natural hazards (per the Federal Land Policy and Management Act of 1976).

Assessment Management Team (AMT): BLM's team of BLM staff and partners that provides overall guidance to the REA regarding ecoregional goals, resources of concern, conservation elements, CAs, MQs, tools, methodologies, models, and output work products. The team generally consists of BLM State Resources Branch Managers from the ecoregion, a point of contact (POC), and a variety of agency partners depending on the ecoregion.

Attribute: A defined characteristic of a geographic feature or entity.

Change Agent (CA): An environmental phenomenon or human activity that can alter/influence the future status of resource condition. Some CAs (e.g., roads) are the result of direct human actions or influence. Others (e.g., climate change, wildland fire, or 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 preserve elements occurring at finer spatial scales.

Community: Interacting assemblage of species that co-occur with some degree of predictability and consistency.

Conservation Element (CE): A renewable resource object of high conservation interest often called a conservation target by others. For purposes of this TO, conservation elements will likely be types or categories of areas and/or resources including ecological communities or larger ecological assemblages.

Development: A type of change (CA) resulting from urbanization, industrialization, transportation, mineral extraction, water development, or other non-agricultural/silvicultural human activities that occupy or fragment the landscape or that develops 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.

Ecological 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. The rating or ranking will be relative, either to the historical range of variability for that criterion (e.g., a wildland fire regime criterion) or relative to a time period when the criterion did not exist (e.g., an external partnerships/collaboration criterion). (also see *Status)*

Ecological System: In this REA, ecological systems are defined as groups of plant communities that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients; the term is used to refer to ecological systems as classified by Nature Serve (Comer et al. 2003) and mapped by NatureServe (2013)

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 (Omernik and Bailey 1997).

Ecosystem: The interactions of communities of native fish, wildlife, and plants with the abiotic or physical environment.

Element Occurrence: A term used by Natural Heritage Programs. An element occurrence generally delineates the location and extent of a species population or ecological community stand, and represents the geo-referenced biological feature that is of conservation or management interest. Element occurrences are documented by voucher specimens (where appropriate) or other forms of observations. A single element occurrence may be documented by multiple specimens or observations taken from different parts of the same population, or from the same population over multiple years.

Extent: The total area under consideration for an ecoregional assessment. For the BLM, this is a CEC Level III ecoregion or combination of several such ecoregions plus the buffer area surrounding the ecoregion.

Fine Filter: A focus of ecoregional analyses that is based upon conserving resource elements that occur at 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 always capture some concerns, such as when a listed threatened or endangered species is a conservation element.

Fire Regime: Description of the patterns of fire occurrences, frequency, size, severity, and sometimes vegetation and fire effects as well, in a given area or ecosystem. A fire regime is a generalization based on fire histories at individual sites. Fire regimes can often be described as cycles because some parts of the histories usually get repeated, and the repetitions can be counted and measured, such as fire return interval (NWCG 2006).

Fragmentation: The separation or division of habitats by intervening infrastructure (e.g., roads or utility corridors) or anthropogenic land uses (development, agriculture); as patches of habitat are increasingly divided into smaller and smaller units or increasingly isolated from other patches of habitat, their utility as habitat may be lost.

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

Grid Cell: When used in reference to raster data, a grid cell is equivalent to a pixel (also see *pixel*). When a raster data layer is converted to a vector format, the pixels may instead be referred to as grid cells.

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.

Heritage: See *Natural Heritage Program.*

Heritage Program: See *Natural Heritage Program.*

Hydrologic Unit: An identified area of surface drainage within the U.S. system for cataloging drainage areas, which was developed in the mid-1970s under the sponsorship of the Water Resources Council and includes drainage-basin boundaries, codes, and names. The drainage areas are delineated to nest in a multilevel, hierarchical arrangement. The hydrologic unit hierarchical system has four levels and is the theoretical basis for further subdivisions that form the *watershed boundary dataset* containing the 5th and 6th levels. (USGS and NRCS 2009).

Indicator: Components of a system whose characteristics (e.g., presence or absence, quantity, distribution) are used as an index of an attribute (e.g., land health) that are too difficult, inconvenient, or expensive to measure (NRCS et al. 2005).

Inductive Model: Geo-referenced observations (e.g., known observations of a given species) are combined with maps of potential explanatory variables (climate, elevation, landform, soil variables, etc.). Statistical relationships between dependent variables (observations) and independent explanatory variables are used to derive a new spatial model.

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. Species that become dominant for only one to several years (e.g., in a short-term response to drought or wildfire) are not invasives (modified from BLM Handbook 1740-2, Integrated Vegetation Handbook; see http://www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_handbook.Par.59510.File.dat/H-1740-2.pdf).

Key Ecological Attribute (KEA): An attribute, feature, or process that defines and characterizes an ecological community or system or entity; in conjunction with other key ecological attributes, the condition or function of this attribute or process is considered critical to the integrity of the ecological community or system in question. In the BLM REAs, various analyses will be conducted to calculate scores or indexes indicating the status of key ecological attributes for various Conservation Elements (CEs).

Landscape Species: Biological species that use large, ecologically diverse areas and often have significant impacts on the structure and function of natural ecosystems (Redford et al. 2000).

Landscape Unit: Because an REA considers a variety of phenomena, there will be many phenomena and process (or intrinsic) grain sizes. These will necessarily be scaled to a uniform support unit, which herein is called a *landscape unit*. This landscape unit will be the analysis scale used for reporting and displaying ecoregional analyses.

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

Metadata: The description and documentation of the content, quality, condition, and other characteristics of geospatial data.

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. Models imbed hypotheses about resource structures and functions, and they generate predictions about the effects of management actions. (Adaptive Management: DOI Technical Guide, Williams et al. 2009; see http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf).

Native Plant and Animal Populations and Communities: Populations and communities of all species of plants and animals naturally occurring, other than as a result of an introduction, either presently or historically in an ecosystem (BLM Manual H-4180-1;

see http://www.blm.gov/pgdata/etc/medialib/blm/wo/Information_Resources_Management/policy/blm_manual.Par.23764.File.dat/4180.pdf).

Native Species: Species that naturally occur in a particular geographic area and were not introduced by humans.

Natural Community: An assemblage of plant species or other organisms native to an area that is characterized by distinct combinations of species occupying a common ecological zone and interacting with one another.

Natural Heritage Program: An agency or organization, usually based within a state or provincial natural resource agency, whose mission is to collect, document, and analyze data on the location and condition of biological and other natural features (such as geologic or aquatic features) of the state or province. These programs typically have particular responsibility for documenting **at-risk species and threatened ecosystems. (See natureserve.org/ for additional information on these programs.)**

Occurrence: See *Element Occurrence*.

Pixel: A pixel is a cell or spatial unit comprising a raster data layer; within a single raster data layer, the pixels are consistently sized; a common pixel size is 30 x 30 meters square. Pixels are usually referenced in relation to spatial data that are in raster format. In this REA, some pixels sizes included 30 x 30 m and 2 x 2 km (also see *Grid Cell*).

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

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

Resource Value: An ecological value, as opposed to a cultural value. Examples of resource values are those species, habitats, communities, features, functions, or services associated with areas with abundant native species and few non-natives, having intact, connected habitats, and that help maintain landscape hydrologic function. Resource values of concern to the BLM can be classified into three categories: native fish, wildlife, or plants of conservation concern; regionally important terrestrial ecological features, functions, and services; and regionally important aquatic ecological features, functions, and services.

Scale: Refers to the characteristic time or length of a process, observation, model, or analysis. ***Intrinsic scale*** refers to the scale at which a pattern or process actually operates. Because nature phenomena range over at least nine orders of magnitude, the intrinsic scale has wide variation. This is significant for ecoregional assessment, where multiple resources and their phenomena are being assessed. ***Observation scale***, often referred to as sampling or measurement scale, is the scale at which sampling is undertaken. Note that once data are observed at a particular scale, that scale becomes the limit of analysis, not the phenomenon scale. ***Analysis*** or ***modeling scale*** refers to the resolution and extent in space and time of statistical analyses or simulation modeling. ***Policy scale*** is the scale at which policies are implemented and is influenced by social, political, and economic policies.

Scaling: The transfer of information across spatial scales. ***Upscaling*** is the process of transferring information from a smaller to a larger scale. ***Downscaling*** is the process of transferring information to a smaller scale.

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. The rating or ranking will be relative, either to the historical range of variability for that criterion (e.g., a wildland fire regime criterion) or relative to a time period when the criterion did not exist (e.g., an external partnerships/collaboration criterion).

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.

Stressor: A factor causing negative impacts to the biological health or ecological integrity of a CE. Factors causing such impacts may or may not have anthropogenic origins. In the context of the REAs, these factors are generally anthropogenic in origin.

Subwatershed: A subdivision of a *watershed*. A *subwatershed* is the 6th-level, 12-digit unit and smallest of the hydrologic unit hierarchy. Subwatersheds generally range in size from 10,000 to 40,000 acres. (USGS and NRCS 2009).

Value: See *resource value*.

Watershed: A watershed is the 5th-level, 10-digit unit of the hydrologic unit hierarchy. Watersheds range in size from 40,000 to 250,000 acres. Also used as a generic term representing a drainage basin or combination of hydrologic units of any size. (USGS and NRCS 2009).

Watershed Boundary Dataset (WBD): A national geospatial database of drainage areas consisting of the 1st through 6th hierarchical hydrologic unit levels. The WBD is an ongoing multiagency effort to create hierarchical, integrated hydrologic units across the U.S. (USGS and NRCS 2009).

Wildland Fire: Any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined and include wildfire, wildland fire use, and prescribed fire (NWCG 2006).

8 List of Abbreviations

Not all acronyms listed here have yet been applied in this REA; however, those listed have been commonly used in other REAs and so are included here.

AADT	Annual Average Daily Traffic
ACEC	Area of Critical Environmental Concern
AMT	Assessment Management Team
AR4	International Panel on Climate Change - Fourth Assessment Report
AZGFD	Arizona Game and Fish Department
BLM	Bureau of Land Management
CA	Change Agent
CCVI	Climate Change Vulnerability Index
CE	Conservation Element
CLF	Chiricahua Leopard Frog
COR	Contracting Officer Representative
CVS	Conservation Value Summary
CWNA	Climate Western North America
DEM	Digital Elevation Model
DMP	Data Management Plan
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
EIA	Ecological Integrity Assessment
EIS	Environmental Impact Statement
EO	Element Occurrence
EPCA	Energy Policy and Conservation Act
ESA	Endangered Species Act
ESA	Ecological Status Assessment
ESD	Ecological Site Description
FO	Field Office
FRI	Fire Return Interval
GA	Grazing Allotment
GCM	General Circulation Model
GIS	Geographic Information System
HMA	Herd Management Area
HRV	Historical Range of Variation
HUC	Hydrologic Unit Code
ILAP	Integrated Landscape Assessment Project
IPCC	Intergovernmental Panel on Climate Change
KEA	Key Ecological Attribute
LCM	Landscape Condition Model
LF	LANDFIRE (Landscape Fire and Resource Management Planning Tools)
MAR	**M**adrean **Ar**chipelago

MLRA	Major Land Resource Area
MQ	Management Question
MRDS	Mineral Resource Data System
NHD	National Hydrography Dataset
NHNM	Natural Heritage New Mexico
NMDGF	New Mexico Department of Game and Fish
NOC	BLM's National Operations Center
NPMS	National Pipeline Mapping System
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRV	Natural Range of Variability
NTAD	National Transportation Atlas Database
NWI	National Wetland Inventory
ORV	Off-road Vehicle
PRISM	Parameter-elevation Regressions on Independent Slopes Model
REA	Rapid Ecoregional Assessments
REAWP	Rapid Ecoregional Assessment Work Plan
RegCM	International Centre for Theoretical Physics Regional Climate Model
ROC	Receiver Operating Characteristic
SDM	Species Distribution Model
SDR	Southwest Decision Resources
SIA	Sky Island Alliance
SOW	Statement of Work (for REA contract)
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
SWAP	State Wildlife Action Plan
TWI	Topographic Wetness Index
USFWS	U.S. Fish and Wildlife Service
USFS	U.S. Forest Service
USGS	U.S. Geological Survey