Chihuahuan Desert
Rapid Ecoregional Assessment

Final Report


Photo: Jason Karl

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

October 2017

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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1 Executive Summary

This report constitutes the Phase II (i.e., Assessment) report for the Chihuahuan Desert Rapid Ecoregional Assessment, prepared for the U.S. Department of the Interior, Bureau of Land Management. This chapter summarizes the report.

1.1 Purpose and Structure of Rapid Ecoregional Assessments

Bureau of Land Management (BLM) Rapid Ecoregional Assessments (REAs) seek to provide information to natural resource managers concerning (a) ecoregional-scale ecological conditions and trends, (b) the major factors that shape these conditions and trends, and (c) opportunities to conserve ecological resources across management boundaries. REAs integrate diverse sources of information to support conservation, restoration, and the development of cohesive ecological management programs.

REAs provide a foundation for adaptive ecosystem management by summarizing current ecological understanding, and provide a baseline for comparisons with future data and understanding. These comparisons can examine ecological trends and the effectiveness of management practices, for example, to help ecological resource managers assess which practices are working and where practices need to be modified. REAs do not make management decisions. They provide information to help natural resource managers make good management decisions.

REAs do not address all ecological resources in an ecoregion, as this is an impossible task. Instead, they focus on a limited set of key resources, termed Conservation Elements (CEs), consisting of regionally-significant terrestrial and aquatic habitats and species of management concern. Additionally, REAs do not attempt to assess all threats to the CEs in an ecoregion, another impossible task. Instead, REAs focus on a limited set of key stressors, termed Change Agents (CAs). REAs also develop a set of specific, high-priority questions to answer concerning the CEs and CAs, termed Management Questions (MQs), which the REA seeks to address using geospatial data.

Each REA has two phases. During Phase I, the Pre-Assessment phase, the REA team identifies the Conservation Elements, Change Agents, and Management Questions on which to focus the REA. The REA team then develops conceptual models to (1) identify potentially measurable key ecological attributes for each Conservation Element; (2) document present understanding of how each Change Agent may affect each Conservation Element; and (3) provide a means for translating the Management Questions into terms specific to each individual Conservation Element and/or Change Agent. Phase II, the Assessment phase, uses existing geospatial data and publications to map the distribution of the Conservation Elements and, where feasible, assess the condition of these Conservation Elements, assess the impacts of the Change Agents, assess possible future impacts of Change Agents where appropriate, and address the key Management Questions identified during Phase I. The present report constitutes the Phase II or Assessment report for the Chihuahuan Desert REA.

The word “Rapid” in the term, “Rapid Ecoregional Assessment” bears emphasis. REAs collect no new data. They are built on existing data and published reports. REAs address large-scale conditions and concerns that cut across managerial boundaries, and work with Conservation Elements distributed across thousands of square miles. REAs necessarily focus on broad characteristics of these large areas that can be captured in large-scale geospatial data. As a result, ecological resource managers interested in applying REA findings always need to compare the results of any REA against finer-scale, local information before taking actions based on the REA findings. REAs do not replace fine-scale data or the expertise of local managers. Rather, they place local concerns in an ecoregional context and provide framework for considering integrated responses that address large scale change agents and resource issues. At the same time, REAs provide crucial information on gaps in existing large-scale data or knowledge, to help ecological resource managers identify needs for future monitoring and/or research.

1.2 Chihuahuan Desert REA Geographic Extent

Each REA focuses on an individual Level-III ecoregion or a group of adjacent Level-III ecoregions, based on the boundaries established by the U.S. Environmental Protection Agency (USEPA 2013). The Chihuahuan Desert Level-III ecoregion (see Chapter 2, Figure 2-1) covers portions of both the U.S. and Mexico (Wiken et al. 2011), with approximately three quarters lying within Mexico (Dinerstein et al. 2001, Monger et al. 2006). However, the Chihuahuan Desert REA addresses only lands within the U.S. The U.S. portion of the Chihuahuan Desert ecoregion covers significant portions of western Texas and southern New Mexico, extending north-south approximately from the latitude of Del Rio, Texas, to the latitude of Socorro, New Mexico, and east-west approximately from the eastern margins of the Pecos River valley westward to the Arizona border, with a small extension into southeastern Arizona. The Madrean Archipelago and Southern Great Plains REAs address the landscapes immediately to the west and northeast, respectively. Every REA addresses an area slightly larger than its Level-III ecoregion(s), termed the "analysis extent," that includes all watersheds that overlap the Level-III boundaries. The analysis extent for the Chihuahuan Desert REA overlaps with the analysis extents for the Madrean Archipelago and Southern Great Plains REAs.

The analysis extent for the Chihuahuan Desert REA includes parts of the BLM Albuquerque, Las Cruces, and Pecos Districts in New Mexico and part of the BLM Gila District in Arizona (see Chapter 2, Figure 2-2). The BLM does not operate district or field offices in west Texas. The analysis extent encompasses approximately 201,000 km^2 (approx. 77,500 mi^2). This includes approximately 2,000 km^2 (approx. 750 mi^2) in Arizona, 97,000 km^2 (approx. 37,400 mi^2) in New Mexico, and approximately 102,000 km2 (approx. 39,350 mi^2) in Texas. The BLM manages 36,488 km^2 (14,088 mi^2) of these lands, including 688 km^2 (266 mi^2) in Arizona and 35,799 km^2 (13,822 mi^2) in New Mexico.

The Chihuahuan desert is the largest desert in North America and the southernmost desert in the U.S., stretching from the Southwest U.S. to the Central Highlands of Mexico (see Chapter 2, Figure 2-1). The two dominant ground cover types in the U.S. portion of the ecoregion consist of grasslands and scrub, the relative areas of which have fluctuated back and forth at least three times in the past 3,000 years alone (Havstad and Schlesinger 2006). The perennial grasses in the U.S. portion of the ecoregion today, including black grama grass (*Bouteloua eriopoda*), may be relicts from wetter conditions during the mid-

Holocene (Havstad and Schlesinger 2006). Since the mid-1800s, shrub-dominated cover has expanded at the expense of grassland cover (NMDGF 2006, Ruhlman et al. 2012). The relative importance of the several possible causes for this latter transition, including excessive livestock grazing, climate change, and altered fire regimes, remain a matter of debate (Ruhlman et al. 2012).

The western two thirds of the analysis extent consists of a basin and range province of mostly north-south trending mountain ranges separated by broad desert basins (Monger et al. 2006) (See Chapter 2, Figure 2-3). Additional mountain ranges and high country occur in the region of the Big Bend of the Rio Grande, spanning the southernmost portion of the analysis extent. The easternmost lands of the analysis extent are less mountainous, including the western margins of the Llano Estacado, a high tableland that extends across much of northwestern Texas. Much of the eastern third of the Chihuahuan Desert REA analysis extent overlies the western formations of the Permian Basin, a distinctive geologic region with unique karst and cave features around its western margins. The Permian Basin also constitutes the most productive and heavily developed oil and gas region in North America.

Elevations within the Chihuahuan Desert REA analysis extent (See Chapter 2, Figure 2-3) reach to over 2,700 m above sea level in the San Andres Mountains in New Mexico, over 2,600 m in the Guadalupe Mountains straddling the Texas-New Mexico border, and over 2,500 m in the Davis Mountains in Texas. Other high mountain ranges within the U.S. portion of the ecoregion include the Oscura and Organ Mountains in New Mexico and the Sierra Diablo and Hueco, Eagle, Chinati, Del Norte, Chisos, and Glass Mountains in Texas. Several ranges with high peaks above 3,000 m straddle the boundaries of the analysis extent, including the Capitan and Sacramento Mountains between the Pecos and the central closed basins, and the Black Range and Magdalena Mountains along the west side of the Rio Grande basin in New Mexico. The lowest point in the analysis extent lies at 350 m above sea level where the Rio Grande enters Amistad Reservoir. Other low points, within closed basins, include Lordsburg Playa, 1,266 m above sea level, Playas Lake, 1,305 m, Lake Lucero, 1,188 m, and the Salt Basin near Dell City, TX, 1,102 m. This elevation range, combined with variations in topographic aspect, create a wide variety of macro- and micro-climates.

The analysis extent includes portions of three major rivers and their associated basins (see Chapter 2, Figures 2-3 and 2-4): the Gila River basin in the far west, the Rio Grande basin through the center and south, and the Pecos River basin in the east. It also includes a large portion of the closed Guzmán (aka Mimbres River) basin in the far southwest; a group of closed basins roughly in the center of the analysis extent, consisting of the Jornada del Muerto, Jornada Draw, Tularosa, and Salt basins; and a small portion of the Devil's River basin in the far southeast. The Gila River, Rio Grande, and Pecos River all originate outside the boundaries of the analysis extent; the Gila River and Rio Grande also continue flowing past the boundaries of the analysis extent. Flows along the Pecos River and Rio Grande are highly altered through the operations of numerous dams and diversions, both within and upstream from the ecoregion. The analysis extent also contains numerous perennial streams and rivers that originate and terminate entirely within its boundaries, springs, cenotes, seeps, playa lakes, and reservoirs, all with associated wetlands. Intermittently wetted runoff channels and playas also contribute to the diversity of wetted habitats in the ecoregion.

The U.S. portion of the Chihuahuan desert ecoregion is hot and dry, and experiences a wide range of variation in temperature across seasons and elevation (see Chapter 2, Figures 2-5 and 2-6). Maximum summer temperatures in the U.S. portion of the ecoregion, at an elevation of 1,300 meters, average 34 °C (93°F) and minimum temperatures in the coldest months average -5 °C (23 °F) (Wainwright 2006). Precipitation is low and highly variable (see Chapter 2, Figures 2-5 and 2-6). The northern portion of the ecoregion, at an elevation of 1,300 meters, receives an average of 245 mm (9.65 in) yr^{-1} of precipitation, accompanied by an average 220 cm (86.7 in) yr^{-1} of potential evaporation (Wainwright 2006). About half of the precipitation arrives in the form of convective storms during the late summer monsoon, supplied by moisture circulated from over the Gulf of Mexico. The remainder arrives in winter storms carrying moisture from over the Pacific Ocean. May and June are typically the driest months (Havstad and Schlesinger 2006). El Niño years typically bring 1.5 times the average winter (October to May) precipitation to the northern portion of the extent, while La Niña years typically bring half the average winter precipitation (Wainwright 2006). Neither El Niño nor La Niña conditions significantly affect summer moisture.

The biological and ecological diversity of the ecoregion, including its U.S. portion, are shaped by geologic and climatic history and diversity of the ecoregion, its high diversity of topographical settings including biologically isolating settings, and its location at the intersection of several terrestrial and aquatic biological regions. In combination, these conditions contribute to a high level of species richness and endemism (e.g., Dinerstein et al. 2001, see also the Pre-Assessment report, Chapters 2 and 5-17, Unnasch et al. 2017).

The U.S. portion of the Chihuahuan Desert ecoregion is mostly sparsely populated (see Chapter 2, Figure 2-7) with an economy based on ranching, irrigated farming, manufacturing, mining, oil and gas production, and military testing and training (Anderson and Gerber 2008). The Borderplex Region of Las Cruces, New Mexico, El Paso, Texas, and Ciudad Juarez, Chihuahua, Mexico, is the seventh largest manufacturing area in North America. Its combined population of approximately 2.5 million people, nearly 1.2 million of whom live in the U.S., shares use of the Rio Grande and local aquifers (Hogan 2013, Borderplex Alliance 2016, TWDB 2016). Other populous (populations > 20,000) urban areas in the U.S. portion of the ecoregion include Roswell, Alamogordo, and Carlsbad, New Mexico. Smaller urban areas include Artesia, Socorro, and Truth or Consequences, New Mexico, and Fort Stockton, Texas. Floodplain development for irrigated agriculture and other uses is widespread. Oil and gas production across the Permian Basin, with its associated access roads, pipelines, and waste management and pumping facilities, dominates the economy of southeastern New Mexico and a large adjacent portion of Texas.

1.3 Overview of the Chihuahuan Desert Ecoregion

The Chihuahuan desert is the largest desert in North America and the southernmost desert in the U.S., stretching from the Southwest U.S. to the Central Highlands of Mexico (see Chapter 2, Figure 2-1). The two dominant ground cover types in the U.S. portion of the ecoregion consist of grasslands and scrub, the relative areas of which have fluctuated back and forth at least three times in the past 3,000 years alone (Havstad and Schlesinger 2006). The perennial grasses in the U.S. portion of the ecoregion today, including black grama grass (*Bouteloua eriopoda*), may be relicts from wetter conditions during the mid-Holocene (Havstad and Schlesinger 2006). Since the mid-1800s, shrub-dominated cover has expanded at the expense of grassland cover (NMDGF 2006, Ruhlman et al. 2012). The relative importance of the several possible causes for this latter transition, including excessive livestock grazing, climate change, and altered fire regimes, remain a matter of debate (Ruhlman et al. 2012).

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1.4 Chihuahuan Desert REA Conservation Elements

The Chihuahuan Desert REA selected fourteen (14) Conservation Elements for assessment. These consist of three dry (terrestrial) ecological system types, five wet (aquatic-wetland) ecological system types, four individual species, and two assemblages of species of management concern associated with terrestrial ecological systems. Chapter 3, below, summarizes the process that led to the selection of these fourteen CEs, discussed in greater detail in the Pre-Assessment report (Unnasch et al. 2017). One of the aquatic-wetland CEs, "Playas and Playa Lakes," has both wet (inundated) and dry phases, and thus shares features with both wet and dry system types. The term, "ecological system" here refers to "… recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding" (Comer et al. 2003).

The Chihuahuan Desert REA Conservation Elements are as follows:

Dry-System (aka Terrestrial Ecological System) Conservation Elements

- Chihuahuan Desert Grasslands
- Chihuahuan Desert Scrub
- Pinyon-Juniper Woodlands

Wet-System (aka Aquatic-Wetland Ecological System) Conservation Elements

- Montane-Headwater Perennial Streams
- Lowland-Headwater Perennial Streams
- Large River-Floodplain Systems
- Springs-Emergent Wetlands
- Playas and Playa Lakes

Species and Species Assemblage Conservation Elements

- Pronghorn, *Antilocapra americana*
- Mule Deer, *Odocoileus hemionus*
- Banner-tailed Kangaroo Rat, *Dipodomys spectabilis*
- Black-tailed Prairie Dog, *Cynomys ludovicianus*
- Grassland Bird Assemblage (Arizona grasshopper sparrow, *Ammodramus savannarum ammolegus*; Baird's sparrow, *Ammodramus bairdii*; Cassin's sparrow, *Aimophila cassinii*; Chestnut-collared longspur, *Calcarius ornatus*; and Scaled quail, *Callipepla squamata*)
- Grassland Small Mammal Assemblage (Chihuahua deer mouse, *Peromyscus maniculatus blandus*; Hispid cotton rat, *Sigmodon hispidus*; Southern Plains woodrat, *Neotoma micropus*; Tawny-bellied cotton rat, *Sigmodon fulviventer*; and Yellow-nosed cotton rat, *Sigmodon ochrognathus*)

1.5 Chihuahuan Desert REA Change Agents

The Chihuahuan Desert REA addresses six Change Agents. These include the four overarching Change Agents addressed by all REAs: climate change, development, invasive species, and wildfire. Wildfire *per se* is a type of natural disturbance that can affect most – if not all – of the fourteen CEs selected for the Chihuahuan Desert REA. However, alterations to the natural fire regime that result in *unusual* fire patterns do constitute a Change Agent. The present REA therefore includes "uncharacteristic wildfire" as a Change Agent. The "development" CA for the present REA includes crop production, various types of commercial and industrial development including oil and gas production, and urban and suburban growth. The two additional Change Agents addressed by the present REA concern excessive domestic grazing and landscape restoration. Landscape restoration is not a stressor but an intentional counter-measure against some stressors that can bring about significant changes of interest to the BLM. Chapter 3, below, summarizes the process that led to the selection of these six CAs, discussed in greater detail in the Pre-Assessment report (Unnasch et al. 2017).

1.6 Chihuahuan Desert REA Management Questions

All REAs, including the Chihuahuan Desert REA, address four basic Management Questions concerning the geographic distribution of each CE, how the condition of each CE varies across its geographic distribution, the geographic distribution of each CA, and the forecasted future geographic distributions of impacts of those CAs for which forecasts are available. Table 1-1 lists these four core MQs, designated MQ A – MQ D, and indicates the CE(s) and CA(s) to which each question applies.

REAs also addresses additional MQs, focused on management concerns that cannot be resolved by individual offices alone and have regional importance. The Chihuahuan Desert REA addressed thirteen such additional MQs, which concern: (1) interactions between specific CAs and specific CEs; (2) specific attributes or indicators of individual CEs, such as particular habitat types or particular groups of species within an ecosystem; or (3) additional environmental conditions that can affect some CEs or CAs. Table 1-1 lists these thirteen additional MQs, designated MQ 1 – MQ 13, and indicates the CE(s) and CA(s) to which each question applies. Chapter 3, below, summarizes the process that led to the selection of these thirteen additional CAs for the Chihuahuan Desert REA, discussed in greater detail in the Pre-Assessment report (Unnasch et al. 2017).

1.7 Chihuahuan Desert REA Conceptual Ecological Models

The Chihuahuan Desert REA also developed conceptual ecological models for all fourteen Conservation Elements (see Chapters 4-17 in Unnasch et al. 2017). Conceptual models for ecological resources summarize scientific understanding about (1) how and why the condition of the resource varies in response to natural variation in driver conditions, and (2) how and why it would be expected to change in response to changes in driver conditions beyond natural ranges of variation. At the same time, the conceptual model for an ecological resource identifies the sources of information available concerning the resource and the drivers of its condition, and the certainty of this information. In effect, all statements in the conceptual model for an ecological resource constitute hypotheses about how characteristics of the resource are likely to vary or change as a result of changes in its drivers, including changes due to management actions. These hypotheses can then guide management action, including actions to test hypotheses to improve the model.

Table 1-1. Chihuahuan Desert REA Management Questions.

MQ #	Question	CE(s)	CA(s)
A	What is the geographic distribution of each CE?	All	n/a
B	What is the current condition of each CE across its geographic distribution?	All	n/a
C	What is the current geographic distribution of the impacts of each CA, both in general and in relation to each CE?	All	All except Climate Change, for which "current distribution" is the baseline for MQ #D.
D	What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?	All	Climate Change, Development
1	Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?	All Dry-System CEs	Landscape Restoration
2	What is the geographic distribution of the Chihuahuan desert amphibian assemblage?	All Dry- and Wet-System CEs	n/a
3	Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?	All Wet Systems	Uncharacteristic Wildfire
4	What areas of potential black-tailed prairie dog habitat would support restoration?	Black-tailed Prairie Dog	Landscape Restoration
5	Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?	All Species and Species Assemblage CEs	n/a
6	Where will urban and industrial growth impact intact grasslands or impede their recovery?	Chihuahuan Desert Grasslands CE	Development, Landscape Restoration
7	How do the current and historic geographic distributions of the dry-system CEs differ?	All Dry-System CEs	n/a
8	How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?	Grassland Bird Assemblage CE	Development
9	What and where are the aquifers and their recharge zones that support the wet systems?	All Wet-System CEs	Development
10	How do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?	All Wet-System CEs except Playas	n/a
11	Where are the breeding, winter, and year-around habitats for pronghorn and mule deer?	Pronghorn; Mule Deer	n/a
12	Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?	All Wet-System CEs	Invasive Species; Landscape Restoration
13	What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?	All	All except Climate Change

The conceptual ecological models developed for the fourteen Conservation Elements for the Chihuahuan Desert REA have three purposes: (1) to document present understanding of how each

Change Agent may affect each Conservation Element, (2) to identify potentially measurable "key ecological attributes" for each Conservation Element, and (3) to provide a foundation for translating each Management Question into terms specific to each individual Conservation Element and/or Change Agent to which the Management Question pertains. Overarching "dry system" and "wet system" conceptual models provide a hierarchical framework for organizing and integrating the conceptual models for the individual Conservation Elements, following the recommendations of Miller et al. (2010).

Key ecological attributes include defining physical, biological, and ecological characteristics of a Conservation Element, along with its abundance and/or spatial distribution. When one or more key ecological attributes of a CE become stressed in a specific setting, i.e., are altered so that they depart significantly from long-term historic conditions, the entire Conservation Element in that setting is degraded or, in extreme circumstances, will disappear. A well-constructed conceptual model for a Conservation Element necessarily identifies a *limited* set of key ecological attributes to represent the overall condition of the CE. Ecosystem complexity, the limits of scientific knowledge, and the constraints of budgets prevent evaluation of all possible characteristics and processes of any single resource. The key ecological attributes identified in the conceptual ecological models for the fourteen Conservation Elements for the Chihuahuan Desert REA served as crucial guides for identifying datasets for analysis during the Assessment phase of the REA.

1.8 Chihuahuan Desert REA, Assessment Phase Process

The Chihuahuan Desert REA followed the normal sequence of steps for Phase II. This sequence involved (1) reviewing the literature and working with the BLM and other agencies and organizations to identify and acquire the data and metadata needed to address the Management Questions, (2) designing and carrying out analyses of the data to address the Management Questions, and (3) assessing and documenting the findings. Chapters 4-10 present the results. Chapters 4-10 and an Appendix also describe in detail the data used and the methods and processes brought to bear in the assessment of these data.

1.9 Chihuahuan Desert REA Findings

1.9.1 Conservation Element Current Geographic Distributions

The REA mapped the current distributions of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs at the 30-m pixel scale based on the distribution of several closely related ecological system types. These three CEs together currently cover 84% of the lands within the analysis extent: Chihuahuan Desert Scrub, 59%, Chihuahuan Desert Grasslands, 22%, and Pinyon-Juniper Woodlands, 3%. Their current distributions largely reflect the interactions of topography and climate, specifically temperature and precipitation gradients.

The REA mapped the current distributions of twenty Montane-Headwater Perennial Streams, fifteen Lowland-Headwater Perennial Streams, and three Large River-Floodplain Systems based on a combination of information on their channel (flow line) locations and adjacent wetland and riparian vegetation. Montane-Headwater Perennial Streams are more common across the northern half of the analysis extent and Lowland-Headwater Perennial Streams more common across the southern half. Mapping of the current distribution of the Springs-Emergent Wetlands CE combined data on point locations with data on surrounding wetland vegetation. Occurrences of this CE are widely but extremely unevenly distributed throughout the analysis extent, with concentrations around the Davis and Del Norte Mountains, the Big Bend region, the southern San Andres Mountains, and the southern flanks of the Mogollon Mountains. Mapping of the Playas and Playa Lakes CE combined information on water bodies with information on surrounding barrens and potentially hydrologically associated vegetation communities such as wetlands and patches of phreatophytic vegetation. Small occurrences of the Playas and Playa Lakes CE occur throughout the analysis extent but large occurrences are limited to the larger closed basins, such as the Tularosa and Salt Basins, the Jornada del Muerto valley, and the Lordsburg and Playas valleys near the Arizona border.

The REA could map the current distributions of the Pronghorn and Banner-tailed Kangaroo Rat CEs at the 30-m scale only across the analysis extent within Arizona and New Mexico, but could map the current distribution of the Black-tailed Prairie Dog CE at this scale across the entire analysis extent. The assessment relied on polygon data for the distribution of the Mule Deer CE across the entire analysis extent, and included polygon data on the estimated ranges of the Pronghorn and Banner-tailed Kangaroo Rat CEs in Texas for reference. The current distributions of all four individual species CEs include essentially all areas dominated by the Chihuahuan Desert Grasslands CE, as well as areas along the northeastern edge of the analysis extent dominated Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe, ecological system types that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands. The current distribution of the Pronghorn CE also includes Pinyon-Juniper Woodlands areas. The Black-tailed Prairie Dog also occupies some areas of Pinyon-Juniper Woodlands as well as some areas of Chihuahuan Desert Scrub. The Mule Deer and Banner-tailed Kangaroo Rat distributions both also include areas of Chihuahuan Desert Scrub.

The REA could map the current distributions of the five species in the Grassland Bird Assemblage CE at the 30-m scale across the entire analysis extent. Among these five species, Cassin's sparrow is widely distributed year-round across almost the entire analysis extent. Scaled quail also is widely distributed, although differently than Cassin's sparrow. The other three species have more restricted distributions but do not occur in any area that is not also within the distribution of Cassin's sparrow or scaled quail. As a result, the combined distribution of the five species covers the entire analysis extent except for the highest elevations and a few barren areas. Their combined distribution includes areas dominated by the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs. The chestnut-collared longspur also occurs in riparian vegetation.

The REA located data on current distributions for four of the five individual species in the Grassland Small Mammal Assemblage CE. The REA could map the current distributions of the Southern Plains woodrat, hispid cotton rat, tawny-bellied cotton rat, and yellow-nosed cotton rat at the 30-m scale only across the analysis extent within Arizona and New Mexico. The current distribution of the Chihuahua deer mouse could not be accurately mapped. The Southern Plains woodrat occurs almost everywhere within the analysis extent in Arizona and New Mexico, except for riparian corridors, the extreme northeastern margin of the Pecos River valley, and some higher elevations. The hispid cotton rat also occurs almost everywhere within the analysis extent in Arizona and New Mexico, but can occupy riparian corridors and avoids higher elevations more than does Southern Plains woodrat. In contrast, the tawny-bellied cotton rat and yellow-nosed cotton rat distributions include only portions of the analysis extent west of the Rio Grande valley. However, neither of these latter two mammals occurs in any area that is not also within the joint distribution of the hispid cotton rat and Southern Plains woodrat. As a result, the combined distribution of the Grassland Small Mammal Assemblage CE covers almost all of the analysis extent in Arizona and New Mexico.

1.9.2 Conservation Element Current Conditions

The REA assessed the current conditions of the CEs using information on: (1) the distribution of impacts from the Change Agents, (2) current conditions for which no reference values are available, and (3) current conditions for which information on estimated reference conditions is available for comparison.

The indicators used to assess the current conditions of the three terrestrial ecological system CEs include estimates of vegetation cover density (percent cover) and height, a comparison of current generalized vegetation cover types with estimated conditions prior to Euro-American settlement, and an assessment of vegetation departures from natural disturbance regimes. The results indicate significant alterations from conditions prior to Euro-American settlement. Only 29% of the area estimated to have had predominantly grassland cover under historic conditions remains grassland today, while nearly 65% of the area estimated to have had predominantly grassland cover under historic conditions has transitioned to scrub today. In contrast, nearly 72% of the area estimated to have had predominantly scrub cover under historic conditions remains scrub today, while only 21% of the area of historic scrub cover has transitioned to grassland. Vegetation disturbance regimes, which affect not only vegetation cover composition but also structural stage and canopy closure, are estimated to be significantly altered over large areas of the analysis extent. However, several large areas also are estimated to have experienced very little departure from the historic disturbance regimes.

The REA used five indicators to assess the current conditions of the five aquatic-wetland ecological system CEs, including estimates of: (1) the current versus likely historic extent of riparian habitat, (2) the current extent of modification or conversion of natural river/stream channel to artificial hydrologic features, (3) the current extent of water quality impairment as defined under state water quality standards, (4) the current versus historic distribution of sensitive native fish species, and (5) the current distribution of the Chihuahuan Desert amphibian assemblage. Most of these quantitative indicators pertain only to the three perennial stream and large river CEs. The results indicate significant alterations to these CEs, including: (1) significant losses of riparian vegetation relative to historic conditions; (2) widespread artificial modification of stream and river channels; (3) impaired water quality along most of the lengths of the Pecos River and Rio Grande within the analysis extent, as well as along a few tributaries to all three large rivers and other perennial streams; and (4) widespread reductions in the distributions of native fishes. No historic data were located for comparison to the current distribution of the Chihuahuan Desert amphibian assemblage, but the REA noted the presence of significant development across the ranges of two of the four species.

The REA assessed the degree of vegetation departures from natural disturbance regimes across lands occupied by each of the four individual species CEs. The results indicate that, across the areas in which pronghorn are estimated to occur, nearly 70% currently shows moderate to large departures from natural disturbance regimes. This metric is lower for mule deer, at 66%, but higher, 73%, for the black-tailed kangaroo rat and even higher, 79%, for the black-tailed prairie dog. The vegetation disturbance regimes across the distributions of all four individual species CEs thus are moderately highly altered.

The REA also assessed the degree of vegetation departures from natural disturbance regimes across lands occupied by each of the two species assemblage CEs. The results indicate that approximately 65% of the area in which the Grassland Bird Assemblage CE occurs, and approximately 71% of the area in which the Grassland Small Mammal Assemblage CE occurs, has experienced moderate to severe departure from natural disturbance regimes.

1.9.3 Change Agent Geographic Distributions and Impacts

1.9.3.1 Climate Change

The assessment of climate change has two quantitative parts. The first focused on six seasonal and annual climate variables: the mean temperatures of the warmest and coldest quarters, annual mean temperature and mean annual precipitation, and the mean precipitation of the wettest and driest quarters that strongly affect ecological conditions across the U.S. portion of the ecoregion. This part of the climate change assessment compared historic conditions for these six variables, 1950-2000, to forecasted conditions in two future bi-decadal periods, 2041-2060 (period mean, 2050), and 2061-2080 (period mean, 2070). The second part of the climate change assessment used a larger suite of climate variables to model the ways in which climate change potentially will affect the relative distributions of grasslands, scrub, and woodlands. This second part of the climate change assessment compared historic conditions, 1950-2000, to forecasted conditions for 2061-2080 (period mean, 2070).

The results of the assessment of climate change indicate that the U.S. portion of the ecoregion will experience widespread increases in annual mean temperature, the maximum temperature of the warmest month, and the minimum temperature of the coldest month by 2050, with additional increases by 2070. At the same time, the U.S. portion of the ecoregion will experience widespread decreases in annual precipitation, precipitation of the wettest month, and precipitation of the driest month by 2050, with additional decreases by 2070. The forecasted increases in the three temperature variables across the current distributions of the three terrestrial ecological system CEs are all in the range of 2-3 °C by 2050, with an additional approximately 1 °C by 2070, while the forecasted decreases in annual precipitation are all in the range of approximately 16-20 mm by 2050, with further decreases of approximately 2-19 mm by 2070. The forecasted decreases in precipitation during the historically wettest month range from approximately 0.8 mm to 5 mm by 2050, with up to an additional 3 mm decrease by 2070. The forecasted decreases in precipitation during the historically driest month range from approximately 0.4 mm to 1 mm by 2050, with up to an additional 0.5 mm decrease by 2070.

The results of the quantitative modeling of the impacts of climate change by 2070 on the future distributions of the woodlands, grasslands, and scrub indicate that large areas of current grassland will likely transition to scrub cover, as will small areas current pinyon-juniper woodlands. Other areas of pinyon-juniper woodlands will likely transition to grassland, resulting in a significant loss of pinyon-juniper woodlands. However, the total area of pinyon-juniper woodlands that transition to grassland will be small, and not enough to make up for losses of grassland to scrub cover elsewhere within the U.S. portion of the ecoregion. As a result, grasslands also are forecast to experience a large net decrease throughout the U.S. portion of the ecoregion. These forecasted changes in vegetation cover reflect the increases in temperature and decreases in precipitation, with the increased temperatures necessarily resulting in increased rates of evapotranspiration loss, further increasing moisture stress.

The assessment of climate change also includes a summary of information from the conceptual ecological models developed for the Pre-Assessment report (Unnasch et al. 2017), addressing the ways in which forecasted changes in temperatures, precipitation, and evapotranspiration would be expected to affect the five aquatic-wetland ecological system CEs. The forecasted changes in temperatures, precipitation, and evapotranspiration within the ecoregion – and across the watersheds of the Gila River, Rio Grande, and Pecos River outside the ecoregion – would be expected to result in reduced surface runoff, reduced groundwater recharge, the disappearance of snowfall and snowmelt as components of the water budget resulting in further changes in both the magnitude and timing of mountain runoff and recharge, a greater rates of evapotranspiration losses of water across water bodies and their associated aquatic-wetland and floodplain vegetation. These changes in turn will result in altered runoff and baseflow magnitudes, more rapid seasonal declines in water tables, and reduced wetted surface areas, with attendant significant impacts on aquatic and wetland habitat quality. The magnitudes of these impacts on the aquatic-wetland CEs are difficult to forecast, however, because the same changes in regional temperatures and precipitation will also affect people and their patterns of water management and use. Increases in water use and changes in water management will have their own, additional impacts on the aquatic-wetland CEs.

1.9.3.2 Development

The REA mapped the current distribution of development using 30-m and vector data on six broad categories of development: (1) residential, commercial, industrial, other non-agricultural development; (2) military and other secured-area development; (3) agricultural development; (4) energy production and mining development; (5) transportation and utility development; and (6) water control development. The results show all major and minor features of development across the analysis extent, including all areas of high-, medium-, and low-density residential, commercial, and industrial development; all areas of irrigated agriculture, both along and away from the large-river floodplains; reservoirs; transportation corridors; oil and gas development; and water wells and tanks.

Residential, commercial, industrial, and irrigated agricultural development has eliminated natural wetland and floodplain habitat along a large fraction of the Gila River, Rio Grande, and Pecos River riparian corridors and elsewhere within the analysis extent. Water consumption and water management systems associated with residential, commercial, irrigated agricultural, and industrial development, including oil and gas production, have altered surface water hydrology and groundwater storage. These factors largely account for the losses of riparian habitat noted above.

Development has not substantially eliminated habitat for any of the four individual species CEs or the Grassland Bird Assemblage CE. However, development does overlap or conflict with species habitat in several local areas. Similarly, development has not substantially reduced the overall availability of habitat for any of the four individual species that comprise the Grassland Small Mammal Assemblage CE. However, development does overlap or conflict with habitat for this CE locally in numerous areas, including the large area of oil and gas production across southeastern New Mexico and western Texas.

The REA mapped forecasts of development across the analysis extent using data from the U.S. Environmental Protection Agency, Integrated Climate and Land Use Scenarios (ICLUS) project, Version 2 (USEPA 2009, 2016). The ICLUS methodology focuses on nine types of developed land cover, including parks and golf courses, low-density exurban land use, high-density exurban land use, suburban land use, low-density urban land use, high-density urban land use, commercial land use, industrial land use, and transportation infrastructure. The ICLUS methodology takes into account a range of climate forecasts and demographic and socioeconomic scenarios, along with information on the ways in which differences in climate – specifically differences in average monthly humidity-adjusted temperature and average seasonal precipitation for both summer and winter – affect migration between counties across the U.S.

The ICLUS results, across all climate forecasts and demographic and socioeconomic scenarios, forecast substantial expansions of developed land between 2010 and 2050, with moderate further expansions between 2050 and 2070. Areas of greatest extent of expansion are forecasted to include areas in New Mexico around Silver City and Deming, around Las Cruces, around and along a corridor connecting Alamogorda and Carrizozo, and around Roswell; around El Paso and Del Rio, Texas; and along and close to the Interstate Highway 10 and Interstate Highway 20 corridors in Texas from their intersection at Kermit, Texas, eastward, including the area around Pecos, Texas.

The REA did not include a quantitative, geospatial forecast of oil and gas development. However, the amounts of oil and gas predicted to be available within the Permian Basin under existing and emerging technologies, changes in oil and gas field development technologies, and continuing demand for both oil and natural gas, all strongly predict that oil and gas production will continue to expand spatially within the analysis extent. This development currently is concentrated in a part of the ecoregion largely dominated by the Chihuahuan Desert Scrub CE and, to a lesser extent, the Chihuahuan Desert Grasslands CE. Oil and gas development also is occurring in areas with cover types that are not parts of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs. The geology of the Permian Basin will confine future development of oil and gas resources roughly within the outer perimeter of the present overall geographic extent of such development.

1.9.3.3 Excessive Domestic Grazing

Livestock ranching in the U.S. portion of the ecoregion focuses on cattle ranching, with some sheep and goat ranching. Most grazing in Arizona and New Mexico takes place on public lands administered by the U.S. Forest Service and BLM, which control the spatial distribution and intensity of grazing through permits and leases for grazing on specifically designated lands, termed "allotments." The REA used data on the locations and boundaries of these grazing allotments. Most lands within the analysis extent in Texas are privately owned. U.S. Forest Service and BLM grazing allotments cover almost the entire analysis extent across Arizona and New Mexico. Notable exceptions include military reservations, publicly protected areas, developed lands, and reservoirs, and private lands. Grazing allotments generally do not exclude other compatible land uses, such as oil and gas production or wind and solar electrical generation. The allotments within the analysis extent in Arizona and New Mexico include nearly every area of occurrence of the Chihuahuan Desert Grasslands CE; nearly every occurrence of the Montane-Headwater Perennial Streams, Lowland-Headwater Perennial Streams, and Springs-Emergent Wetlands CEs, and many Playas and Playa Lakes; significant fractions of the distributions of all four individual species CEs; and significant fractions of the distributions of the species that comprise the Grassland Bird and Grassland Small Mammal Assemblage CEs.

Unfortunately, no systematic data were available on grazing intensity by allotment in Arizona and New Mexico, nor on the spatial distribution or intensity of grazing on private lands in any of the three states. Consequently, the REA could not assess how grazing intensity varies across the analysis extent, or how grazing intensity may be affecting any of the CEs.

1.9.3.4 Invasive Species

The REA examined the spatial distributions of fourteen regionally ecologically significant invasive plants – including invasive grasses, other herbaceous species, and woody species – across terrestrial habitats. Unfortunately, distribution data were available only at the county scale for these fourteen species. Such county records do not represent the results of systematic surveys to map the distributions of invasive species. As a result, it is not possible to assess how well they represent actual conditions that affect any particular CEs. However, the plant species involved are highly invasive, and their presence anywhere in a county can reasonably be taken as evidence of their widespread presence within that county – although not as evidence that they necessarily occur "edge to edge" in the county. The county distribution data indicate that the fourteen assessed species together cover every county within and overlapping the analysis extent many times over.

The REA also examined the spatial distributions of four regionally ecologically significant invasive plants and four ecologically significant invasive animals across aquatic-wetland habitats. Unfortunately, distribution data again were available only at the county scale for three of the four plant species, two of which also appear on the list of species assessed across terrestrial habitats. As noted above, however, the plant species involved are highly invasive, and their presence anywhere in a county can reasonably be taken as evidence of their widespread presence. Aquatic-wetland invasive plants, notably Russian olive and tamarisk (aka salt cedar) are present throughout the analysis extent. They are widely regarded as threats to native ecological communities and to the hydrology of the aquatic-wetland communities they invade. Other invasive species affecting the aquatic-wetland ecological system CEs have more limited distributions. However, neither the county data nor the point data on the other plant and four animal species represent the results of systematic surveys to map the distributions of these invasive species. As a result, it is not possible to assess how well they represent actual conditions.

1.9.3.5 Uncharacteristic Wildfire

The REA examined wildfire patterns in the U.S. portion of the ecoregion using data on: (1) the distribution of individual fires since 1985, both overall and in relation to each of the three terrestrial ecological system CEs; (2) vegetation departure from conditions expected under a historic fire regime, both overall and in relation to the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs; and (3) wildfire hazard potential overall. Numerous wildfires burned within the analysis extent between 1985 and 2016. A large proportion of the burns covered both grasslands and adjacent pinyon-juniper woodlands within the same perimeter. Overall, between 1985 and 2016, 3% of the area of the Chihuahuan Desert Scrub CE, 7% of the Chihuahuan Desert Grasslands, and 12% of the Pinyon-Juniper Woodlands CE experienced one or more burns.

The assessment of vegetation departures from natural disturbance regimes identified large departures across most of the current distribution of the Chihuahuan Desert Grasslands CE, largely but not exclusively a consequence of altered fire patterns. The results also indicate similarly severe departures across the majority of the current distribution of Chihuahuan Desert Scrub CE. In contrast, barely half of the current distribution of the Pinyon-Juniper Woodlands CE has experienced such large departures from natural disturbance regimes. The extensive, severe alteration of disturbance regimes across the distributions of the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs necessarily affect habitat for the four individual species CEs and two species assemblage CEs, the current distributions of which overwhelmingly fall within the distributions of these two terrestrial ecological system CEs. The assessment of vegetation departures from natural disturbance regimes identified large departures across the current distributions of the Spring-Emergent Wetlands and Playas-Playa Lakes CEs. In contrast, the current distributions of Montane-Headwater Perennial Stream, Lowland-Headwater Perennial Stream, and Large River-Floodplain CEs have experienced much less such alteration.

The REA used to the “Wildfire Hazard Potential” (WHP) metric developed by the U.S. Department of Agriculture, Forest Service (USDA FS 2015) to assess the relative potential for wildfires that would be difficult to contain. The results indicate three areas within the analysis extent with high to very high potential: across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range foothills; across a large portion of the upper Pecos River valley roughly from the vicinity of Roswell, New Mexico, northward; and along the east side of the entire Tularosa Basin. Areas with moderate potential include the northwest flanks of the Davis Mountains in Texas, the crest of the Guadalupe Mountains in Texas and New Mexico, and scattered low mountain ranges in far southwestern New Mexico.

The REA also sought data with which to assess how invasive species and wildfire patterns may interact. Unfortunately, the invasive terrestrial plant distribution data available to this REA proved too coarse for such a comparison.

1.9.3.6 Landscape Restoration

The REA assessment of landscape restoration used data on the locations and types of restoration work carried out in Arizona and New Mexico. Comparable data were not available for Texas. The data for Arizona and New Mexico unfortunately do not provide systematic information on the effectiveness of restoration efforts. However, the REA could assess the distributions of three broad categories of chemical, prescribed fire, and physical (e.g., mechanical) treatments reported in the dataset for Arizona and New Mexico, relative to the three terrestrial ecological system CEs. The results indicate that chemical and physical (mechanical) treatments have been applied more often to the Chihuahuan Desert Scrub CE than to the other two terrestrial ecological systems CEs. Prescribed fire treatments have been applied roughly equally the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs. Areas dominated by the Pinyon-Juniper Woodlands CE have received the least attention, across all three treatment types. Among the five aquatic-wetland ecological system CEs, chemical and prescribed fire treatments have been applied heavily to playas and playa lake occurrences, while prescribed fire and, especially, physical (mechanical) treatments have been applied heavily to the riparian corridors of large river-floodplain systems.

1.9.4 Management Questions

MQ 1: Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?

The REA sought to address MQ 1 through the analysis of landscape restoration data, as discussed above. However, as also noted above, the available data supported an assessment of where different types of treatments have been applied but not any analysis of the effectiveness of these treatments.

MQ 2: What is the geographic distribution of the Chihuahuan desert amphibian assemblage?

The REA examined the geographic distribution of sensitive Chihuahuan desert amphibians as part of its assessment of indicators of the condition of aquatic-wetland ecological systems, summarized above.

MQ 3: Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?

The REA addressed MQ 3 by combining data on the susceptibility of soils to erosion with the data on Wildfire Hazard Potential acquired for the assessment of uncharacteristic wildfire as a Change Agent. These data were used to identify 5th-Level watersheds with high risks of severe wildfire, across which the elimination of ground cover by such severe wildfires could result in significant soil erosion during subsequent runoff events. The resulting erosion could then potentially result in sedimentation and loss of habitat among aquatic-wetland ecological system occurrences into which the runoff flows. The distribution of these watersheds was then compared to the distributions of the aquatic-wetland ecological system CEs. These results identify several occurrences of the Montane- and Lowland-Headwater Perennial Stream and Playa-Playa Lake CEs that lie within the watersheds that meet the aforementioned criteria.

MQ 4: What areas of potential black-tailed prairie dog habitat would support restoration?

The REA addressed MQ 4 by identifying locations within the analysis extent that met four criteria: (1) The current ground cover at the location consists of grassland, including not only the Chihuahuan Desert Grassland CE but other types of grassland such as Western Plains grasslands, which the black-tailed prairie dog may inhabit as well. (2) The location falls within the species range but (3) does not fall within the current distribution of the species, indicating unoccupied habitat. (4) The location is not developed. The results indicate a substantial concentration of areas with restoration potential in the far west of the analysis extent, from the western margins of the Rio Grande valley westward to the far edge of the analysis extent in New Mexico but not significantly into Arizona. An arc of substantial areas potentially suitable for restoration extends eastward from the foothills of the Davis Mountains to the eastern edge of the analysis extent in Texas. Other areas of potential interest exist east and southeast of the vicinity of Kermit, Texas, and southeast to southwest of Carlsbad, New Mexico. Resource managers presumably would apply additional criteria to narrow down the resulting pool of locations, possibly including factors such as distance from local threats, accessibility for restoration and protection, available contiguous area, and others.

MQ 5: Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?

The REA addressed MQ 5 by combining the 30-m pixel distribution data for the thirteen species that comprise all of the individual species and species assemblage CEs taken together: pronghorn, mule deer, banner-tailed kangaroo rat, black-tailed prairie dog, Arizona grasshopper sparrow, Baird's sparrow, Cassin's sparrow, Chestnut-collared longspur, scaled quail, hispid cotton rat, Southern Plains woodrat, tawny-bellied cotton rat, and yellow-nosed cotton rat. At the request of the AMT, the REA also included in the assessment of MQ 5 the four species that comprise the Chihuahuan Desert amphibian assemblage: Arizona toad, Chiricahua leopard frog, Northern leopard frog, and Yavapai leopard frog. The REA then tabulated how many of these seventeen species are estimated to occur in each 30-m pixel, i.e., tabulated species richness by pixel. The results indicate that species richness is highest in the far west of the analysis extent in Arizona and New Mexico, and in fact generally high across most lands between Las Cruces, New Mexico and the Arizona border, although with several included patches of very low richness. An area of widespread, consistently high species richness also occurs within the Fort Bliss Military Reservation in New Mexico, extending southward from the foothills of the Sacramento Mountains toward and presumably into Texas. Species richness is lowest across all higher elevations, in the vicinities of all heavily developed areas in New Mexico within the analysis extent, and across barrens in the Tularosa Basin and the Jornada del Muerto valley east of Socorro, New Mexico.

MQ 6: Where will urban and industrial growth impact intact grasslands or impede their recovery?

The REA addressed MQ 6 as part of its assessment of the ICLUS forecasts of development and the spatial relationships of areas of forecast development with the current distribution of the Chihuahuan Desert Grasslands CE, summarized above.

MQ 7: How do the current and historic geographic distributions of the dry-system CEs differ?

The REA addressed MQ 7 as part of its assessment of the current conditions of the three terrestrial ecological system CEs, summarized above.

MQ 8: How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?

The REA addressed MQ 8 as part of its assessment of the ICLUS forecasts of development and the spatial relationships of areas of forecast development with the current distribution of the Grassland Bird Assemblage CE, summarized above.

MQ 9: What and where are the aquifers and their recharge zones that support the wet systems?

Systematic data were not located on the specific aquifers that supply the groundwater to the perennial streams, large rivers, springs, or playa lakes within the U.S. portion of the ecoregion. Hydrogeological studies have identified the aquifers that support particular aquatic-wetland resources, but only on a case-by-case basis. Such studies also often show that surface geology and topography do not consistently provide reliable clues to the locations of the recharge zones for individual groundwater flow paths. These flow paths often appear to depend on the presence and orientation of bedrock fault and fracture systems that act as either barriers or conduits to groundwater movement. The resulting patchwork of local studies does not lend itself to the kind of geospatial analysis appropriate for an REA.

However, groundwater recharge occurs in a generally well understood geographic pattern in the region. Mapping this pattern provides guidance on where recharge may be vulnerable to the effects of change agents. Specifically, groundwater recharge in the Southwest takes place in two general settings: (1) across mountain ranges and their foothills in the region, and (2) at lower elevations, focused along stream and river courses and across their floodplains, and along permeable irrigation ditches, during runoff and flood events and during irrigation delivery and return flows. Recharge takes place in the mountain and foothill settings because these are zones of greater precipitation and lower rates of evapotranspiration, often with coarser soils that allow for greater rates of infiltration. Recharge rates in these settings vary with the amount of precipitation received, whether the precipitation occurs as rain or snow (melting snow recharges more effectively than does rainfall), and air temperature through its effect on evapotranspiration. Recharge rates in the lowland settings vary with the amount of water present (e.g., from runoff) and air temperature through its effect on evapotranspiration.

The REA mapped these two general settings for recharge in the U.S. portion of the ecoregion based on the types of vegetation associated with these geophysical settings. The REA mapped areas of mountain recharge based on the distribution of conditions suitable for montane conifer and hardwood woodlands, which also require the greater magnitudes of precipitation and cooler temperatures that occur in these orographic settings. The REA mapped areas where focused, lower-elevation recharge may occur based on the distribution of conditions suitable for riparian vegetation. The data sources for these distributions consisted of models for the distributions of conifer and hardwood woodlands and riparian vegetation in the ecoregion prior to Euro-American settlement, based on their geophysical requirements.

The results identify multiple recharge areas within the analysis extent. These include the Sacramento Mountains, recharge across which is estimated to support groundwater flows to the Tularosa Basin, the Salt Basin immediately west of the Guadalupe Mountains, and Bitter Lake National Wildlife Refuge; the Guadalupe and Davis Mountains, recharge from which is estimated to support groundwater flows to numerous springs in west Texas, including the San Solomon Spring complex in the Toyah Creek watershed; and the mountains in the extreme west of the U.S. portion of the ecoregion in both New Mexico and Arizona, recharge from which supports the groundwater systems of the Animas and Lordsburg Basins and their associated playas. The results also correctly identify the Rio Grande along the Mesilla Valley as a large area of focused recharge for both river and irrigation water that also receives some groundwater from bedrock aquifers recharged in the adjacent mountain ranges.

MQ 10: How do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?

The REA addressed MQ 10 as part of its assessment of the current conditions of the perennial stream and large river-floodplain system CEs, summarized above.

MQ 11: Where are the breeding, winter, and year-around habitats for pronghorn and mule deer?

The REA sought to address MQ 11 by seeking systematic geospatial data with which to differentiate breeding, winter, and year-round habitats for these two species. Unfortunately, the REA could not locate appropriate datasets for this purpose.

MQ 12: Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?

The REA focused its work on this MQ specifically on the distribution of tamarisk beetles (*Diorhabda* spp.) across the analysis extent and its impact on their target plant, the tamarisk or salt cedar. Data maintained and provided by the Tamarisk Coalition (2016) indicate that tamarisk beetles first arrived in the analysis extent in 2010 along the Rio Grande in the Big Bend region. The beetle population then expanded along the Rio Grande and Pecos River and some of their tributaries as well as into the Tularosa Basin in 2012-2014, and expanded again in 2016 within the Tularosa Basin, along the Rio Grande, and westward toward the Arizona border. The Tamarisk Coalition data for each year also indicate locations where beetles previously had occurred but were no longer present in that year. The data provided by the coalition are current through 2016, and therefore include all locations where the beetle was absent in 2016 after having been observed in those locations in 2015. The “absence” locations in the 2016 data fall within the Tularosa Basin and along the Rio Grande and Pecos River potentially. Such locations indicate sites where the beetles have at least temporarily exhausted the supply of salt cedar on which they feed and which they thereby defoliate. The beetles potentially could also soon exhaust the supply of salt cedar in adjacent locations where they have fed for multiple years. Managers could target such sites of completed or imminent defoliation as areas potentially warranting restoration or treatments to control succession. However, the beetles can return quickly to locations where the tamarisk has recovered following prior defoliation by the beetles. Consequently, the data on absences in 2016 may no longer provide the best guidance on areas of particularly severe defoliation in 2017.

MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

This MQ focuses on the possible ecological effects of gypsic soils and waters on the CEs and CAs. The REA did not locate any single systematic geospatial database on the distribution of gypsic soil and water conditions across the analysis extent. Instead, the REA compiled and qualitatively tested a provisional model of this distribution. The model builds on a substantial body of reports documenting a strong relationship between the bedrock geology of the ecoregion and the distribution of gypsic geologic, geochemical, soil, and watershed conditions across the U.S. portion of the ecoregion. This relationship, together with the availability of data on the distribution of gypsum- and anhydrite-bearing geologic formations and gypsic soils across the U.S. portion of the ecoregion, makes it possible to assess the geographic distribution of localities where gypsic geochemical, soil, and watershed conditions may affect ecological conditions and resources.

The REA used geological and soils data to identify all 5th-Level watersheds within the analysis extent that contain soils with percent gypsum > 1% and/or surface exposures of any gypsic or anhydric geological formations. This set of watersheds closely matches the distribution of gypsophilous plant species across the region mapped by Moore and Jansen (2007). These watersheds span most of the New Mexico portion of the Pecos River basin and much of the Texas portion, including almost all watersheds originating in the Guadalupe, San Andres, Oscura, Davis, Glass, Chinati, and Chisos Mountains. The only substantial portions of the analysis extent not included in these watersheds are the plains east of the Pecos River in Texas, the plains east of the Pecos River in extreme southeastern New Mexico, and most of the ecoregion west of the Rio Grande. Current ground cover across these watersheds largely consists of the Chihuahuan Desert Scrub and Chihuahuan Desert Grasslands CEs, although some watersheds reach into higher elevations dominated by the Pinyon-Juniper Woodlands CE. Grasslands are more common in affected watersheds to the north, but grasslands are more common across the northern portions of the analysis extent in general. It should be noted that, as Moore and Jansen (2007) discuss, gypsophilous plants in the region tend to occur only in discrete patches with locally elevated soil gypsum levels within larger areas of grasslands and shrublands. The geologic and soils data appropriate for a rapid ecoregional assessment are not suitable for identifying such local soil patches. The data developed for the present REA provide the basis only for identifying watersheds within which such patches are likely to occur.

1.10 Data Gaps and Weaknesses

The individual chapters of this report, and their findings summarized above, identify several gaps and weaknesses in the data available for the present REA. Eliminating or reducing these gaps and weaknesses would enhance the abilities of resource management agencies to manage the ecological resources of the ecoregion.

1.10.1 Conservation Elements

The data available on the distributions of the aquatic-wetland ecological system CEs did not include information with which to categorize spring types based on their hydrology or geochemistry, or on the aquifers that supply each spring. Management concerns for individual springs may vary with such factors. The data available on the distributions of the aquatic-wetland ecological system CEs also did not include or distinguish sinkholes or cenotes as a groundwater-fed ecological resource type. Such features exist across the northeastern quadrant of the analysis extent because of its distinctive karst geology, and ecological studies indicate they can harbor diverse aquatic and wetland communities. Such communities may present unique management concerns.

Systematic geospatial data on the distributions of most individual species CEs and the species that comprise the Grassland Small Mammal Assemblage CE were not available for Texas, limiting some analyses in this REA to the analysis extent within only Arizona and New Mexico. These data may become available in the near future. Validation and/or refinement of the available distribution data would require systematic surveys on the ground.

The conceptual ecological models developed for the Pre-Assessment report (Unnasch et al. 2017) identified several key ecological attributes for each CE, systematic geospatial data on which would provide a basis for assessing the condition of each CE. The REA was not able to locate systematic geospatial data on indicators for the vast majority of these key ecological attributes, particularly for the terrestrial ecological system CEs and the species CEs and species assemblage CEs within them. As a result, the present REA mostly focuses on indirect information on CE condition, specifically information on the distributions of the CAs relative to the CEs.

1.10.2 Change Agents

A spatially explicit forecast of oil and gas development covering the entire analysis extent for the present REA would benefit ecological resource managers. The available forecast for the southeast corner of New Mexico provides a comprehensive template for such a larger-scale forecast. Assessment of the impacts of livestock grazing would be enhanced by the systematic availability of data on actual grazing intensities.

The availability of only county-level data on the distributions of invasive plants limited the ability of the REA to assess the impacts of these species on the native ecological resources of the ecoregion. County-level data are spatially too coarse to be of much use for management, and depend on voluntary reporting, the completeness of which cannot be evaluated. The point data used to examine the distributions of invasive species in aquatic-wetland settings also have clear weaknesses. The data also depend on voluntary reporting, the completeness or accuracy of which cannot be evaluated. Closing such gaps in knowledge would require systematic ground surveys. The database on landscape restoration treatments assessed in the present REA for Arizona and New Mexico did not include potentially useful information on the purposes or effects of individual treatments, or any data on treatments in Texas.

1.10.3 Models of Recharge Zone and Gypsic Conditions

The REA developed data models to represent two types of areas, for which there were no existing datasets: a model of the distribution of recharge zones for groundwater in the ecoregion, and a model of the distribution of gypsic soil and surface water conditions. Both of these provisional models would benefit from field studies to help fine-tune and validate their design.

1.11 Chihuahuan Desert REA Assessment Report Structure

The Chihuahuan Desert REA Assessment report consists of eleven (11) chapters, including the present chapter. Chapter 2 presents an overview of the ecoregion and how it “works” as a set of interconnected ecological systems. Chapter 3 presents the Conservation Elements, Change Agents, and Management Questions for the REA, and summarizes the processes followed to select these crucial REA building blocks. The Pre-Assessment report (Unnasch et al. 2017, Chapter 3) discusses the selection of the Conservation Elements, Change Agents, and Management Questions for the REA in greater detail. Three chapters address the Change Agents: Chapter 4 addresses climate change, Chapter 5 addresses development and grazing, and Chapter 6 addresses invasive species, uncharacteristic wildfire, and landscape restoration. In turn, Chapters 7-10 address the current distribution and, when feasible, the condition of the individual Conservation Elements, and address the Management Questions that bear on each Conservation Element. Specifically, Chapter 7 addresses the terrestrial ecological system Conservation Elements, Chapter 8 addresses the aquatic-wetland ecological system Conservation Elements, Chapter 9 addresses the four individual species Conservation Elements, and Chapter 10 addresses the two grassland species assemblage Conservation Elements. Chapter 11 summarizes the findings of the REA and offers recommendations concerning data management, monitoring, and research needs. An Appendix provides detailed information on the datasets used and data processing steps undertaken for all analyses.

2 Introduction to the Chihuahuan Desert Rapid Ecoregional Assessment

This chapter parallels Chapter 2 in the Chihuahuan Desert REA Pre-Assessment report (Unnasch et al. 2017), and includes background information on the ecoregion also provided in the Pre-Assessment report.

2.1 Purpose and Structure of Rapid Ecoregional Assessments

BLM REAs seek to provide natural resource managers with systematic information concerning (a) ecoregional-scale ecological conditions and trends, (b) the major factors that shape these conditions and trends, and (c) opportunities to conserve ecological resources across management boundaries. REAs provide a foundation for adaptive ecosystem management, by summarizing current ecological understanding and providing a baseline for comparisons with future data and understanding. These comparisons can examine ecological trends and the effectiveness of management practices, for example, to help ecological resource managers assess how well management practices are working. REAs are advisory, and offer recommendations only on needs for closing gaps in available data.

No REA can ever hope to address all ecological resources in an ecoregion. Instead, each REA focuses on a limited set of key resources, termed Conservation Elements (CEs), consisting of regionally-significant terrestrial and aquatic habitats and species of management concern. Similarly, no REA can ever hope to assess all threats to the CEs in an ecoregion. Instead, each REA focuses on a limited set of key causes of change, termed Change Agents (CAs). Each REA then develops and prioritizes a set of specific questions to answer concerning the CEs and CAs, termed Management Questions (MQs), which the REA seeks to address using geospatial data.

REA development occurs in two phases. During the Pre-Assessment phase (aka "Phase I"), the REA team identifies the CEs, CAs, and MQs on which to focus the REA, and prepares conceptual ecological models for all CEs. The conceptual model for each CE: (a) identifies potentially measurable key ecological attributes for the CE; (b) documents present understanding of how each CA may affect the CE; and (c) provides a foundation for translating MQs into CE-specific terms. During the Assessment phase (aka "Phase II"), the REA team uses existing geospatial data and published information to map the distribution of the CEs at an ecoregion-wide scale and, where feasible using existing data, assess the condition of these CEs, assess the distribution and impacts of the CAs, assess possible future impacts of CAs where appropriate, and address the MQs raised during Phase I. The present report constitutes the Assessment (Phase II) report for the Chihuahuan Desert REA.

As noted in the Pre-Assessment report, REAs are called "rapid" because they collect no new data and do not exhaustively review the literature. REAs address large-scale conditions and concerns that cut across managerial boundaries and can be addressed using large-scale geospatial data. They place local concerns in a regional context and provide framework for considering integrated responses that address large-scale change agents and resource issues. REAs do not replace fine-scale data or the expertise of local managers, and field offices always need to compare the results of REAs against finer-scale, local information before taking actions based on REA findings. At the same time, REAs provide crucial information on gaps in existing large-scale data or knowledge, to help ecological resource managers identify needs for future monitoring and/or research.

2.2 Purpose and Structure of the Chihuahuan Desert Assessment Report

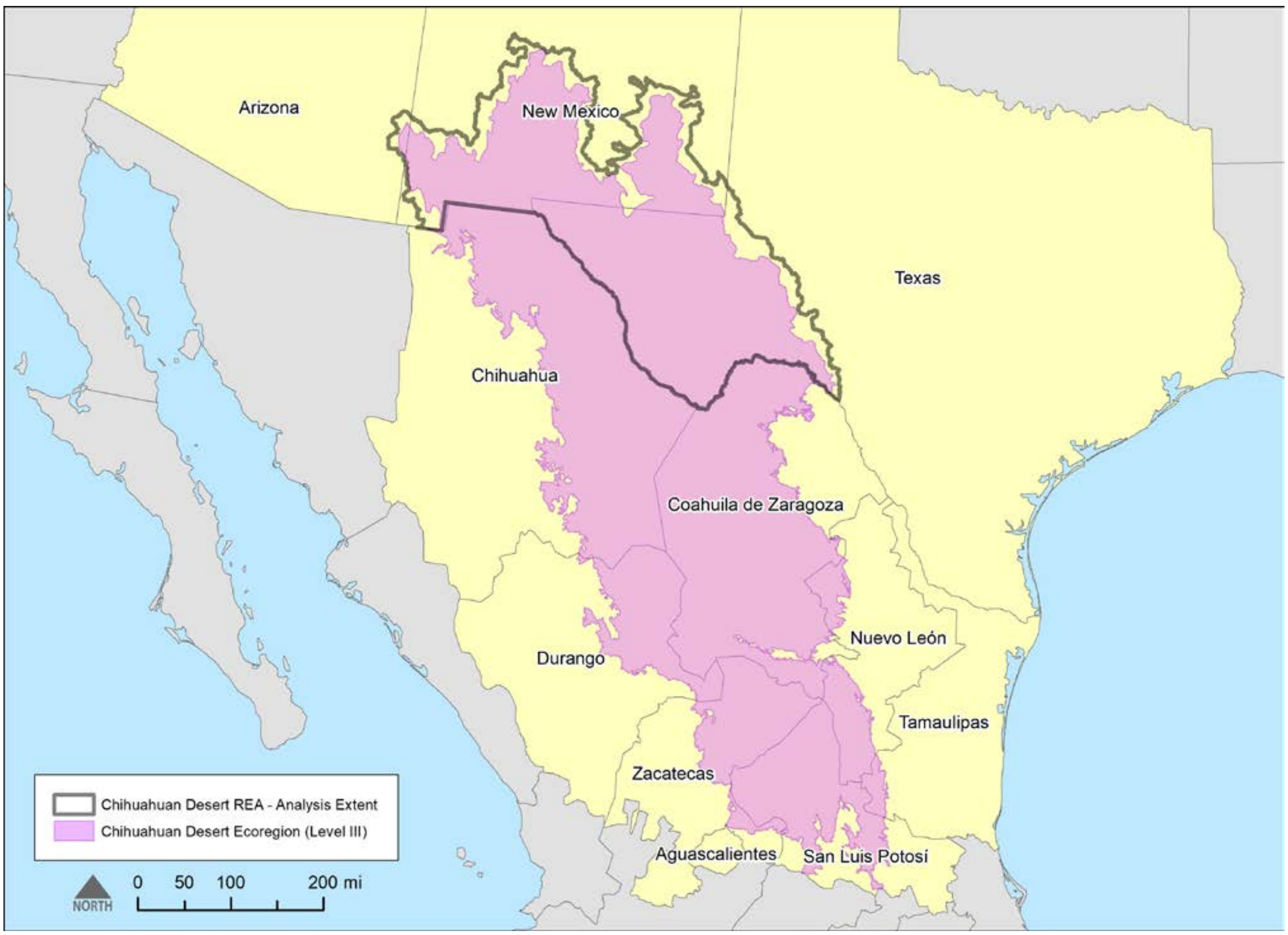
The present report is the second of two reports on the Chihuahuan Desert REA, as noted above. The present report consists of 11 chapters, including an Executive Summary (Chapter 1). The present chapter introduces the ecoregion and presents background information on how the ecoregion "works" as a set of interacting ecological and human systems. The present chapter repeats or summarizes a significant portion of the information presented in Chapter 2 of the Pre-Assessment Report (Unnasch et al. 2017). The information from the Pre-Assessment report is provided here for easier reference, because Chapters 4-10, below, all refer to this information. Chapter 3 of the present report reviews the REA methodology and the CEs, CAs, and MQs selected for the Chihuahuan Desert REA. Chapter 4 presents an assessment of climate change, one of six CAs assessed in the present REA, and its potential impacts on the present CEs, with particular emphasis on terrestrial CEs. Chapter 5 assesses two CAs, development – both present and forecasted – and grazing. Chapter 6 assesses the remaining three CAs selected for the Chihuahuan Desert REA, invasive species, uncharacteristic wildfire, and landscape restoration. Chapters 7-10 assess the current distribution and, where feasible, the condition of the individual CEs, and address the MQs that bear on each CE. Chapter 7 specifically focuses on terrestrial ecological system CEs, Chapter 8 on aquatic-wetland ecological system CEs, Chapter 9 on individual species CEs, and Chapter 10 on two grassland species assemblage CEs. Chapter 11 summarizes the findings of the REA and offers recommendations concerning data management, monitoring, and research needs.

2.3 Chihuahuan Desert Ecoregion and REA Analysis Extent

As discussed in the Pre-Assessment report (Unnasch et al. 2017), each BLM REA focuses on an individual Level-III ecoregion or a group of adjacent Level-III ecoregions. The Chihuahuan Desert ecoregion is designated as Level-III ecoregion No. 24 (USEPA 2013) (Figure 2-1). It covers portions of both the U.S. and Mexico (Wiken et al. 2011). In fact, approximately three quarters of the Chihuahuan Desert Level-III ecoregion lies in Mexico (Dinerstein et al. 2001, Monger 2006). However, as with all REAs for ecoregions that straddle the borders of the U.S. with Canada or with Mexico, the Chihuahuan Desert REA addresses only lands within the U.S. The U.S. portion of the Chihuahuan Desert ecoregion covers significant portions of western Texas and southern New Mexico approximately from the eastern margins of the Pecos River valley westward to the Arizona border, with a small extension into southeastern Arizona.

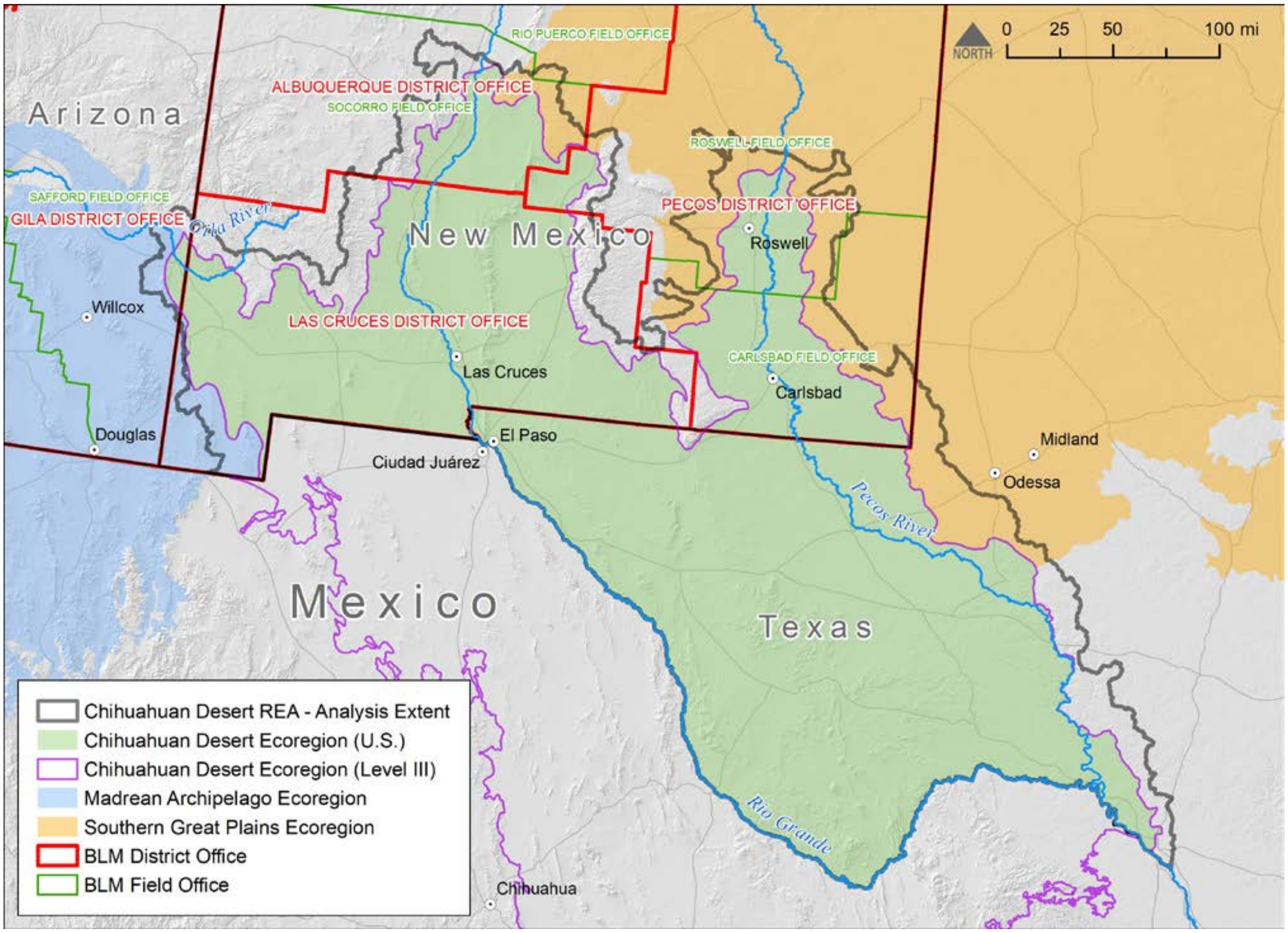
Every REA addresses conditions not only within the Level-III ecoregion of interest but also within all watersheds – specifically, watersheds identified by a 5th-Level (aka "10-digit") Hydrologic Unit Code (HUC; Seaber et al. 1987) – that overlap the boundaries of the target Level-III ecoregion. The resulting watershed-based "analysis extent" necessarily includes adjacent portions of neighboring Level-III ecoregions. The analysis extent for the Chihuahuan Desert REA, shown in Figure 2-1 and Figure 2-2, includes small portions of adjacent Level-III ecoregions for which the BLM has undertaken an REA: the Madrean Archipelago ecoregion to the west (Crist et al. 2014) and the High Plains and Southwestern Tablelands to the north and northeast. The Southern Great Plains REA addresses the latter two together with the Central Great Plains Level-III ecoregion. The analysis extent for the Chihuahuan Desert REA also includes small portions of three other adjacent Level-III ecoregions for which the BLM has not undertaken an REA: the Edwards Aquifer and Southern Texas Plains ecoregions to the southeast, and the Arizona/New Mexico Mountains ecoregion to the northwest. A peninsula of mountains classified as a section of the Arizona/New Mexico Mountains ecoregion also extends into the analysis extent for the Chihuahuan Desert REA from the north.

Figure 2-1. The Chihuahuan Desert ecoregion and REA analysis extent.



The U.S. portion of the ecoregion includes parts of the Albuquerque, Las Cruces, and Pecos BLM districts in New Mexico, which include the Roswell, Socorro, and Carlsbad Field Offices, and also includes part of the Gila District, Safford Field Office in Arizona (Figure 2-2). The BLM does not operate district offices in west Texas. The analysis extent includes approximately 201,000 km^2 (approx. 77,500 mi^2). This includes approximately 2,000 km^2 (approx. 750 mi^2) in Arizona, 97,000 km^2 (approx. 37,400 mi^2) in New Mexico, and approximately 102,000 km^2 (approx. 39,350 mi^2) in Texas. The BLM manages 36,488 km^2 (14,088 mi^2) of these lands, including 688 km^2 (266 mi^2) in Arizona and 35,799 km^2 (13,822 mi^2) in New Mexico.

Figure 2-2. The U.S. portion of the Chihuahuan Desert ecoregion, analysis extent, and adjacent REAs.

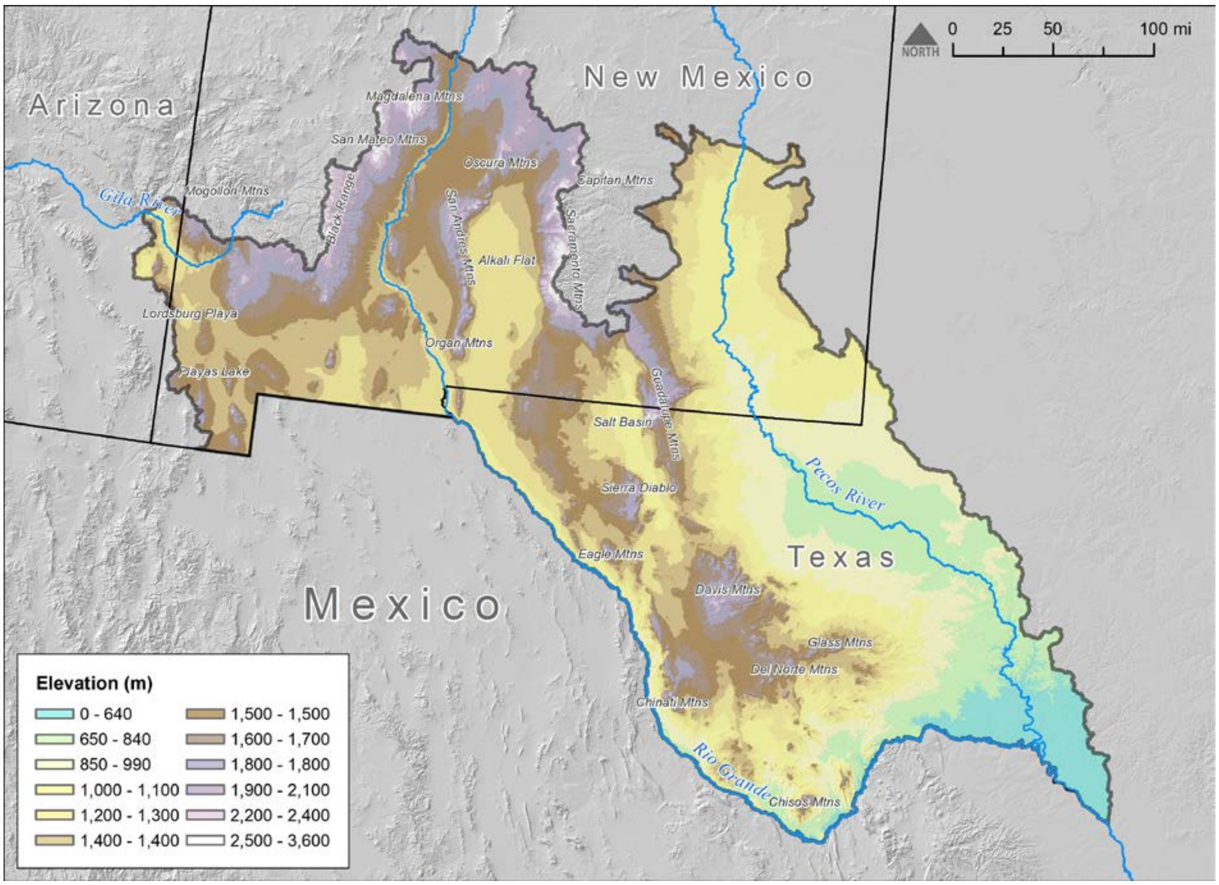


2.4 Chihuahuan Desert Biophysical Setting

This section of Chapter 2, along with the following two sections—Chihuahuan Desert Biodiversity, and Chihuahuan Desert Human Landscape—together summarize information on how the ecoregion “works” as a set of interacting ecological and human systems. Together, these three sections describe the biophysical setting that shapes the biodiversity of the ecoregion, the resulting broad patterns of biodiversity across the ecoregion, and the patterns of human land- and water-use across the ecoregion that further shape the present distribution and condition of the ecological resources of the region.

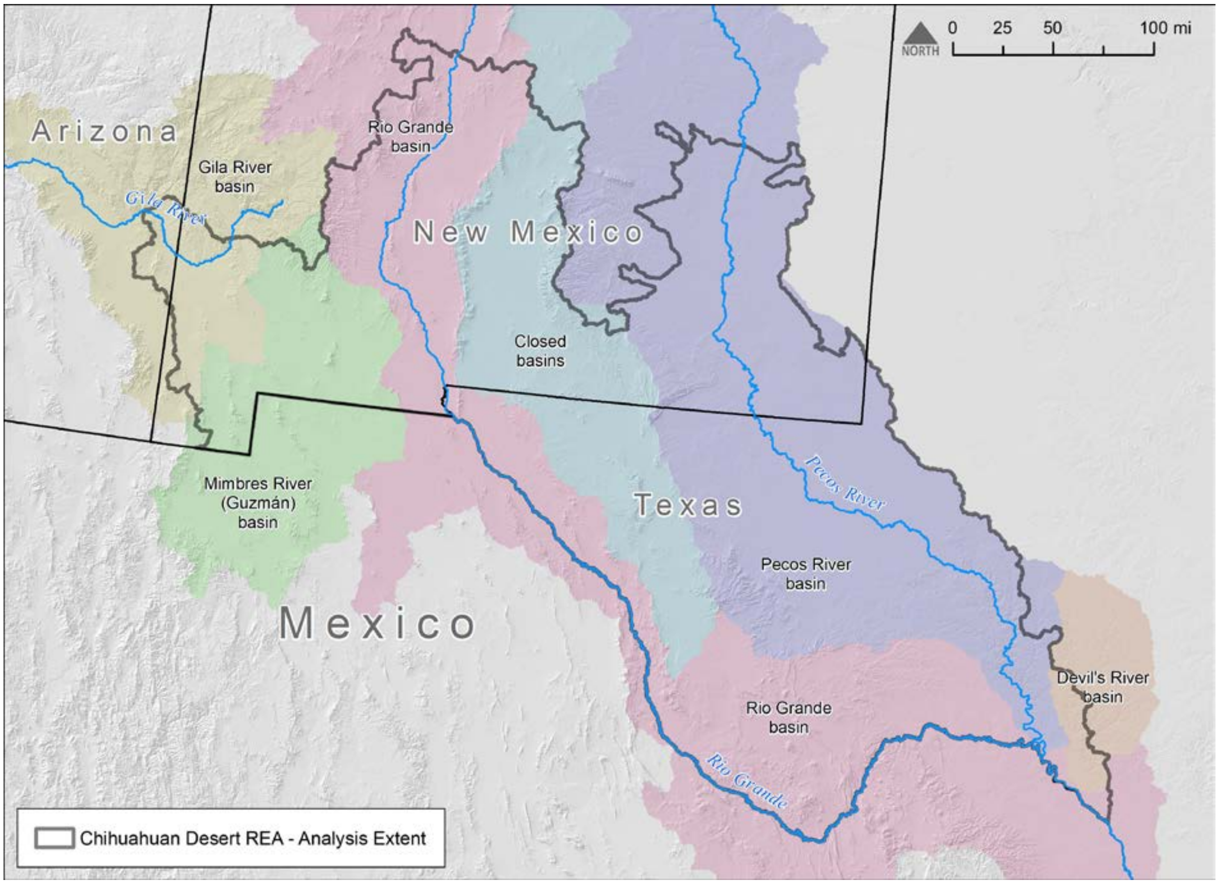
The Chihuahuan desert, the largest desert in North America, stretching from the Southwest U.S. to the Central Highlands of Mexico (Figure 2-1). It is the southernmost desert in the U.S. and the only one located east of the Continental Divide (Havstad et al. 2006). It is in some respects a relatively young ecoregion, having developed its major ecological characteristics only within the past 9,000 years as a result of changes in climate following the end of the Pleistocene (Havstad et al. 2006). The dominant ground cover in the U.S. portion of the ecoregion may have transitioned from grassland to shrubland and back three times in the past 3,000 years alone (Havstad and Schlesinger 2006). The perennial grasses in the U.S. portion of the ecoregion today, including black grama grass (*Bouteloua eriopoda*), may be relicts from wetter conditions during the mid-Holocene (Havstad and Schlesinger 2006). Since the mid-1800s, shrub-dominated cover has expanded at the expense of grassland cover (NMDGF 2006, Ruhlman et al. 2012). The relative importance of the possible causes for this latter transition, including excessive livestock grazing, climate change, and altered fire regimes, remain a matter of debate (Ruhlman et al. 2012). Chapters 4-7, below, present geospatial assessments that address the current distribution of grassland versus shrub-dominated cover, the condition of these broad cover types, and the potential impacts of climate change, livestock grazing, and altered fire regimes.

Figure 2-3. Topographic relief and major landforms.



In other respects, the Chihuahuan desert is an ancient ecoregion, formed millions of years ago in the rain shadow created by the development of the mountains that today comprise the Continental Divide. The ecoregion subsequently has experienced volcanic activity, the rising of mountains and sinking of portions of the Earth's crust, and flooding beneath lakes and seas for millions of years (Dick-Peddie 1993). The resulting topographic diversity promotes and sustains a high diversity of habitats that help make possible the ecoregion's high native biodiversity.

Figure 2-4. Major drainage basins across and extending beyond REA analysis extent.



The western two thirds of the ecoregion in the U.S. consist of a basin and range province of mostly north-south trending mountain ranges separated by broad desert basins (Monger et al. 2006) (Figure 2-3). Additional mountain ranges and high country occur in the Big Bend region spanning the southernmost portion of the ecoregion within the U.S. The easternmost lands of the ecoregion within the U.S. are less mountainous, consisting of portions of the Llano Estacado, a high tableland that extends across much of northwestern Texas.

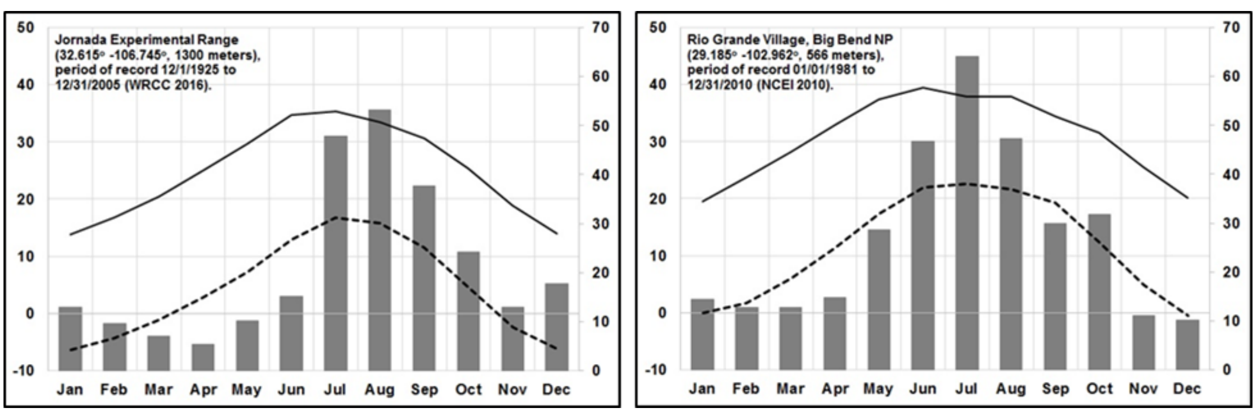
Elevations within the analysis extent for the Chihuahuan Desert REA (Figure 2-3) reach to over 2,700 m above sea level in the San Andres Mountains in New Mexico, over 2,600 m in the Guadalupe Mountains straddling the Texas-New Mexico border, and over 2,500 m in the Davis Mountains in Texas. Other high mountain ranges within the U.S. portion of the ecoregion include the Oscura and Organ Mountains in New Mexico and the Sierra Diablo and Hueco, Eagle, Chinati, Del Norte, Chisos, and Glass Mountains in Texas. Several ranges with high peaks above 3,000 m straddle the boundaries of the analysis extent, including the Capitan and Sacramento Mountains between the Pecos and the central closed basins, and the Black Range and Magdalena Mountains along the west side of the Rio Grande basin in New Mexico. The lowest point in the analysis extent lies at 350 m above sea level where the Rio Grande enters Amistad Reservoir. Other low points, within closed basins, include Lordsburg Playa, 1,266 m above sea level, Playas Lake, 1,305 m, Lake Lucero, 1,188 m, and the Salt Basin near Dell City, TX, 1,102 m. This elevation range, combined with variations in topographic aspect, create a wide variety of macro- and micro-climates.

The analysis extent for the Chihuahuan Desert REA includes portions of three major rivers and their associated basins (Figure 2-3 and Figure 2-4): the Gila River basin in the far west, the Rio Grande basin through the center and south, and the Pecos River basin in the east. It also includes a large portion of the closed Guzmán (aka Mimbres River) basin in the far southwest; a group of closed basins roughly in the center of the analysis extent, consisting of the Jornada del Muerto, Jornada Draw, Tularosa, and Salt basins; and a small portion of the Devil's River basin in the far southeast.

2.4.1 Climate

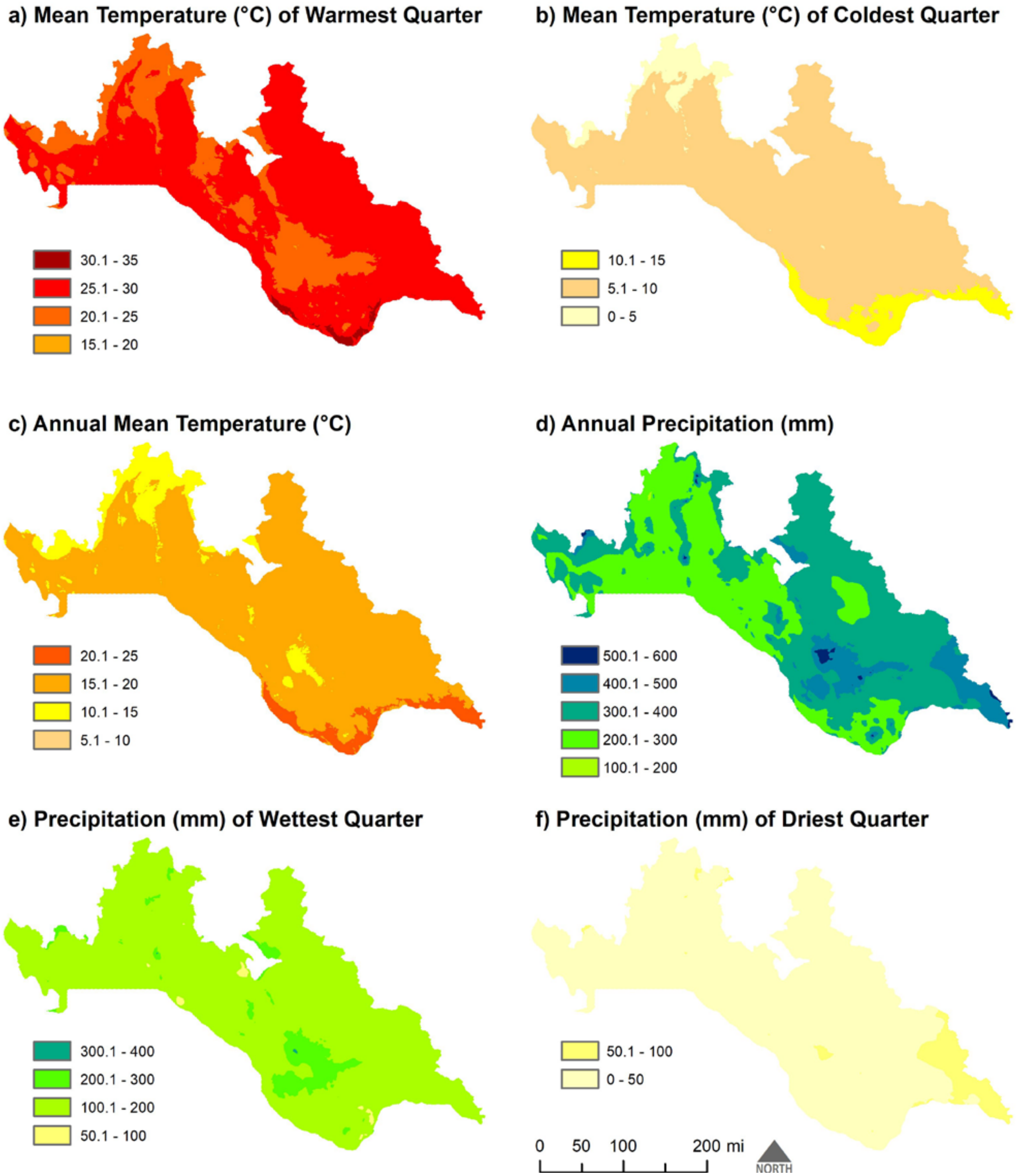
The U.S. portion of the Chihuahuan desert ecoregion experiences a wide range of variation in temperature, as shown in Figure 2-5 and Figure 2-6. Maximum summer temperatures in the U.S. portion of the ecoregion, at an elevation of 1,300 meters, average 34 °C and minimum temperatures in the coldest months average -5 °C (Wainwright 2006). Precipitation is low and highly variable (Figure 2-5 and Figure 2-6). The northern portion of the ecoregion, at an elevation of 1,300 meters, receives an average of 245 mm yr^{-1} of precipitation, accompanied by an average 220 cm yr^{-1} of potential evaporation (Wainwright 2006). About half of the precipitation arrives in the form of convective storms during the late summer monsoon, supplied by moisture circulated from over the Gulf of Mexico. The remainder arrives in winter synoptic storms, supplied by moisture from over the Pacific Ocean. May and June are typically the driest months (Havstad and Schlesinger 2006). El Niño years typically bring 1.5 times the average winter (October to May) precipitation to the northern portion of the extent, while La Niña years typically bring half the average winter precipitation (Wainwright 2006). Neither El Niño nor La Niña conditions significantly affect summer moisture.

Figure 2-5. Monthly average maximum (solid line) and minimum (dashed line) temperatures (°C), left axis, and precipitation (gray bars) (mm), right axis, at the Jornada Experimental Range, New Mexico, (left; WRCC 2016), and Rio Grande Village in Big Bend National Park, Texas (right; NCEI 2010).



Several factors are responsible for the overall aridity of the ecoregion. The ecoregion is located far from oceans, in a band of dry subtropical high pressure produced by global circulation. Additionally, it lies in the rain shadows of the Sierra Madre Occidental and Sierra Madre Oriental in Mexico and the mountain ranges along and west of the Continental Divide in the U.S. These ranges prevent most moisture-laden winds from the south and west from reaching southern New Mexico and western Texas (Schmidt 1986).

Figure 2-6. Spatial patterns of six climatic variables: Mean temperature of the (a) warmest and (b) coldest quarters; (c) annual mean temperature; (d) annual precipitation; and precipitation of the (e) wettest and (f) driest quarters.



Monthly climate data for the ecoregion, averaged over a 30-year time period, 1981-2010, with a resolution of 800 m were obtained from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group at Oregon State University (Daly et al. 2008 ; http://prism.oregonstate.edu/normals/) to examine the patterns of monthly, quarterly, and annual variation in climate variables across the Level-III ecoregion (Figure 2-6). Quarterly variables are roughly equivalent to different seasons; they are defined in terms of three consecutive months with hottest or coldest temperatures or largest or smallest amounts of precipitation (e.g., mean temperature of warmest quarter or precipitation of wettest quarter).

Figure 2-6 summarizes six seasonal and annual climate variables for the U.S. portion of the ecoregion: the mean temperatures of the warmest and coldest quarters, annual mean temperature and mean annual precipitation, and the mean precipitation of the wettest and driest quarters. Variation in these six climate variables is shaped by global, continental, and regional atmospheric systems, rain-shadow effects, and elevation, as noted above.

The temperature variables, especially annual temperature and mean temperature of the warmest quarter, show similar spatial patterns across the ecoregion (Figure 2-6(a) and Figure 2-6 (c)). In particular, temperatures are higher in the southeastern-most portion of the region, including the area around the Rio Grande on the border between Texas and Mexico and Big Bend Ranch State Park in west Texas. Temperatures are coolest in the north near Socorro, New Mexico and in multiple mountain regions including the Chinati, Chisos, Davis, and Eagle Mountains and Sierra Diablo in Texas and Organ, Oscura, and San Andres Mountains in New Mexico (Figure 2-3). There are also cooler temperatures in the western portion of the region near Silver City, New Mexico. The mountain ranges in Texas do not appear to be as cool relative to their surroundings during the coldest quarter as do the San Andres Mountains and other mountains in New Mexico relative to their surroundings (Figure 2-6(b)).

Annual precipitation and precipitation during the wettest quarter show fairly similar patterns, with areas of higher rainfall roughly corresponding to areas with cooler temperatures as described previously (Figure 2-6(d) and Figure 2-6(e)). However, there are some differences between areas of higher rainfall and relatively cooler temperatures. The area of higher precipitation in the northern-most portion of the ecoregion is more limited to mountain ranges; the area around Socorro, New Mexico, alongside the Rio Grande at 1,400 m elevation does not receive the higher levels of rainfall that fall in the Magdalena Mountains, which rise to nearly 3,000 m to its west. The region of higher precipitation in western Texas is larger than the area of cooler temperatures and encompasses some additional mountain ranges, including the Del Norte and Glass Mountains, both east of the Davis Mountains. Zones of higher precipitation occur northeast of the Guadalupe Mountains and along the Rio Grande valley in the Big Bend region, the southernmost extension of the analysis extent. The latter zone receives higher rainfall during the driest quarter (Figure 2-6(f)) but has higher temperatures and lower rainfall during the wettest quarter.

These six climate variables from the PRISM dataset affect ecological conditions, as discussed in the Pre-Assessment report (Unnasch et al. 2017). For example, black-tailed prairie dogs (*Cynomys ludovicianus*), a species CE, may have lower survival in years with lower precipitation (Facka et al. 2010) (see Chapters 4 and 9, below). For another example, annual precipitation is correlated with scaled quail (*Callipepla squamata*) abundance in the southern portion of the analysis extent (Bridges et al. 2001). Scaled quail also may not tolerate extremely high temperatures (~45 °C) well (Henderson 1971). Scaled quail is a member of the Grassland Bird Assemblage, another CE (see Chapters 4 and 10, below).

Similarly, the three terrestrial ecological system CEs (see Chapters 4 and 7, below) have distributions strongly affected by climate and its interactions with topographic elevation across the ecoregion (compare Figure 2-3 and Figure 2-6). The Chihuahuan Desert Grasslands CE occurs on piedmonts, foothills, and lowlands mainly between 1,100 and 1,700 m in elevation. These topographic settings tend to experience slightly less precipitation and slightly cooler temperatures than do areas at lower elevations in the U.S. portion of the ecoregion, which in turn are dominated by the Chihuahuan Desert Scrub CE. In contrast, the Pinyon-Juniper Woodlands CE generally occurs at elevations between 1,400 and 2,200 m in elevation. These elevations experience slightly greater precipitation and slightly cooler temperatures compared to areas dominated by the Chihuahuan Desert Grasslands CE. Pinyon-juniper woodlands in fact are often bordered by grasslands at their lower elevations. The separation of grasslands from woodlands in the ecoregion reflects the impacts of precipitation patterns and long-term climate variations on fundamental aspects of plant physiology: The success of C_4 perennial grasses at low elevations depends on summer precipitation (Havstad and Schlesinger 2006), while C_3 shrubs in grasslands and woody species at higher elevation rely more on winter precipitation (see Unnasch et al. 2017, Chapters 5-7).

2.4.2 Geology

The geologic history of the U.S. portion of the ecoregion affects the ecological dynamics, biological diversity, and human landscape of the region in several ways, through its effects on topography, hydrography, and geochemistry. The following paragraphs repeat information presented in greater detail in the Pre-Assessment report (see Chapter 2 in Unnasch et al. 2017).

During the late Pennsylvanian and early to middle Permian geological periods, the lands of the future Chihuahuan desert ecoregion lay within the Pangea supercontinent. An inland sea developed within Pangea, filling a geologic basin, now called the Permian Basin, spanning most of what is now west Texas and southeastern New Mexico. The inland sea connected to the ocean surrounding the supercontinent only through a narrow inlet. A lobe of the Permian Basin, called the Delaware Basin, spanned what is today most of the U.S. portion of the ecoregion, roughly from the San Andres Mountains eastward in New Mexico and across all but the Big Bend region and adjacent westernmost portions of the ecoregion in Texas. A massive system of reefs formed around the periphery of the Delaware Basin during the middle to late Permian period and later fossilized as a limestone formation now known as the Capitan Reef complex. Erosion from the surrounding uplands and evaporation from the inland sea filled the Permian Basin and all its lobes with halite and sulfate minerals interlayered with silicates (clay, silt, and sand) and organic matter (Urbanczyk et al. 2001, Monger et al. 2006, George et al. 2011).

Tectonic dynamics following the Permian period raised the Delaware Basin reef limestone and basin sedimentary layers – including their mineral salt layers – high above sea level. The uplift also affected sedimentary rocks that formed after the Permian during another period of marine inundation in the Cretaceous period across the entire portion of the ecoregion in Texas, including what is now the Big Bend Region. Subsequent tectonic extension, faulting, and downward displacement of grabens between faults (approximately 36-20 million years ago) created most of the mountain ranges and intervening basins of the U.S. portion of the ecoregion today. Additional topographic relief within the U.S. portion of the ecoregion comes from intrusive volcanic activity during the Tertiary period, particularly in the westernmost portions of what is now Texas. The Rio Grande valley in the ecoregion consists of a series of large basins created during the period of formation of the basin and range province.

Erosion of the surrounding ranges filled the valleys of the basin and range province with thousands of feet of sedimentary "basin fill" deposits, which now store substantial volumes of groundwater of critical importance to the people of the ecoregion (Kelley 1971, Bachman 1980, Hill 2000, George et al. 2005, Huff and Chace 2006, Monger et al. 2006, George et al. 2011). Some of the basins created by the pattern of faulting of the Permian and Cretaceous sedimentary rocks of the region are closed valleys or "bolsons" – valleys with no surface drainage outlet. Heavy precipitation and runoff during the Pleistocene created lakes in these valleys, some quite large. These lakes later dried, leaving the major playa lakes and playas of today (Hawley 1993, Wilkins 1997, Langford 2003, Allen 2005).

The Capitan Reef complex today forms the most resistant rocks of several mountain ranges in the ecoregion, including the Guadalupe Mountains that straddle the New Mexico-Texas border and the Glass Mountains in Texas. Erosion of salts – both halites and sulfates – from the exposed Delaware Basin sedimentary rocks has resulted in the re-accumulation of these evaporites in the bottoms of all the closed valleys that lie within the original extent of these rock formations. The evaporites include both salt and gypsum. The heavy precipitation of the Pleistocene resulted specifically in the formation of large, salty lakes in these particular valleys, most of which have now also evaporated leaving new re-accumulations of salts, for example in the Tularosa Basin and in the Salt Basin near Dell, Texas (Bachman 1981, 1987, Hussain and Warren 1989, Hawley 1993, Angle 2001, Monger et al. 2006, NPS-CDIMN 2010). Evaporation from gypsum-rich lakes in these closed valleys has sometimes given rise to dune fields of gypsum crystals, such as the famous White Sands in the Tularosa Basin (NPS-CDIMN 2010, Szynkiewicz et al. 2010).

Even outside these closed valleys, exposures of Delaware Basin sedimentary deposits contribute salt and gypsum to the overlying soils (El Hage and Moulton 1998, Monger et al. 2006, McCraw et al. 2007, Moore and Jansen 2007, McCraw 2008, Hudnall and Boxell 2010). Watershed runoff from these areas results in elevated salt and gypsum concentrations in the receiving streams, including the Pecos River (El Hage and Moulton 1998, Cowley et al. 2003, Miyamoto et al. 2005, Hoagstrom 2009, Stafford et al. 2009, Hogan 2013, Szynkiewicz et al. 2015a, 2015b). Subsurface leaching of mineral salt deposits from Delaware Basin sedimentary deposits also results in the formation of karst landscapes, through the collapse of caves created by the dissolution of mineral salts. This subsurface leaching produces elevated concentrations of halites and gypsum in the groundwater that passes through these deposits –

groundwater that in turn may emerge in sinkholes, at springs, or along seepage faces beneath streams (e.g., recently, Stafford et al. 2008a, 2008b, 2008c, 2009, Land and Huff 2010, Partey et al. 2011, Land and Veni 2012, Szynkiewicz et al. 2012, Stafford 2013, Sigstedt et al. 2016).

Salts in soils and water, in general, and gypsum in soils and water, in particular, place severe physiological demands on any plants or animals that may live there, selecting for biota with unique adaptations (e.g., Moore et al. 2015; see Chapter 7, below). The geologic history of the U.S. portion of the ecoregion therefore has selected for an array of plant and animal species with unique physiological adaptations to the saline and/or gypsiferous soils, playas and playa lakes, springs, and streams of much of the area (e.g., Waterfall 1946, Miller 1977, Blinn 1993, Edwards 1997, Hoagstrom and Brooks 1999, Propst 1999, MacRae et al. 2001, Lang and Rogers 2002, Cowley et al. 2003, Howells 2003, Lang et al. 2003, White et al. 2006, Grunstra and Van Auken 2007, Moore and Jansen 2007, Hoagstrom 2009, Turner et al. 2010, USFWS 2010, Turner and Edwards 2012, USBR 2012, USFWS 2013).

The geology of the Permian Basin also has shaped the human history of the ecoregion. The organic matter trapped in the deposits of the basin has become oil and natural gas. The Permian Basin geologic formations comprise the most productive oil and gas fields in North America (e.g., Ruhlman et al. 2012). The industrial activities associated with the exploitation of oil and gas – production, transport, waste disposal, and so forth – consequently have a large footprint in the ecoregion, most notably in the Pecos River valley (see below, this chapter; see also Chapter 5, below). Employment associated with these activities in turn has and continues to significantly affect the demography and economy of the ecoregion. Oil and gas production, brine production, and other industrial activities such as at the nuclear Waste Isolation Pilot Plant (WIPP) east of Carlsbad, New Mexico, can produce briny wastes that must be controlled or treated to prevent contamination of surface waters (Bachman 1980, 1981, 1987, Siegel et al. 1991, Meyer et al. 2012, Klise et al. 2013, Land 2013, Sullivan et al. 2015). Brine production can also result in the creation of anthropogenic sinkholes (Land and Veni 2012, Land 2013). Irrigation of soils with elevated salt concentrations results in return flows with elevated salinity, raising salinity in the receiving rivers and thereby affecting downstream usability of the water (e.g., El Hage and Moulton 1998, Cowley et al. 2003, Miyamoto et al. 2005, Hoagstrom 2009, Stafford et al. 2009, Hogan 2013, Szynkiewicz et al. 2015a, 2015b). Salinity in groundwater can also limit its usability (Mace et al. 2001, Huff 2004a, 2004b, Mills 2005, George et al. 2011, Meyer et al. 2012, Klise et al. 2013), rendering some lands nearly uninhabitable when there is no other source of potable water.

Finally, as already noted, and discussed further, below, the Chihuahuan desert itself exists specifically because of the positioning of several mountain ranges relative to prevailing atmospheric circulation patterns. The rise of these mountains has also shaped the history of aquatic ecosystems by determining which river basins are connected to or isolated from each other (Miller 1977). The Continental Divide separates the biota of the Colorado River Basin to the west from the rest of the U.S. portion of the ecoregion; and also isolates numerous closed basins from the rest of the ecoregion. Not all of these aquatically isolated basins occur geologically within the area of the former Delaware Basin: others occur in the far western extension of the ecoregion in New Mexico, including the Guzmán and Lordsburg basins in the western extension of the ecoregion. However, mountains alone do not set the aquatic ecological boundaries of the ecoregion. On the east side of the ecoregion, the northern half of the present-day Pecos River basin formerly constituted the headwaters of the Portales River, which flowed eastward across the southern Great Plains. The headwaters of the original Pecos River, to the south, eroded northward to capture the waters of the northern Portales River Basin during the Pleistocene (Bachman 1987), introducing fishes from the Great Plains into the Pecos River ecosystem.

2.4.3 Soils

The complex geologic and climatic history of the Chihuahuan Desert ecoregion has produced a range of parent materials, on which myriad soils have developed. Soils at higher elevations receive more precipitation and are generally acidic, leached, and well-developed (Maker et al. 1974). Mollisols and Entisols occur in mountain ranges of this REA area. The former contain a surface layer of high organic matter and the latter include shallow soils over bedrock (NPS CDIMN 2010). Soils in lower and drier areas are less developed and typically neutral to alkaline (Maker et al. 1974). These soils are often Aridisols, which contain accumulations of calcium carbonate ($CaCO_3$) (NPS CDIMN 2010). As noted above, gypsiferous soils and saline soils develop in closed basins and in areas with near-surface bedrock containing mineral salts, creating conditions in which endemic plant species have evolved (Hendrickson 1979, Powell and Turner 1979, Moore and Jansen 2007, Hudnall and Boxell 2010).

Soil nutrient cycling in the Chihuahuan desert depends, in large part, on invertebrates. Subterranean termites (order Isoptera) are keystone organisms and important recyclers of dead plant material and animal dung (Dinerstein et al. 2001, Schlesinger et al. 2006). The ability of these invertebrates to function with limited moisture makes nutrient cycling in this ecoregion less reliant on timing of precipitation than is the case elsewhere (Schlesinger et al. 2006). Specialized soil mites in the ecoregion are also important to nutrient cycling in the dry climate (Dinerstein et al. 2001).

2.4.4 Hydrology

Perennial streams and rivers, springs, cenotes, seeps, playa lakes, and reservoirs create corridors, oases, and expanses of aquatic habitat across the U.S. portion of the Chihuahuan desert, with associated wetlands, as discussed in detail in the Pre-Assessment report (see Chapters 8-11 in Unnasch et al. 2017). Intermittently wetted runoff channels and playas also contribute to the diversity of wetted habitats in the ecoregion. The REA does not address subterranean aquatic biota, and addresses intermittent streams only as components of the terrestrial ecological systems in which they occur.

With three notable exceptions, the natural water bodies (streams, springs, cenotes, seeps, playas and playa lakes) of the U.S. portion of the ecoregion receive their water ultimately from the rainfall and snowfall that occurs within the ecoregion itself, or in the mountains that straddle the present analysis extent (see Chapter 8, below). Some of this “local” water reaches its destination simply as runoff, but much arrives only after infiltrating to a groundwater flow system that may take years to millennia to deliver the water to a natural surface outflow. The three notable exceptions to this pattern are the Rio Grande, the Pecos River, and the Gila River (Figure 2-3).

The Rio Grande is the largest river system flowing through the U.S. portion of the ecoregion, and one of the ten longest rivers in North America. It originates as snow melt and rainfall in the Rocky Mountains of southern Colorado and northern New Mexico, flows south through New Mexico, and serves as the border between Texas and Mexico. Within the U.S. portion of the ecoregion, it receives additional inputs from several tributary streams, local runoff, and groundwater discharge, including from scattered springs in the Big Bend region (NPS CDIMN 2010). It has no large tributaries within the U.S. portion of the ecoregion. However, a major tributary, the Rio Conchos, enters the Rio Grande a few miles south of El Paso, Texas, and most of the flow of the river below this confluence – including through the Big Bend region – consists of water from this tributary, making it debatable which river is tributary to which.

The Pecos River originates in the Sangre de Cristo Mountains of north-central New Mexico, an extension of the Rocky Mountains, and flows southward along the eastern edge of the basin and range province and the western edge of the Great Plains. As noted above, its course north of the ecoregional boundary reflects its history of capturing the former upstream reach of the Portales River. Within the analysis extent of the present REA, the Pecos River flows south- and eventually southeastward to join the Rio Grande near the southeastern edge of the U.S. portion of the ecoregion. It receives inflows from several substantial perennial tributaries within the ecoregion (see Chapter 8, below).

The analysis extent for the Chihuahuan Desert REA includes a small portion of the upper Gila River basin and the Gila River mainstem along the Arizona-New Mexico border. The Gila River originates in the high elevations of the Arizona-New Mexico Mountains ecoregion, adjacent to the Chihuahuan Desert ecoregion but on the west side of the Continental Divide, and flows westward through Arizona to the Colorado River.

Riparian areas once occurred extensively along the Rio Grande, Pecos River, and Gila River, their perennial tributaries, and the Mimbres River, which flows out of the Mogollon Mountains into the closed Guzmán Basin. Where they still occur, these riparian areas provide diverse mesic and wetland habitats, including in the Bosque del Apache and Bitter Lake National Wildlife Refuges along the Rio Grande and Pecos Rivers, respectively, and along the Rio Grande through the Big Bend region. High water tables in alluvial aquifers along some reaches of these perennial rivers and streams once helped support their riparian woodlands and wetlands. The Rio Grande and Pecos Rivers today are highly regulated, impounded behind numerous dams, and extensively diverted for human use in the ecoregion as discussed further below (see Water Use, this Chapter). Pumping from the alluvial aquifers also has significantly reduced the volumes of water they retain in storage, as has pumping from other aquifers in the ecoregion (see Water Use, this Chapter). Climate change is expected to reduce the ability of the Rio Grande system to support ecosystems, agriculture, and cities. A recent study found that "[t]he Rio Grande offers the best example of how climate-change-induced flow declines might sink a major system into permanent drought" (Dettinger et al. 2015).

The U.S. portion of the ecoregion contains numerous perennial springs, as noted above (e.g., Brune 1975, Heitmuller and Williams 2006; see Chapter 8, below). The largest of these originate in aquifers within Cretaceous sedimentary rock formations in Texas. These springs include the well-known San

Solomon Springs complex in the Pecos River valley near Balmorhea, Texas, a popular recreation site, as well as the nearby Phantom Lake, Diamond Y, and Commanche Springs; and the numerous springs of Big Bend National Park. Further north, Bitter Springs National Wildlife Refuge near Roswell, New Mexico, also has numerous springs and cenotes, as does the nearby Bottomless Lakes State Park, New Mexico. The aquifers within the Cretaceous sedimentary rock formations in Texas are important water resources for the people of the ecoregion, as are aquifers in the basin fill deposits of the basin and range province.

The U.S. portion of the ecoregion also contains numerous ephemeral water bodies (Dinerstein et al. 2001). Specialized organisms, including endemic invertebrates, live in playas and pools across the ecoregion, many of which have highly brackish chemistry, as noted above (e.g., Lang and Rogers 2002, Lang et al. 2003). The disjunct nature of these water bodies has created high beta diversity among their biota. The freshwater invertebrates in playas are important food for migrating waterfowl (Dinerstein et al. 2001).

2.4.5 Wildfire

Wildfire historically played a significant role in the ecological dynamics of the U.S. portion of the ecoregion, episodically resetting and directing plant succession across burn areas of varying size. However, the effects of fire varied among the different major terrestrial ecological systems, with wildfire less significant in the scrublands compared to the grasslands and woodlands at higher elevations. As discussed in detail in the Pre-Assessment report (see Chapters 3 and 5-7 in Unnasch et al. 2017), the frequency, spatial extent and severity of wildfire in the U.S. portion of the ecoregion have shifted since the late 1800s. European settlers brought livestock that removed the grasses that carry fire and suppressed many fires that did ignite (Gebow and Halvorson 2005). Less frequent fires are one factor thought to have allowed shrubs to expand into grasslands (Rhulman et al. 2012). Recent climate change may also have exacerbated both shrub expansion and changes in fire regimes (Ruhlman et al. 2012).

Prior to the late 1800s, the patchy distribution of grassland vegetation may not have been highly conducive to the spread of large wildfires (Dick-Peddie 1993) (see Chapter 5 in Unnasch et al. 2017). Black grama grass, a dominant species in Chihuahuan desert grasslands, may not provide sufficient fine fuels to carry fire very well during most years (Cable 1965, Drewa and Havstad 2001, Peters and Gibbens 2006). However, prior to the late 1800s, some fires burned more than a hundred square miles (Bahre 1991, Humphrey 1949, McPherson 1995). Other factors than fire alone – particularly drought dynamics – appear to have played a greater role in shaping where different plant species grow in the kinds of desert grasslands found in the U.S. portion of the ecoregion (Burgess 1995). Nevertheless, wildfire historically helped maintain Chihuahuan desert grasslands by limiting shrub dominance (Humphrey 1958, McPherson 1995).

Burn intervals prior to the late 1800s may have been as short as 6–7 years in mountain shrub communities and 4–9 years in grasslands (Gebow and Halvorson 2005). Chihuahuan Desert grasses generally recover well after fire, given adequate moisture, and most mature trees and shrubs survive and will resprout after low-intensity fire (Gebow and Halvorson 2005). Succulents, on the other hand, are damaged by fire, especially during dry periods (Gebow and Halvorson 2005). Gebow and Halvorson

(2005) concluded from their literature review that fire is a natural part of northern Chihuahuan Desert communities, and suggest that a "mixed" fire regime was typical before European settlement, with patchy, variable fire histories across landscapes.

At higher elevations, in turn, pinyon-juniper woodlands experienced frequent fire. The distribution, composition, and condition of pinyon-juniper woodlands in the Chihuahuan desert are highly sensitive to the seasonal timing, frequency, and severity of wildfire (see Chapter 7 in Unnasch et al. 2017). Wildfires of low to mixed severity in pinyon-juniper woodlands in the ecoregion have become rare because livestock grazing has reduced fine fuel loads, fire suppression has limited fire spread, and droughts have reduced production of fuels. These changes have allowed pinyon-juniper trees to spread and become increasingly abundant in adjacent terrain. This expansion often reduces herbaceous cover, especially on shallow soil, reducing the potential for low-intensity fires carried by understory fuels and increasing the potential for severe, stand-replacing fires that harm all vegetation. These changes have also promoted soil erosion in some areas, leaving insufficient understory cover to slow overland flows (Gori and Bate 2007).

2.5 Chihuahuan Desert Biodiversity

2.5.1 Species Richness

The Chihuahuan desert overall, including the U.S. and Mexican portions together, contains over 2,000 known species of vascular plants, over 100 species of mammals, over 100 species of reptiles, over 200 species of birds, over 200 species of butterflies, and roughly 20 amphibian species (Dinerstein et al. 2001). This richness reflects the diverse topography and climates of the ecoregion, the connectedness of the ecoregion to surrounding ecoregions and biogeographic provinces, and its mesic past.

The basin and range landscape of the ecoregion creates islands of disjunct terrestrial communities, the dry climate of the ecoregion overall creates innumerable isolated water bodies, and the unique geochemistry of the ecoregion creates settings that have selected for unique terrestrial and aquatic adaptations, as discussed in detail in the Pre-Assessment report (Unnasch et al. 2017). Additionally, wide variation in climate over the last 10,000 years has produced a range of conditions that support a wide array of flora and fauna (Dinerstein et al. 2001), some of which have persisted in the ecoregion after subsequent climate changes have set in. For example, regional drying 9,000 years ago (Havstad and Schlesinger 2006) isolated mesic-adapted species in pockets of suitable habitat. As a result, familiar mesic-adapted birds, including blue jay (*Cyanocitta cristata*) and yellow-throated vireo (*Vireo flavifrons*) inhabit riparian forests along the Pecos River (Dinerstein et al. 2001). Eastern U.S. invertebrates, such as fireflies (Lampyridae), occur in the Davis Mountains (Dinerstein et al. 2001). And among the Chihuahuan desert herpetofauna, six species are considered relict species from forested regions (Milstead 1960).

Geologic barriers affect the biogeography of native aquatic and wetland-obligate species in the U.S. portion of the ecoregion, as also noted above. One such barrier consists of the Continental Divide, which separates the Gila River basin – a tributary to the Colorado River – from the Mimbres River and Rio Grande basins. However, some mixing of fish fauna has occurred between headwater streams that arise along the divide, resulting in some sharing of fish fauna among the Gila, Mimbres, and Rio Grande basins (see Unnasch et al. 2017, Chapters 8 and 9; see also Chapter 8, this report).

The closed basins of the ecoregion are hydrologically and therefore biologically isolated from each other today, with high rates of endemism, especially among the cichlid (Cichlidae) and cyprinid (Cyprinidae) fishes (Dinerstein et al. 2001). Even where fish fauna have disappeared in these closed basins, distinct suites of endemic aquatic macroinvertebrates still persist, as noted above (Dinerstein et al. 2001, Lang and Rogers 2002, Lang et al. 2003). However, they have not always been so isolated. For example, pluvial lakes occasionally covered much of the ecoregion during the Pleistocene, connecting many currently isolated basins hydrologically and allowing species exchanges (Dinerstein et al. 2001).

Fish uniquely adapted to springs and other hydrologically and geochemically unique settings in the U.S. portion of the ecoregion have limited distributions. However, their current habitats occur in settings that at least episodically over millennia may become connected to larger drainage networks, and these species appear to have evolved through local selection from ancient members of larger, more widespread taxonomic groups (see Unnasch et al. 2017, Chapters 8-10). Other taxonomic groups of aquatic fauna native to the U.S. portion of the ecoregion are members of groups found across the entire Chihuahuan desert ecoregion of Mexico and the U.S. (Miller 1977). This includes native taxa also found in other river systems that flow into the western Gulf of Mexico. Finally, as a result of the capture of the Portales River of the southern Great Plains by the Pecos River, the latter river contains aquatic fauna native to the southern Plains as well (see above and Unnasch et al. 2017, Chapters 8-10).

The largest gypsum dune field in the world occurs in the U.S. portion of the ecoregion, in the dry, closed Tularosa Basin of southeast New Mexico. Endemic gypsophilic plants and white variants of some animals have adapted to conditions in the 71,000-hectare dune field (NPS 2005). Gypsophilic plants occur not only in the Tularosa Basin but across much of the ecoregion, most numerously in Nyctaginaceae, Brassicaceae, Boraginaceae, Caryophyllaceae, Fouquieriaceae, Papaveraceae, Loasaceae, Onagraceae, Asteraceae, Poaceae, and Scrophulariaceae (Moore and Jansen 2007, Moore et al. 2015, Moore 2015). The richness and diversity of gypsophilic flora in the ecoregion suggest this is a relatively old assemblage (Moore and Jansen 2007, Moore et al. 2015, Moore 2015). This inference of long-term persistence and evolution in the Chihuahuan desert gypsophilous plant assemblage is further supported by the existence of several genera within the ecoregion containing multiple endemic gypsophilous plant species (e.g., Gaillardia, Nama, and Tiquilia) and the similarity among endemic gypsophilous plant species across the entire ecoregion (Moore and Jansen 2007, Moore et al. 2015, Moore 2015). Chapter 7, below, discusses this topic further.

The Tularosa Basin also contains areas of saline soils, as do countless other large and small closed basins in the ecoregion (Hendrickson 1979) for the geologic reasons described above. Halophytic plant species are most numerous in Chenopodiaceae and Poaceae and the former includes about a dozen halophytic plant species endemic to the ecoregion (Hendrickson 1979).

2.5.2 Characteristic and Keystone Species

Creosote bush (*Larrea tridentata*) is the most characteristic plant species of the Chihuahuan Desert. This aromatic shrub is often accompanied by tarbush (*Florensia cernua*), mesquite (*Prosopis glandulosa*), and acacias (*Acacia* spp.). Lechugilla (*Agave lechuguilla*) is the defining succulent species, often joined by yuccas (*Yucca* spp.) and cacti, especially prickly pear (*Opuntia* spp.).

Creosote bush is especially common on the bajada slopes and alluvial fans between mountain ranges and basin floors (Peters and Gibbens 2006). Mesquite is most common on sandy soils and often dominates sites with deep sands and a subsurface calcium carbonate layer (Peters and Gibbens 2006). Black grama grass dominates grassland sites on sandy or gravelly upland sites, especially those with deep, loamy soils (Peters and Gibbens 2006). Tobosa grass (*Pleuraphis mutica*) typically dominates lowland sites with heavy, clayey soils and abundant water. Side oats grama (*Boutelous curtipendula*) and alkali sacaton (*Sporobolus airoides*) grasses are also common on these sites (Peters and Gibbens 2006).

The Chihuahuan desert has few characteristic native mammal species, due to its relatively recent origin and open connection to neighboring ecoregions (Dinerstein et al. 2001). Native mammals occurring in the U.S. portion of the ecoregion include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra Americana*), javelina (*Dicotyles tajacua*), kangaroo rats (*Dipodomys* spp.), woodrats (*Neotoma* spp.), and deer mice (*Peromyscus* spp.). Common bird species include greater roadrunner *Geococcyx californianus*), and scaled quail (*Callipepla squamata*). The now-rare aplomado falcon (*Falco feroralis*) once roamed the region (Dinerstein et al. 2001).

The native herpetofauna of the Chihuahuan desert is more distinctive of the area than the native mammals and birds. Reptile diversity of the area is among the highest of any desert ecoregion (Dinerstein et al. 2001). Endemic lizards in the region include the Texas banded gecko (*Coleonyx brevis*), reticulated gecko (*C. reticulatus*), greater earless lizard (*Cophosaurus texanums*), and several species of spiny lizards (*Scheloporus* spp.) (Dinerstein et al. 2001). Amphibians strongly (but none exclusively) associated with the ecoregion include the Arizona toad (*Anaxyrus microscaphus*), Great Plains Narrowmouth Toad (*Gastrophryne olivacea*), Texas toad (*Anaxyrus speciosus*), barking frog (*Craugastor augusti*), Rio Grande chirping frog (*Eleutherodactylus cystignathoides*), spotted chirping frog *Eleutherodactylus guttilatus*), Great Plains narrowmouth toad (*Gastrophryne olivacea*), mountain or Arizona treefrog (*Hyla wrightorum*), the Rio Grande, Plains, Chiricahua, and Northern leopard frogs (*Lithobates berlandieri*, *L. blairi*, *L. chiricahuaensis*, and *L. pipiens*, respectively), and Mexican treefrog (*Smilisca baudinii*) (see Chapters 3 and 8, below, for additional discussion).

Chapter 8, below, discusses the highly diverse fish assemblages of the U.S. portion of the ecoregion (see also Pre-Assessment report, Unnasch et al. 2017). These assemblages include species adapted to cold-water mountain streams, such as the Rio Grande cutthroat trout (*Oncorhynchus clarki virginalis*) and the Gila trout (*Oncorhynchus gilae*); and species adapted to warm alluvial rivers, such as the freshwater drum *(Aplodinotus grunniens*)*,* Rio Grande sucker *(Catostomus plebeius*), Plains killifish *(Fundulus zebrinus*)*,* Rio Grande chub (*Gila pandora*)*,* Rio Grande silvery minnow (*Hybognathus* amarus*)*, and Rio Grande speckled chub (*Macrhybopsis aestivalis*). The assemblage also includes fishes adapted to springs with various unusual hydro-geo-chemical conditions and varying connections to rivers, such as the Big Bend gambusia (*Gambusia gaigei*), Pecos gambusia (*G. nobilis*), San Felipe gambusia (*G. clarkhubbsi*), Tex-Mex gambusia (*G. speciosa*), Leon Springs pupfish (*Cyprinodon bovinus*), Comanche Springs pupfish (*C. elegans*), and Pecos pupfish (*Cyprinodon pecosensis*); and one species adapted to the hydro-geo-chemically unique springs of the closed Tularosa Basin, the White Sands pupfish (*Cyprinodon tularosa*).

All former keystone predatory mammals of the U.S. portion of the ecoregion are currently missing or greatly reduced in number. These included the Mexican gray wolf (*Canis lupus baileyi*), grizzly bear (*Ursus horribilis*), mountain lion (*Puma concolor*), coyote (*Canis latrans*), and badger (*Taxidea taxus*). Black-tailed prairie dogs (*Cynomys ludovicianus*), a keystone species in grasslands, are greatly reduced in range and abundance (Dinerstein et al. 2001). Keystone subterranean termites (order Isoptera) continue to thrive in desert grasslands, where they play vital roles in nutrient recycling (Whitford and Bestelmeyer 2006).

2.5.3 Ecological Systems

The Pre-Assessment report (Unnasch et al. 2017, Chapters 2, 3, 5-11) discusses the nearly 60 ecological systems recognized across the U.S. portion of the ecoregion. The term, “ecological system” here refers to “… recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding” (Comer et al. 2003). Each of the three terrestrial ecological system CEs and five aquatic-wetland ecological system CEs includes several of these specific ecological systems, as explained in the Pre-Assessment report (Unnasch et al. 2017, Chapters 5-11) and summarized in Chapters 7 and 8 of the present report. Figure 2-7 shows the general types of land cover present across the U.S. portion of the ecoregion today, including natural vegetation cover types and several types of developed land cover. Chapters 4-10, below, discuss the land cover of the U.S. portion of the ecoregion from several perspectives.

2.6 Chihuahuan Desert Human Landscape

The U.S. portion of the Chihuahuan Desert ecoregion is a mostly sparsely populated area (Figure 2-7) with an economy historically based on ranching, farming, mining, oil and gas production, and military testing and training (Anderson and Gerber 2008). Changes in these activities have led to shifts in land use and land cover. This section of the chapter summarizes the major features of the human landscape of the U.S. portion of the ecoregion that affect ecological resources.

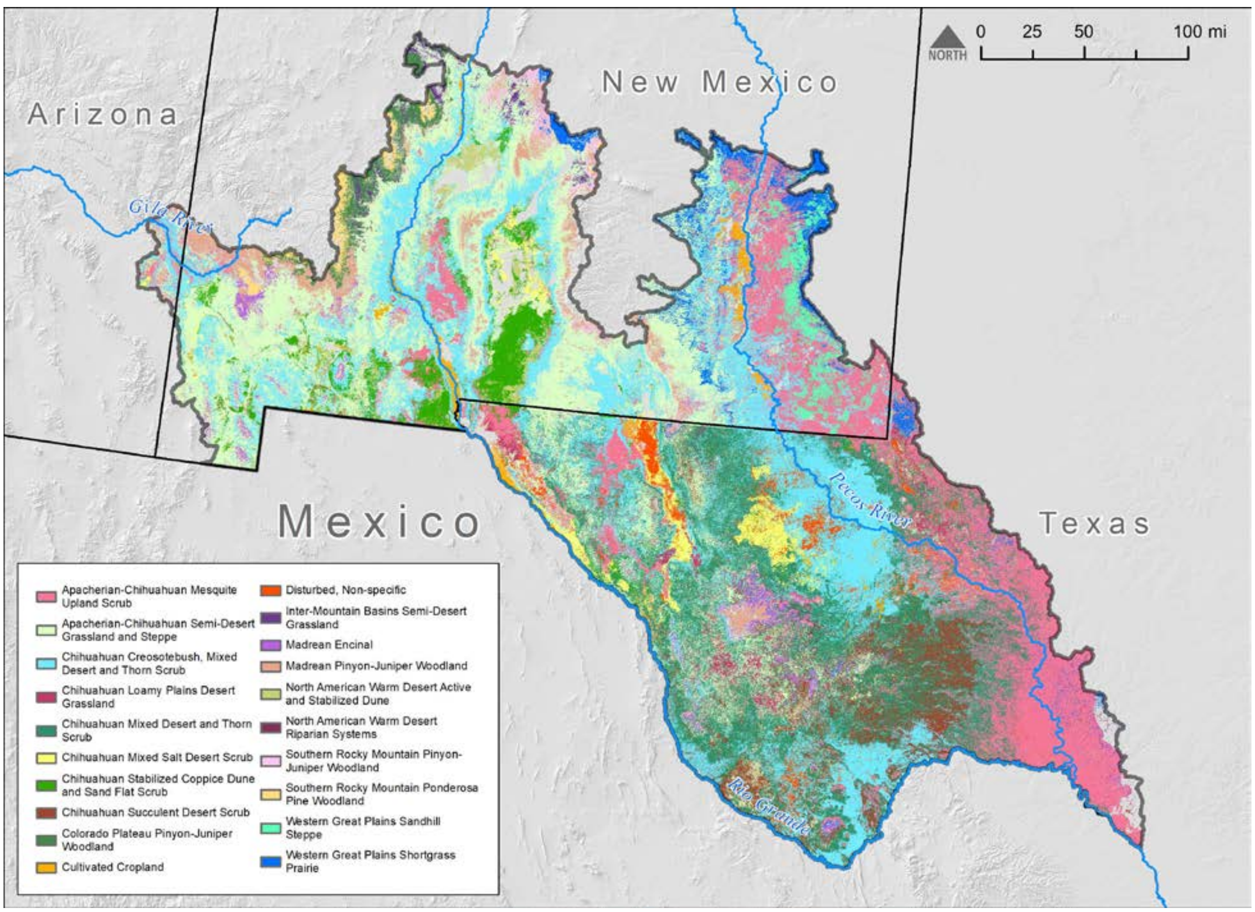
2.6.1 Demography

The number of people living in the U.S. portion of the ecoregion increased by approximately 38% between 1980 and 2000. However, outside of a few large cities, the land is still mostly sparsely populated grasslands and shrublands used mainly for livestock grazing (Ruhlman et al. 2012, Texas Land Trends 2015). Fewer than approximately 1.5 million people lived in the area in 2015, with 60% concentrated in the El Paso area (Texas Demographic Center 2015) and another 15% in the Las Cruces area (New Mexico Demographics 2016). The Borderplex Region of Las Cruces, New Mexico, El Paso, Texas, and Ciudad Juarez, Chihuahua, Mexico, is the seventh largest manufacturing area in North

America (MVEDA undated). It has a combined population of approximately 2.5 million people, over 1.3 million of whom live in Mexico and share use of the Rio Grande and local aquifers with the U.S. population of the Borderplex (Hogan 2013, Borderplex Alliance 2016, TWDB 2016). Other populous (populations > 20,000) urban areas in the U.S. portion of the ecoregion include Roswell, Alamogordo, and Carlsbad, New Mexico. Smaller urban areas include Artesia, Socorro, and Truth or Consequences, New Mexico, and Fort Stockton, Texas.

Populations in and around these urban areas are forecasted to grow, as discussed in detail in Chapter 5, below. For example, El Paso County, Texas, is projected to grow from more than 670,000 people in 2000 to more than 1.14 million by 2040 (Borderplex Alliance 2016). Population growth in the Borderplex Region is driven by commerce stimulated by economic agreements between the U.S. and Mexico (Anderson and Gerber 2008, Borderplex Alliance 2016, TWDB 2016). The growth, with its increasing numbers of vehicles and commercial sources of pollution, has adversely affected air quality (Anderson and Gerber 2008) and increased water demand.

Figure 2-7. General land cover types.



Several military installations in the region support nearby cities. Alamogordo and Las Cruces New Mexico are located near White Sands Missile Range and Holloman Air Force Base, and Fort Bliss is outside El Paso Texas. Although these installations contain within them large areas of relatively undisturbed land, they significantly affect adjacent development.

Except for Alamagordo, New Mexico, and Fort Stockton, Texas, the urban areas of the U.S. portion of the ecoregion all straddle or lie alongside rivers: Roswell, New Mexico, alongside the Rio Hondo; Carlsbad and Artesia, New Mexico, alongside the Pecos River, and Socorro, Truth or Consequences, and Las Cruces, New Mexico, and El Paso, Texas, alongside the Rio Grande. Ciudad Juarez, Mexico, lies immediately across the Rio Grande from El Paso. These locations result in urban development of floodplains and implementation of measures to prevent flooding of developed lands. These trends of floodplain development around urban areas are expected to continue into the foreseeable future, as documented below in Chapter 5 (see also Ruhlman et al. 2012, Theobald et al. 2013, Borderplex Alliance 2016).

2.6.2 Land Ownership

Figure 2-8 shows the distribution of publicly managed lands within the U.S. portion of the ecoregion, with emphasis on Arizona and New Mexico, based on data provided by the BLM. Figure 2-9 shows all protected areas within the entire U.S. portion of the ecoregion, based on data from the U.S. Geological Survey National Gap Analysis Program, Protected Areas Database (UGSG-GAP 2016; https://gapanalysis.usgs.gov/padus/data/). Figure 2-9 includes lands managed by the State of Texas, additional lands managed by the federal government in Texas, and conservation lands managed by private individuals and organizations. Most public lands within the analysis extent are managed by the BLM and the Department of Defense, the latter of which manages the White Sands Missile Range, Holloman Air Force Base, and Fort Bliss. National Park lands include White Sands National Monument, Carlsbad Caverns National Park, Guadalupe Mountains National Park, and Big Bend National Park. U.S. Fish and Wildlife Service lands include the Bosque del Apache, San Andres, and Bitter Lake refuges in New Mexico. Both states manage large parks, the largest of which is the 120,000-hectare Big Bend Ranch State Park, the largest state park in Texas.

Figure 2-8. Publicly managed lands with emphasis on Arizona and New Mexico.

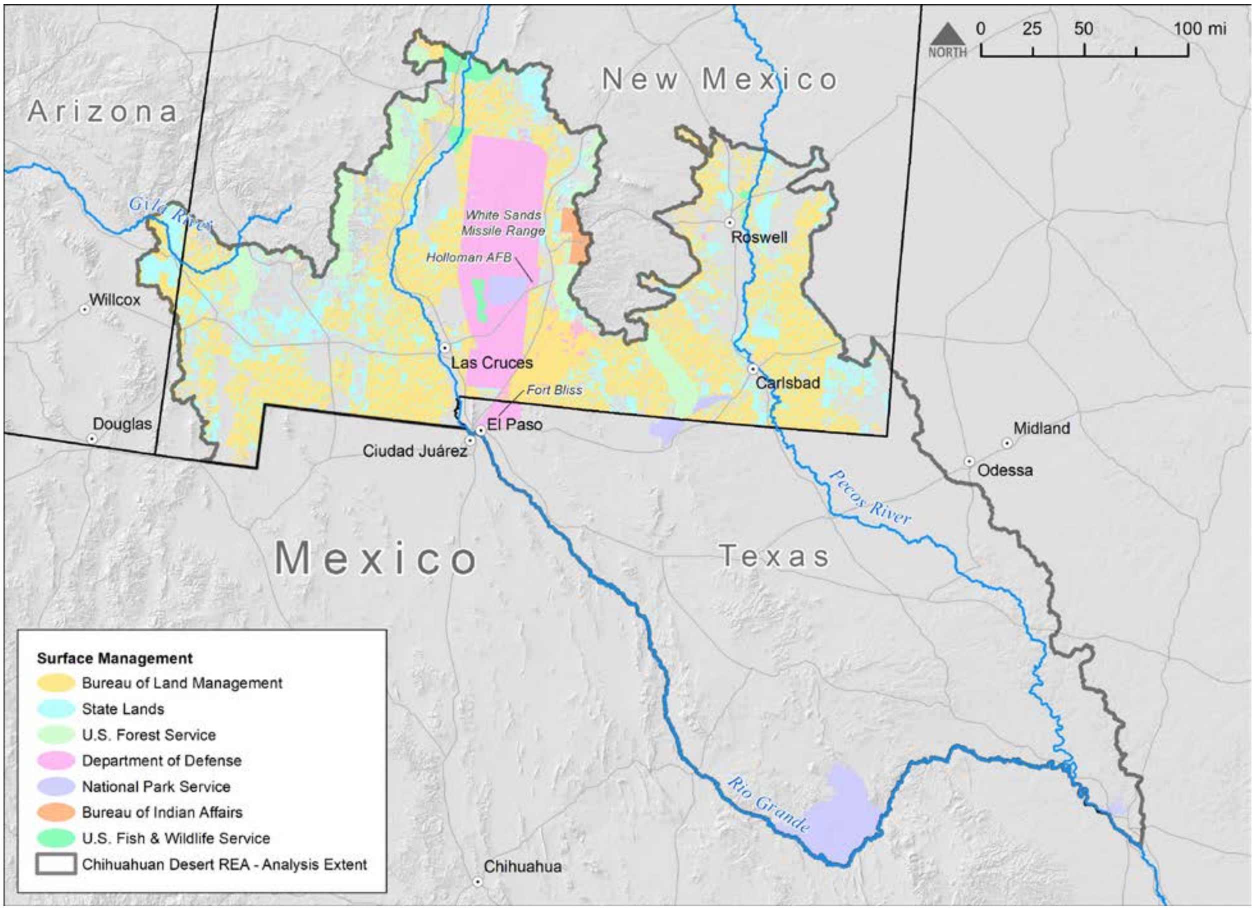
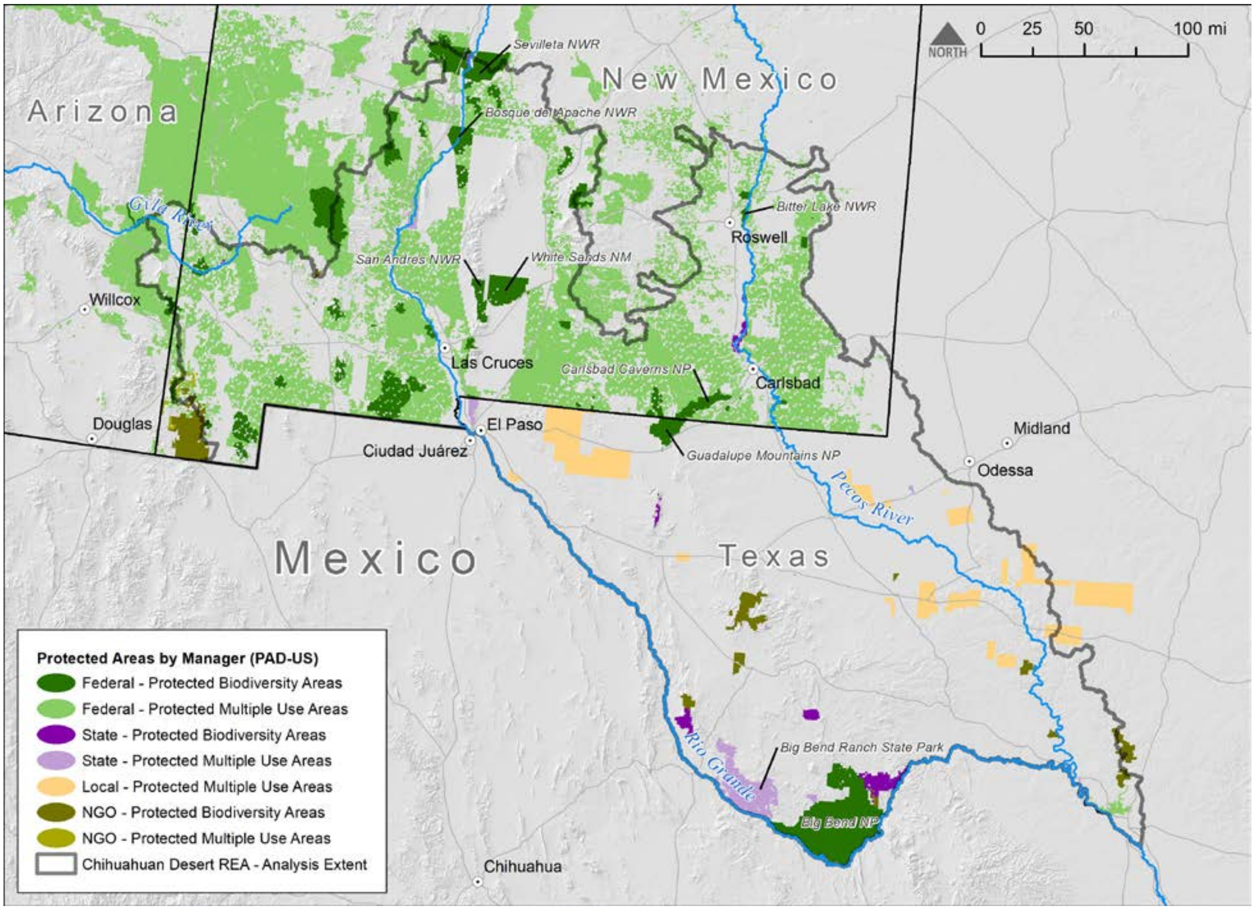


Figure 2-9. Protected areas.



2.6.3 Land Use

Numerous reports document changes in land use and land cover across the U.S. portion of the ecoregion over the past 50-150 years, as discussed throughout the Pre-Assessment report (Unnasch et al. 2017). Most investigators attribute the changes in land cover to altered fire regimes, inappropriate grazing, climate change, and development (Ruhlman et al. 2012). The pace of change attributable to development has slowed since the early 1970s (Ruhlman et al. 2012). About 0.5 percent of land changed from one land cover type to another between 1973 and 2000 (Ruhlman et al. 2012), with only four types of land cover changing by more than 100 km^2. These changes most commonly involved the conversion of grasslands and shrublands to mining and/or oil and gas production (217 km^2) or to developed properties (187 km^2), while some agricultural land reverted to grasslands or shrublands (158 km^2; Ruhlman et al. 2012). Chapter 5, below assesses these changes further.

Most of the impacts of oil and gas extraction on land cover have occurred in the eastern portion of the analysis extent (e.g., Engler et al. 2012, Engler and Cather 2014; see below, Chapter 5). Most of the mapped increase in residential and commercial development have occurred near urban areas and Holloman Air Force Base. The conversion of grasslands and shrublands to mining and residential/commercial land is projected to continue into the future (Ruhlman et al. 2012; see also Chapter 5, below).

Ranching, farming, and mining have deep roots in the U.S. portion of the ecoregion (NMDGF 2006, Texas Land Trends 2015). These are still important to the region's economy, although the shape of these industries has changed with time. Livestock ranching spread north from New Spain and reached the U.S. portion of the ecoregion by A.D. 1600 (Havstad et al. 2006). Sheep vastly outnumbered cattle in the region until 1821, and cattle ranching became dominant after the U.S. Civil War. By the late 1800s, rangelands in the region were widely reported to be degraded by improper grazing (Havstad and Schlesinger 2006, Havstad et al. 2006).

The Permian Basin, straddling the New Mexico-Texas border, is the most prolific oil producing area in the U.S. (Engler et al. 2012, Engler and Cather 2014, USEIA 2014), as noted above. Oil and gas production in the Basin began in the late 1920s (see Geology, this Chapter), increased during and following World War II, and increased sharply again between 2009 and 2015 (USEIA 2016). The increased and enhanced use of horizontal drilling and hydraulic fracturing (*aka* "fracking") in the most recent two decades has resulted in the extraction of oil and gas from so-called "tight" formations where it was previously unavailable (Engler et al. 2012, Engler and Cather 2014, USEIA 2014). This most recent development is concentrated in a band from Fort Stockton to Pecos, Texas, and north into southeastern New Mexico (Texas General Land Office 2015, USEIA 2015). Impacts from oil and gas development include not only the development of drill sites and the road networks among them, but the construction and operation of pipelines and waste disposal and pumping facilities (see Chapter 5, below). Drill sites for horizontal drilling occupy half the area needed for individual vertical drilling sites, while reaching twice the area of oil or gas deposits, thus reducing the surface impact of the drilling; but fracking requires larger volumes of water, particularly already- scarce fresh water (Engler et al. 2012, Engler and Cather 2014).

Irrigation agriculture contributes significantly to the economy and patterns of land development in the U.S. portion of the ecoregion. Important crops in the area include tree nuts, onions, grains, cotton, vegetables, and fruits. However, farmers at least in the New Mexico portion of the ecoregion lately have shifted emphasis away from traditional crops to higher value crops such as pecans, pistachios, and chili peppers (SENMEDD/COG 2010). Irrigated farming is concentrated on former floodplains, where it depends both on surface water diversions and on groundwater pumping, largely from alluvial aquifers. Additional areas of irrigation agriculture rely exclusively on groundwater (see Water Use, below). Large dairies are increasing in this area, especially in Chavez County, where the average herd has over 2,100 cows (NASS 2013). Farming of floodplains requires the construction and maintenance of drainage systems to carry return flows and natural soil drainage back to surface water bodies. Levees, especially along the Rio Grande, protect farmlands and other developed lands on the floodplains from potentially harmful floods.

2.6.4 Water Use

Water use from both surface waters and aquifers in the U.S. portion of the ecoregion is highly regulated under irrigation district and state law, interstate compacts, and bi-national agreements (Hogan 2013). Two major dams (Elephant Butte and Caballo) and six smaller diversion dams (San Acacia, Leasburg, Mesilla, American, International, and Riverside) on the Rio Grande within the ecoregion store and divert water for municipal use, irrigated agriculture, hydroelectric power generation, and to meet treaty obligations for the delivery of water to Mexico (U.S. Bureau of Reclamation 2011, Ruhlman et al. 2012, Hogan 2013). Beyond the ecoregional boundaries, ten other dams lie upstream on the Rio Grande, and the international Amistad and Falcon dams lie downstream. Nearly 600 miles of canals and laterals, and over 450 miles of drains support extensive agriculture along the Rio Grande in south-central New Mexico and west Texas (U.S. Bureau of Reclamation 2011, Hogan 2013, NMOSE 2016). Amistad Reservoir, behind Amistad Dam on the Rio Grande, inundates the confluence of the Pecos River with the Rio Grande. Seven dams regulate the flow of the Río Conchos and three of its major tributaries (Kelly 2001). Three moderate-size dams on the Pecos River – Brantley, Avalon, and Red Bluff – store and divert water for irrigated agriculture and, in the case of Red Bluff, generate hydroelectric power. Beyond the ecoregional boundaries, two other dams lie upstream on the Pecos River in New Mexico.

Most of the waters of the Pecos River, Rio Grande, and lower reaches of their perennial tributaries are diverted for use by municipalities and irrigation districts in the U.S. and in Mexico (Hoyt 2002, Hogan 2013). The impoundments also inundate large sections of floodplain and trap almost all of the sediment that these rivers formerly carried past their locations – sediment historically crucial to habitat dynamics within the rivers and across their floodplains. Further, the combination of diversions, consumption of the diverted water, and operation of the impoundments has significantly altered river hydrology and connectivity. The Rio Grande sometimes runs dry for some distance below Elephant Butte Dam and again below El Paso as a result of upstream water consumption and impoundment (Hogan 2013). Return flows from agricultural and municipal water uses carry heavy loads of dissolved salts (Hogan 2013, IBWC 2013). River regulation, dams, diversions, and return flows with degraded water quality have contributed to changes in native fish populations and floodplain forests and wetlands (see Chapter 8).

The Gila River presently has no dams along its mainstem, and diversions along the mainstem within the U.S. portion of the ecoregion deliver water only to local users. However, efforts are ongoing to permit construction of a large diversion facility somewhere along the mainstem immediately upstream from the present analysis extent, under the terms of the New Mexico-Arizona Water Settlement Act of 2004 (New Mexico Interstate Stream Commission 2017).

Farmers, municipalities, and some industries also heavily use groundwater in the ecoregion. Some aquifers lie under multiple jurisdictions, receive recharge from the Rio Grande, or discharge (or formerly discharged) to the Rio Grande or Pecos River, resulting in jurisdictional conflicts (Hogan 2013), as discussed in the Pre-Assessment report (Unnasch et al. 2017). Groundwater extraction from basin fill and alluvial aquifers along both the Rio Grande and Pecos River has reduced the flow of water from springs and lowered floodplain water tables, which can negatively affect floodplain and emergent wetlands, endemic fish, and invertebrate species. Some of the groundwater in the U.S. portion of the ecoregion also is brackish (e.g., Huff and Chace 2006, George et al. 2011, Meyer et al. 2012), and its use results in salt deposition at the ground surface and/or releases of brackish wastewater into the surface water system.

The oil and gas development in the Permian Basin between 2009 and 2015, noted above, involved a massive expansion in the use of hydraulic fracturing to force open geologic formations to permit the escape of the oil or gas, as noted above. This practice requires large volumes of water, only some of which can be recycled following use. It also poses risks of water pollution from flowback, well leakage, and waste spills, although these risks are subject to significant regulation (NMOGA 2012, NMEMNRD 2016). Hydraulic fracturing has been used in oil and gas extraction in the ecoregion for many decades (NMOGA 2012), but its use is expanding as a result of the more recent coupling of hydraulic fracturing with horizontal drilling technologies (USEIA 2015, NMEMNRD 2016). The USGS estimates that water use for oil and gas extraction accounted for the largest increase in water use in New Mexico between 2005 and 2010 (Maupin et al. 2014). However, changes in technology have reduced the amount of water needed, including both fresh and brackish water (NMEMNRD 2016, New Mexico Energy Forum 2016).

Finally, many springs in the ecoregion, such as the Balmorhea Springs complex in Texas, have been developed for recreational use. While not resulting in water consumption, such recreational development typically eliminates wetland habitats and significantly alters aquatic habitat conditions.

3 Conservation Elements, Change Agents, Management Questions, and Assessment Methodology

The Pre-Assessment Phase (*aka* Phase I) for the Chihuahuan Desert Rapid Ecoregional Assessment (REA) (Unnasch et al. 2017) focused on (1) identifying the Conservation Elements, Change Agents, and Management Questions that would guide the REA, and (2) developing conceptual ecological models for the Conservation Elements. The conceptual models show how the Change Agents may affect each Conservation Element, and provide a means for translating Management Questions into terms specific to each individual Conservation Element and/or Change Agent. This chapter presents the Conservation Elements, Change Agents, and Management Questions identified for the Chihuahuan Desert REA. This chapter closely follows Chapter 3 in the Pre-Assessment Report (Unnasch et al. 2017).

3.1 Conservation Elements

No REA can ever assess all ecological values in an ecoregion. Instead, REAs focus on a limited set of key resources, termed *Conservation Elements* (CEs), consisting of regionally-significant terrestrial and aquatic species and ecological systems of management concern. The Assessment Management Team (AMT) for the Chihuahuan Desert REA identified the CEs for this REA in cooperation with a Technical Team through discussions that also considered the most pressing Change Agents (see below) for the U.S. portion of the ecoregion and the ecological resources they affect.

The AMT and Technical Team identified fourteen CEs for the Chihuahuan Desert REA listed in Table 3-1. These consist of three dry (terrestrial) ecological system types, five wet (aquatic-wetland) ecological system types, four individual species CEs, and two assemblages of species of management concern associated with terrestrial ecological systems. One of the aquatic-wetland CEs, “Playas and Playa Lakes,” has both wet (inundated) and dry phases, and thus shares features with both wet and dry system types.

Table 3-1. Chihuahuan Desert REA Conservation Elements

Conservation Element Group	Conservation Element Name
Dry System Types	• Chihuahuan Desert Grasslands • Chihuahuan Desert Scrub • Pinyon-Juniper Woodlands
Wet System Types	• Montane-Headwater Perennial Streams • Lowland-Headwater Perennial Streams • Large River-Floodplain Systems • Springs-Emergent Wetlands • Playas and Playa Lakes
Species and Assemblages	• Pronghorn • Mule Deer • Banner-tailed Kangaroo Rat • Black-tailed Prairie Dog • Grassland Bird Assemblage • Grassland Small Mammal Assemblage

The term, “ecological system” here refers to “… recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding” (Comer et al. 2003). The following paragraphs briefly describe the fourteen CEs for the Chihuahuan Desert REA. The conceptual models in Chapters 5-17 of the Pre-Assessment Report (Unnasch et al. 2017) provide detailed descriptions of the individual CEs.

3.1.1 Terrestrial Ecological System Conservation Elements

The three terrestrial or “dry” ecological system CEs selected for the Chihuahuan Desert REA consist of groups of similar, related terrestrial ecological system types that occur across the U.S. portion of the ecoregion. Together, these three CEs cover 84% of the lands in the U.S. portion of the ecoregion (Chihuahuan Desert Grasslands – 22%, Chihuahuan Desert Scrub – 59%, and Pinyon-Juniper Woodlands – 3%).

The Chihuahuan Desert Grasslands CE occurs on piedmonts on coalesced alluvial fans, foothills on colluvium, lowlands on basins and playas, and sandy plains on sand sheets across the U.S. portion of the ecoregion, typically between 1,100 and 1,700 m in elevation. Different herbaceous plant species dominate the ground cover in different settings. Black grama grass (*Bouteloua eriopoda*), bush muhly (*Muhlenbergia porteri*), and fluffgrass (*Dasyochloa puchella*) typically dominate the plant cover on the piedmonts. Sideoats grama (*Bouteloua curtipendula*), curlyleaf muhly (*Muhlenbergia setifolia*), New Mexico feathergrass (*Hesperostipa neomexicana*), and bullgrass (*Muhlenbergia emersleyi*) typically dominate on foothills. Dominant grasses in lowland areas include tobosagrass (*Pleuraphis mutica*), burrograss (*Scleropogon brevifolius*), alkali sacaton (*Sporobolus airoides*), big sacaton (*Sporobolus wrightii*), or vine mesquite (*Panicum obtusum*) with less abundant grasses including blue grama (*Bouteloua gracilis*) and bush muhly (*Muhlenbergia porteri*). The dominant herbaceous plants on the sand sheets include black grama grass (*Bouteloua eriopoda*), sand dropseed (*Sporobolus cryptandrus*), mesa dropseed (*Sporobolus flexuosus*), spike dropseed (*Sporobolus contractus*), ear muhly (*Muhlenbergia arenacea*), and sand muhly (*Muhlenbergia arenicola*). Although dominated by grasses, occurrences of this CE may also include shrubs or sub-shrubs as natural parts of the plant community. Chihuahuan Desert grasslands can grow on a range of soil types ranging from clayey to rocky. Fire, grazing, and drought are common natural disturbances shaping plant community composition in these grasslands. Droughts, inappropriate livestock grazing, human use, changed fire regime, and climate change over the past 150 years have allowed native desert scrub plants and some non-native plant species to invade and dominate areas historically dominated by grasslands.

The Chihuahuan Desert Scrub CE occurs across the lower elevations of the U.S. portion of the ecoregion on multiple landforms from basin floors to piedmont alluvial fans and foothills. Much of the desert scrub vegetation occurs over limestone parent material. Fire and drought are common sources of natural disturbance although fire has less influence in some settings than others. The most common dominant plant species of the Chihuahuan desert scrub is creosote bush *Larrea tridentata*, which often occurs with tarbush *Flourensia cernua*. Other potentially dominant shrubs include whitethorn acacia *Acacia constricta*, viscid acacia *Acacia neovernicosa*, Rio Grande saddlebush *Mortonia scabrella*, and ocotillo *Fouquieria splendens*.

The Pinyon-Juniper Woodlands CE occurs on a variety of landforms across the U.S. portion of the ecoregion, including basins, hills, and slopes on a variety of soils at moderate elevations between 1,400 and 2,200 m in elevation. Juniper is often more common than pinyon at lower elevations. However, this pattern is reversed in southern New Mexico, likely because of greater summer precipitation in this part of the ecoregion. Common tree species in this CE include Mexican pinyon *Pinus cembroides*, border pinyon *Pinus discolor*, two-needle pinyon *Pinus edulis*, alligator juniper *Juniperus deppeana*, one-seed juniper *Juniperus monosperma*, redberry juniper *Juniperus coahuilensis*, and Pinchot's juniper *Juniperus pinchotii*. The most influential natural disturbances that modify juniper-pinyon community structure are climate variation, fire, and insect infestations.

3.1.2 Aquatic-Wetland Ecological System Conservation Elements

The five aquatic-wetland or “wet” ecological system CEs selected for the Chihuahuan Desert REA consist of groups of aquatic, wetland and other closely associated ecological system types that occur across the lands managed by the BLM in the U.S. portion of the Chihuahuan Desert ecoregion. The REA does not include other seasonal and perennial wetland ecological systems that occur within the U.S. portion of the ecoregion but that do not occur on lands managed by the BLM within the ecoregion, such as wetland types that occur only at higher elevations in the ecoregion.

The Chihuahuan Desert REA distinguishes two types of perennial streams based on the sources of their waters and the geological conditions that characterize these sources. Montane-Headwater Perennial Streams originate at higher-elevation, montane settings. The elevation of these settings results in higher rates of precipitation than occur at lower elevations across the surrounding valley floors, with some of the precipitation occurring as snowfall. Streams that originate in these settings receive their water as runoff from both rainfall and snowmelt, as groundwater drainage from shallow montane soils and montane bedrock aquifers, and at discrete tributary springs. Cooler air temperatures, cold-air drainage along stream valleys, and montane riparian vegetation canopies help maintain relatively cool water temperatures. However, water temperatures vary with the time of day, season, and hydrologic conditions. The montane topographic settings result in steeper stream gradients and higher flow velocities on average, than found in streams with comparable discharge in lowland settings.

Lowland-Headwater Perennial Streams, in contrast, originate around the bases of mountains or in surrounding valleys. Streams that originate in these settings receive their water primarily from discharges of groundwater – sometimes at discrete springs – from lower-montane bedrock, basin-fill, and other larger-scale aquifers. The groundwater discharged into these streams originates as recharge at higher elevations, but may spend years, decades, or longer moving through the groundwater system before re-emerging. As a result, the water in each stream emerges with a distinct but relatively constant temperature year-round, controlled by the temperatures in the aquifers through which the water has passed, some of which may be affected by geothermal activity. The water in each resulting stream also emerges with a distinct pattern of concentration of dissolved matter, controlled by the chemistry of the groundwater pathways along which the water has traveled. Finally, because of their geological and topographic settings, lowland-headwater streams have relatively low gradients with relatively constant rates of baseflow year-round.

Many montane-headwater perennial streams in the ecoregion flow out onto valley floors, where they may develop wider floodplains and where groundwater discharge, evapotranspiration, and infiltration further alter their flow, temperature, and chemistry regimes. The lowland reaches of such streams may in fact resemble lowland-headwater perennial streams. In both perennial stream types, the combined effects of evapotranspiration and infiltration at lower elevations may cause flow to become seasonal or otherwise intermittent rather than perennial. However, flooding along large river-floodplain systems downstream can force floodwaters upstream along the lower reaches of tributary streams. Other natural disturbances include riparian fire, which may originate in the surrounding uplands, and droughts.

The Large River-Floodplain Systems CE consists of the three largest rivers in the U.S. portion of the ecoregion, the Gila River, Rio Grande, and Pecos River. This aquatic-wetland CE type contrasts with both types of perennial stream types in several ways. Most influentially, these three rivers receive their greatest headwater inputs almost entirely outside this ecoregion. The Gila River originates in the Mogollon Mountains to the north and northwest of the ecoregional boundary, and the Pecos River originates in the southern Rocky Mountains to the north. The Rio Grande originates both in the southern Rocky Mountains to the north and in the mountains of the Rio Conchos basin to the southwest, in Mexico, the latter of which joins the Rio Grande just upstream from the Big Bend of the river. The external, mountainous sources of these three large rivers produce greater annual discharges of water and transported matter and different seasonal patterns of discharge than would occur if these rivers originated entirely within the U.S. portion of the ecoregion. Natural short-term disturbances included riparian fire, which may originate in the surrounding uplands, droughts, and inundation and sediment erosion and deposition by floods.

The Rio Grande and Pecos River today are fragmented, strongly regulated by dams, and greatly diminished by diversions, with many of these alterations taking place both inside and outside the U.S. portion of the ecoregion. Prior to their regulation, however, the flows of water and sediment along these two rivers maintained more complex channels, much larger and more geologically active floodplains with extensive wetlands within the U.S. portion of the ecoregion, and much larger alluvial aquifers than associated with any montane- or lowland-headwater stream in the ecoregion. Their longer flow distances also resulted in higher water temperatures and higher concentrations of dissolved matter, both conditions exacerbated by river regulation. Historically, these two rivers – and the Gila River mostly to the west of the ecoregion – supported fauna and flora adapted to large, warm-water river settings, active river-floodplain exchanges of water and nutrients, flood cycles and disturbances, and extensive riparian wetland and woodland communities. Further, their riparian wetlands, particularly along the Rio Grande and Pecos River, provided – and in some areas still provide – substantial areas of stopover or over-wintering habitat for numerous migratory bird species, some in very large numbers.

“Springs-Emergent Wetlands” in the U.S. portion of the ecoregion occur across a wide range of elevations, wherever discharge from one or more aquifers reaches the ground surface at a location that does not lie beneath some other waterbody. The recharge zones for the contributing aquifers may be nearby or distant; the aquifers may differ greatly in their geochemistry and geothermal activity; and the water may take years, decades, or longer to move through the groundwater system before re-emerging.

As a result, springs in the ecoregion necessarily vary widely in their discharge rates and/or water levels, water temperatures, and chemistry. However, a lack of systematic data on spring hydrogeology, morphology, discharge rates, chemistry, fauna, and flora precludes distinguishing any sub-types for purposes of this REA. Some springs in the ecoregion discharge into and may even constitute the dominant source(s) of water for a perennial stream, while others may only support a localized wetland that rarely or never connects to the regional surface drainage network. Connections with the regional surface drainage network – even on a geologic time scale – allow aquatic species to move among spring-emergent wetland sites or between springs and streams: the more isolated a site, the more likely the site will come to harbor unique, endemic species. Natural disturbances include climate and weather variation that affect recharge and/or affect evapotranspiration at the spring site, and fire in the emergent or surrounding vegetation.

"Playas and Playa Lakes" consist of barren and sparsely vegetated depressions in topographic lows that experience seasonal or episodic wetting. The larger such features in the U.S. portion of the ecoregion are remnants of Pleistocene lakes. Wetting today comes from runoff following seasonal or episodic storms, supported by a rise in the local water table following such storms. Annual variation in precipitation strongly affects the inundation regime of playas. Some may fill and dry multiple times per year while others may remain dry for years. Dune fields, such as those at White Sands National Monument, New Mexico, may form downwind of larger playas. Intermittent flooding followed by evaporation concentrates alkaline salts in the water and soils. The distinctive chemistry and highly variable hydrology create conditions that support distinctive vegetation; unique assemblages of clam shrimp, fairy shrimp, and beetles; and tolerant frogs and toads. Playa lakes in the ecoregion in fact provide stopover habitat for migratory birds.

3.1.3 Species and Species Assemblage Conservation Elements

The four individual species and two assemblages of species selected as CEs for the Chihuahuan Desert REA either depend on or significantly affect the landscape-scale ecological integrity of grasslands across the U.S. portion of the ecoregion.

Pronghorn (*Antilocapra Americana*) is a wide-ranging ungulate herbivore. Its overall geographic range extends well beyond the boundaries of the ecoregion, but it uses and moves among several natural communities within the U.S. portion of the ecoregion. Pronghorn travel in herds and are highly visible because they occupy open habitat consisting primarily of flat prairies, shrub steppes, and semiarid grasslands. They avoid mountainous terrain. They feed preferentially on low vegetation, primarily on forbs and small shrubs rather than grass, but require taller vegetation as cover for fawns that are nearly immobile shortly after birth. Competition between pronghorn and other native ungulates appears to be minimal, although there is dietary overlap with mule deer (*Odocoileus hemionus*). The pronghorn is an important prey species for several of the native large predators, and is an important game species, providing economic benefits to landowners and area commerce. The present assessment does not distinguish subspecies.

Mule deer also is a wide-ranging ungulate herbivore. It uses and moves among several natural communities within the ecoregion, and its overall geographic range extends well beyond the boundaries of the ecoregion. Mule deer occupy a variety of habitats across their overall range, including agricultural lands, forests, grasslands, savannas and shrublands. In much of their range, they migrate from high elevations in the summer to lower elevations in winter. They require adequate and available foraging opportunities, access to water, including water from forage, good visibility and terrain allowing for movement for foraging, safe habitat selection and to avoid predation. In the U.S. Southwest, mule deer occur in desert shrublands, semi-desert shrubland-grasslands, chaparral, mountain shrublands and woodlands and forests at higher elevations. Additionally, riparian zones are important for water, food, escape, and resting, and provide corridors for travel. In the Chihuahuan desert they browse primarily on shrubs and forbs and consume very little grass. As with pronghorn, the mule deer is an important prey species for several of the native large predators; and is an important game species. Deer hunting provides economic benefits to landowners and area commerce.

The banner-tailed kangaroo rat (*Dipodomys spectabilis*) is a nocturnal, granivorous heteromyid rodent found throughout the grasslands of the U.S. portion of the ecoregion. It can be locally common, but is threatened by widespread degradation of its desert grassland habitat throughout much of its range. It is a mound-building rodent, and this ecological engineering can dramatically affect the community structure of both grassland plants and associated animals within the footprint of past and active mounds. Consequently, the banner-tailed kangaroo rat is considered a keystone species for the grasslands of the ecoregion, one with very specific habitat requirements.

The black-tailed prairie dog (*Cynomys ludovicianus*) is a colonial, burrowing rodent that inhabits several types of open grassland habitats from the Great Plains to the deserts of northern Mexico. Its burrowing alters the structure and composition of the grasslands, creating and maintaining suitable habitat for many other species. Many of the ecoregion's predators feed on these rodents, including the federally endangered black-footed ferret (*Mustela nigripes)*, an obligate predator of prairie dogs that formerly but no longer occurs in the U.S. portion of the ecoregion. Estimates suggest that black-tailed prairie dog abundance in the U.S. portion of the ecoregion has fallen by more than 90% from historic levels, particularly as a result of efforts eliminate its burrowing from grazing lands.

Grassland birds as a group have experienced the steepest population decline of any group of North American avifauna. This trend is evident among many bird species that are endemic or near-endemic to the grasslands of the U.S. portion of the ecoregion. The "Grassland Bird Assemblage" selected as a CE for the Chihuahuan Desert REA consists of the Arizona grasshopper sparrow (*Ammodramus savannarum ammolegus*), Baird's sparrow (*Ammodramus bairdii*), chestnut-collared longspur (*Calcarius ornatus*), Cassin's sparrow (*Peucaea cassinii*), and scaled quail (*Callipepla squamata*). These five bird species strongly prefer grassland and mixed grassland-scrub habitat, have similar ecological requirements. Their individual and collective abundances provide an indicator of the overall ecological condition of the grasslands of the ecoregion.

Small rodents consume plants, seeds, and invertebrates in large numbers; act as ecological engineers through their feeding, burrowing, and caching behaviors; and provide food for many predators. Healthy populations of these small mammals are essential for a healthy desert ecosystem. The “Grassland Small Mammal Assemblage” selected as a CE for the Chihuahuan Desert REA consists of the deer mouse (*Peromyscus maniculatus*), southern plains woodrat (*Neotoma micropus*), hispid cottonrat (*Sigmodon hispidus*), tawny bellied cottonrat (*Sigmodon fulviventer*), and yellow-nosed cottonrat (*Sigmodon ochrognathus*). These five species live in a variety of habitats and feed on a variety of organisms, but all can be found in the Chihuahuan desert grasslands and all share grasslands, or a component of grasslands, as critical habitat. Their individual and collective abundances also provide an indicator of the overall ecological condition of the grasslands of the ecoregion.

3.2 Change Agents

No REA can ever assess all threats to CEs in an ecoregion. Instead, REAs focus on a limited set of key stressors, termed *Change Agents* (CAs). All REAs address a core set of four overarching CAs: climate change, wildfire, invasive species, and development. Wildfire *per se* is a type of natural disturbance that can affect most – if not all – of the fourteen CEs selected for the Chihuahuan Desert REA. However, alterations to the natural fire regime that result in *unusual* fire patterns do constitute a Change Agent. The present REA therefore includes “uncharacteristic wildfire” as a Change Agent. The “development” CA for the present REA includes crop production, various types of industrial development including oil and gas production, and urban and suburban growth. The AMT and Technical Team selected two additional CAs for this REA, concerning excessive domestic grazing and landscape restoration. Landscape restoration is not a stressor but an intentional counter-measure against some stressors that can bring about significant changes in this ecoregion of interest to the BLM.

These CAs do not encompass all stressors affecting the CEs of the ecoregion. For example, the taking of plants is especially problematic for some endemic cactus species that may only occur within small areas, where they are highly vulnerable to extinction (Hoyt 2002). REAs cannot adequately assess such highly localized stressors, which require the detailed knowledge of local management districts and experts.

The term “Change Agent” points to a concern with change and possible future conditions. As discussed below – see Management Questions, this Chapter – the present REA examines the present distribution and impacts of all CAs and evaluates the possible future impacts of two CAs, climate change and development, for which geospatially systematic forecasts are available.

3.2.1 Climate Change

The climate of the southwestern U.S. has changed over the past century and particularly over the past few decades (see also Chapter 2, above). Seasonal average temperatures have recently increased by 0.16 – 0.21 °F per decade, particularly during spring and summer (Kunkel et al. 2013a, 2013b). Periods of extreme heat have become hotter and more frequent, while periods of extreme cold have become both less cold and less frequent. Long-term precipitation patterns have not shown significant trends, although there may be a trend of increasing fall precipitation (Kunkel et al. 2013a).

Multiple alternative climate models, run under multiple scenarios for greenhouse gas emissions, consistently predict several changes in the climate of the Chihuahuan Desert in the U.S. over the next century. Temperatures are predicted to increase, with extreme weather events such as droughts becoming more severe (Kunkel et al. 2013a, 2013b, Melillo et al. 2014). The models also predict increasing spatial variability in temperatures, with some areas warming more than others. Additionally, the models predict a decrease in the amount of average annual precipitation and an increase in the number of days with little to no precipitation (Kunkel et al. 2013a).

The conceptual models for the Chihuahuan Desert REA CEs presented in the REA Pre-Assessment report (Unnasch et al. 2017) indicate that climate change potentially will significantly affect all fourteen CEs. All fourteen are vulnerable to the effects of changes in air temperatures and precipitation on the metabolisms of species, which may be individuals CEs, members of species assemblage CEs, or species critical to the dynamics of ecological systems. Changes in air temperatures and precipitation also have the potential to affect wildfire dynamics, groundwater recharge-discharge, surface water runoff, and evapotranspiration, which affect important ecological interactions and disturbance processes for all fourteen CEs, and all of which also affect the viability of invasive species with differing tolerances for the altered climate. Climate change will also result in changes in human activities on the landscape, such as rates of water consumption, which will themselves have additional impacts on CEs.

3.2.2 Uncharacteristic Wildfire

Fire has historically played a different, but significant, role in each of the terrestrial ecological system types within the U.S. portion of the ecoregion. Fire was common in the Chihuahuan Desert Grassland CE, with fire return intervals typically 10 years or less. These frequent fires limited encroachment by shrubs by killing recruits before they get established. Similarly, the Pinyon-Juniper Woodlands CE experienced frequent low-intensity fires that consumed the fine fuels in the herbaceous layer while leaving the trees unscathed.

These historic fire regimes have changed following the introduction of livestock by European settlers. Foraging livestock reduced both the cover and abundance of grasses and forbs, which changed the amount and continuity of the fine fuels resulting in less frequent fire. In the grasslands this allowed for encroaching shrubs to establish further, changing the fire regime. In the woodlands it allowed for an accumulation of woody fuels resulting in larger, more severe fires when they did burn. Such stand replacing fires can result in significant erosion on slopes with erodible soils.

The desert scrub system burned infrequently in the past because of the lack of fine fuels and the discontinuity of the native shrubs. This has not changed significantly, and the current fire regime is likely very similar to the fire regime that existed prior to the introduction of livestock.

3.2.3 Invasive Species

Non-native species introduced into a landscape can have a range of effects, from no measurable impacts to facilitating system transition. The U.S. portion of the Chihuahuan Desert ecoregion presents examples of all types of effects along this spectrum. For example, the non-native buffelgrass (*Pennisetum ciliare*), and Lehmann lovegrass (*Eragrostis lehmanniana*) can both displace native grasses and forbs and change the fire regime of native communities. Non-native cheatgrass (*Bromus tectorum*), which is widely distributed in the U.S. portion of the Chihuahuan Desert ecoregion, has converted thousands of square kilometers of Great Basin sagebrush steppe into monospecific grasslands. Tamarisk (aka saltcedar, Tamarix spp.) has displaced native riparian communities throughout the southwestern U.S.

Native species can also be invasive outside their native ranges. For example, honey mesquite (*Prosopis glandulosa*), readily encroaches into desert grasslands, facilitated by cattle. Once established, it can displace native grasses, causing the land to transition into a mesquite duneland (Peters and Gibbens 2006).

3.2.4 Development

Land development for crop production, industry including oil and gas production, recreation, and urban/suburban growth affects most CEs in the U.S. portion of the ecoregion. Water use associated with these forms of development in turn affects all wet-system CEs. For example, alluvial soils along the Pecos River and Rio Grande and along smaller rivers such as the Mimbres River and Rio Hondo are intensively farmed, irrigated from surface water and groundwater sources. The spatial extent of this intensive, irrigated farming is affected by the availability of water, crop demand, and efficiencies in farming and irrigation practices.

Human population density and urban development have increased over the last 150 years in the southwestern U.S. in general as well as in the Chihuahuan Desert ecoregion in particular (Ruhlman et al. 2012, Theobald et al. 2013 – see also Chapter 2, above, and Chapter 5, below). Much of the increase has occurred in urban areas that continue to expand, along with their surrounding zones suburbs and exurbs (Ruhlman et al. 2012, Theobald et al. 2013). The five largest urban areas in the U.S. portion of the ecoregion (populations > 20,000) are El Paso, Texas, and Las Cruces, Roswell, Alamogordo, and Carlsbad, New Mexico. All except Alamagordo straddle rivers: Roswell straddles the Rio Hondo; Carlsbad, the Pecos River; and Las Cruces and El Paso, the Rio Grande. These juxtapositions result in urban development of floodplains, often at the expense of farming on these same landforms. These trends of population growth and urban expansion are expected to continue into the foreseeable future (Ruhlman et al. 2012, Theobald et al. 2013; see also Chapter 5, below). New Mexico alone is expected to see an increase in population by another third by 2030 according to the Census Bureau's population predictions (Theobald et al. 2013).

Impoundments on the Pecos River and Rio Grande control flooding and supply water to irrigation districts and to municipalities including Las Cruces and Roswell, New Mexico, and El Paso, Texas (Ruhlman et al. 2012). Most of the water from the Rio Grande, much of the water from the Pecos River, and most of the water from the lower reaches of their perennial tributaries is diverted for use by municipalities and agriculture (Hoyt 2002). Together, the diversions, impoundments, and dam operations inundate large areas of former floodplain and alter river hydrology and connectivity. Infiltration from irrigation canals and ditches recharges water significantly alters recharge to some alluvial aquifers (Hogan 2013). The return flows from agricultural and municipal water uses carry heavy loads of dissolved salts. River regulation, dams, diversions, and return flows with degraded water quality have contributed to changes in native fish populations and have also affected floodplain forests and wetlands in the few areas where the floodplains have not been developed for farming or other purposes. Groundwater extraction from both basin fill and alluvial aquifers has reduced the flow of water from springs and lowered water tables, which can negatively affect baseflow, floodplain and emergent wetlands, endemic fish, and invertebrate species.

Many springs in the ecoregion, such as the Balmorhea Springs complex in Texas, have been developed for recreational use. While not resulting in water consumption, such recreational development typically eliminates wetland habitats and significantly alters aquatic habitat conditions.

Land development for solar and wind energy production, and for oil and gas production and transport also have affected and have the potential to further affect CEs in the ecoregion (Engler et al. 2012, Ruhlman et al. 2012, Engler and Cather 2014, USEIA 2015, NMEMNRD 2016). As discussed above, the analysis extent includes the western third of the Permian Basin, an area of extensive conventional oil and gas extraction and the most productive conventional oil and gas basins in the entire U.S. (Engler et al. 2012, Engler and Cather 2014, USEIA 2015), as discussed above (Chapter 2, this report) and in the Pre-Assessment report (Unnasch et al. 2017). This same landscape also contains several “tight oil and gas plays,” geologic formations suitable for non-conventional methods of oil and gas extraction through horizontal drilling and hydraulic fracturing (Engler et al. 2012, Engler and Cather 2014, USEIA 2016). As a result, this portion of the ecoregion has a high density of oil and gas wells and associated processing and transport infrastructure, from which radiate additional pipelines. Both conventional and non-conventional oil and gas extraction are expected to continue expanding in the ecoregion (Engler et al. 2012, Engler and Cather 2014, USEIA 2015, NMEMNRD 2016). Hydraulic fracturing requires large volumes of water, only some of which can be recycled following use. It also poses risks of water pollution from well leakage and waste spills, although these risks are subject to significant regulation (NMOGA 2012, NMEMNRD 2016). Hydraulic fracturing has been used in oil and gas extraction in the ecoregion for many decades (NMOGA 2012), but its use is expanding as a result of the more recent coupling of hydraulic fracturing with horizontal drilling technologies (Engler et al. 2012, Engler and Cather 2014, USEIA 2015, NMEMNRD 2016). The USGS estimates that water use for oil and gas extraction accounted for the largest increase in water use in New Mexico between 2005 and 2010 (Maupin et al. 2014). However, changes in hydraulic fracturing technologies have reduced needs for both fresh and brackish water (NMEMNRD 2016, New Mexico Energy Forum 2016).

3.2.5 Excessive Domestic Grazing

The Chihuahuan desert was not heavily grazed by bison or other ungulates for at least the last 10,000 years prior to European-American colonization (Mack and Thompson 1982, Bock and Bock 1993, Havstad and Schlesinger 2006). The lack of continuous, intensive grazing pressure from large ungulates encouraged the spread of plant species with low tolerance to defoliation and grazing, along with less palatable plants. Spaniards arriving in the 1500s introduced cattle grazing as a new disturbance to the ecoregion (Havstad et al. 2006). The intensity of cattle grazing increased significantly in the U.S. portions of the ecoregion following the acquisition of these lands by the U.S. At the peak of grazing intensity between 1890 and 1920, ranchers grazed more than a million cattle in the southwestern U.S. (Frederickson et al. 1998), altering vegetation, soil structure and erosion, and runoff dynamics.

Excessive domestic grazing is considered to be one of the major degraders of rangeland health in the U.S. portion of the ecoregion. Briefly, cattle consume those more palatable herbaceous plants that have fewer defenses against herbivory. This reduces the amount of space, nutrients, and water taken up by palatable plants and leaves more available for less palatable plants including shrubs to increase in size and density. Honey mesquite (*Prosopis glandulosa*), a woody species, illustrates this process in the ecoregion (Havstad et al. 2006). This plant has physical and chemical characteristics that deter consumption of its greenery but produces seeds that are readily consumed and dispersed by livestock (Havstad et al. 2006). The resulting expansion of honey mesquite into former grasslands alters ecological processes including net primary productivity, nutrient cycling, energy flow, fire regimes, and food web dynamics (Sims and Singh 1978, Detling 1988, Archer and Smiens 1991, Hobbs et al. 1991, Havstad et al. 2006). Reductions in herbaceous species and increases in shrub species can also negatively affect native grassland wildlife while simultaneously benefiting shrubland wildlife. Trampling of wetland habitat and stream banks, and inputs of cattle wastes into water bodies, also can alter CEs.

3.2.6 Landscape Restoration

Upland restoration in the U.S. portion of the ecoregion has focused largely on recovering degraded grasslands. Desert grasslands occur between the desert scrub at lower elevations and the pinyon-juniper woodlands at higher elevations, as discussed above in this chapter and in Chapter 2 (see also Chapters 4 and 7, below). As noted above, the introduction of livestock into the U.S. portion of the ecoregion dramatically altered the fire regimes within the region, resulting in the expansion of woody scrub and trees into areas that were historically grasslands.

Grassland restoration efforts have focused on shrub removal, through mechanical (e.g., chaining), chemical (e.g., herbicide), or prescribed fire treatments.

3.3 Management Questions

Every REA focuses on a limited set of core Management Questions (MQs) concerning its CEs and CAs that can be addressed using geospatial data, as discussed in Chapter 2. All REAs address four basic MQs concerning the geographic distribution of each CE, how the condition of each CE varies across its geographic distribution, the geographic distribution of each CA, and the forecasted future geographic distributions of impacts of those CAs for which forecasts are available. Table 1-1 lists these four core MQs, designated MQ A – MQ D, and indicates the CE(s) and CA(s) to which each question applies.

REAs also addresses additional MQs, focused on management concerns that cannot be resolved by individual offices alone and have regional importance. Thirteen additional MQs addressed in the present REA concern: (1) interactions between specific CAs and specific CEs; (2) specific attributes or indicators of individual CEs, such as particular habitat types or particular groups of species within an ecosystem; or (3) additional environmental conditions that can affect some CEs or CAs.

The Pre-Assessment report for the Chihuahuan Desert REA (Unnasch et al. 2017) describes the process through which the AMT developed the final list of additional MQs concerning the U.S. portion of the ecoregion. Table 1-1 lists these thirteen additional MQs, designated MQ 1- MQ 13, and indicates the CE(s) and CA(s) to which each question applies.

Table 3-2. Chihuahuan Desert REA Management Questions.

MQ #	Question	CE(s)	CA(s)
A	What is the geographic distribution of each CE?	All	n/a
B	What is the current condition of each CE across its geographic distribution?	All	n/a
C	What is the current geographic distribution of the impacts of each CA, both in general and in relation to each CE?	All	All except Climate Change, for which "current distribution" is the baseline for MQ #D.
D	What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?	All	Climate Change, Development
1	Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?	All Dry-System CEs	Landscape Restoration
2	What is the geographic distribution of the Chihuahuan desert amphibian assemblage?	All Dry- and Wet-System CEs	n/a
3	Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?	All Wet Systems	Uncharacteristic Wildfire
4	What areas of potential black-tailed prairie dog habitat would support restoration?	Black-tailed Prairie Dog	Landscape Restoration
5	Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?	All Species and Species Assemblage CEs	n/a
6	Where will urban and industrial growth impact intact grasslands or impede their recovery?	Chihuahuan Desert Grasslands CE	Development, Landscape Restoration
7	How do the current and historic geographic distributions of the dry-system CEs differ?	All Dry-System CEs	n/a
8	How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?	Grassland Bird Assemblage CE	Development
9	What and where are the aquifers and their recharge zones that support the wet systems?	All Wet-System CEs	Development
10	How do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?	All Wet-System CEs except Playas	n/a
11	Where are the breeding, winter, and year-around habitats for pronghorn and mule deer?	Pronghorn; Mule Deer	n/a
12	Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?	All Wet-System CEs	Invasive Species; Landscape Restoration
13	What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?	All	All except Climate Change

The AMT also posed potential MQs about the individual CEs that needed to be addressed in the conceptual model for each CE rather than through analyses of geospatial data. The Pre-Assessment Report for the Chihuahuan Desert REA (Unnasch et al. 2017) discusses these conceptual questions, which concern the ways in which each CA potentially could affect each CE – the causal processes and outcomes involved. For example, through what causal processes might climate change affect the condition of montane-headwater perennial streams, or through what causal processes might a change in the wildfire regime affect the condition of habitat for pronghorn? The conceptual model for each CE was developed in part with these questions in mind. In this way, the conceptual models for the CEs set the stage for answering several of the geospatial MQs listed in Table 1-1.

Several of the MQs in Table 1-1 require additional explanation. Chapter 7, below, provides a full explanation of MQ 13, concerning "gypsum in the soil and water." Chapter 8 provides full explanations of MQ 2, concerning the "Chihuahuan desert amphibian assemblage," and MQ 10, concerning the "Pecos River and Gila River fish assemblages." Chapter 10, finally, provides a full explanation of MQ 5, concerning "faunal species biodiversity." Chapter 7 provides a detailed explanation of MQ 13, and Chapter 8 provides detailed explanations for MQs 2 and 10, expanding on the original presentations in the Pre-Assessment Report (Unnasch et al. 2017).

3.4 Assessment Methodology

The Chihuahuan Desert REA followed the normal sequence of steps for Phase II, reviewing the literature and working with the BLM and other agencies and organizations to identify and acquire the data and metadata needed to address MQs A-D and 1-13. Chapters 4-10 and an Appendix to this report describe in detail the data used and the methods and processes deployed in the assessment of these data.

4 Climate Change

Chapter 2 includes a summary of the current climate of the U.S. portion of the ecoregion. As noted there and throughout the Pre-Assessment Report, climate variation across the U.S. portion of the ecoregion significantly and climate variability over time together strongly shape the distributions of species and ecological systems across this landscape. Consequently, climate change is one of the six Change Agents (CAs) addressed in the Chihuahuan Desert REA. It is also one of two CAs for which the REA assesses forecasts of future conditions and their potential impacts – the other forecasted CA is development. Climate change therefore is one of the two CAs addressed in Management Question D, What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?

This chapter presents the results of an assessment of the potential impacts of climate change on the U.S portion of the Chihuahuan desert ecoregion. The assessment has three components:

(1) A general quantitative assessment of the potential impacts of climate change on the three terrestrial ecological system CEs and their associated individual species and species assemblage CEs, based on six climate variables: annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, annual precipitation, precipitation of the wettest month, and precipitation of the driest month. This assessment compares historic conditions, 1950-2000, to forecasted conditions in two future bi-decadal periods, 2041-2060 (period mean, 2050), and 2061-2080 (period mean, 2070).

(2) A more intensive quantitative assessment of impacts only to the three terrestrial ecological system CEs based on a larger suite of climate variables to address two specialized questions: Where will climate change result in transitions in land cover from grass to shrub dominance, grass to woodland dominance, or vice-versa? Where will climate change result in shifts in grassland distribution (e.g., expand, contract, shift)? This assessment again compares historic conditions, 1950-2000, to forecasted conditions in two future bi-decadal periods, 2041-2060 (period mean, 2050), and 2061-2080 (period mean, 2070).

(3) A literature-based assessment of the potential impacts of climate change on the aquatic and wetland ecological system CEs in the ecoregion, summarized from the conceptual ecological models in the Chihuahuan Desert REA Pre-Assessment report (Unnasch et al. 20017).

4.1 *Climate Change and Dryland Conservation Elements*

This section assesses the potential realistic scenarios for climate change across the U.S. portion of the ecoregion and the potential impacts of these changes on the three terrestrial ecological system CEs and their associated individual species and species assemblage CEs.

4.1.1 Methods and Data

4.1.1.1 Downscaled Climate Datasets

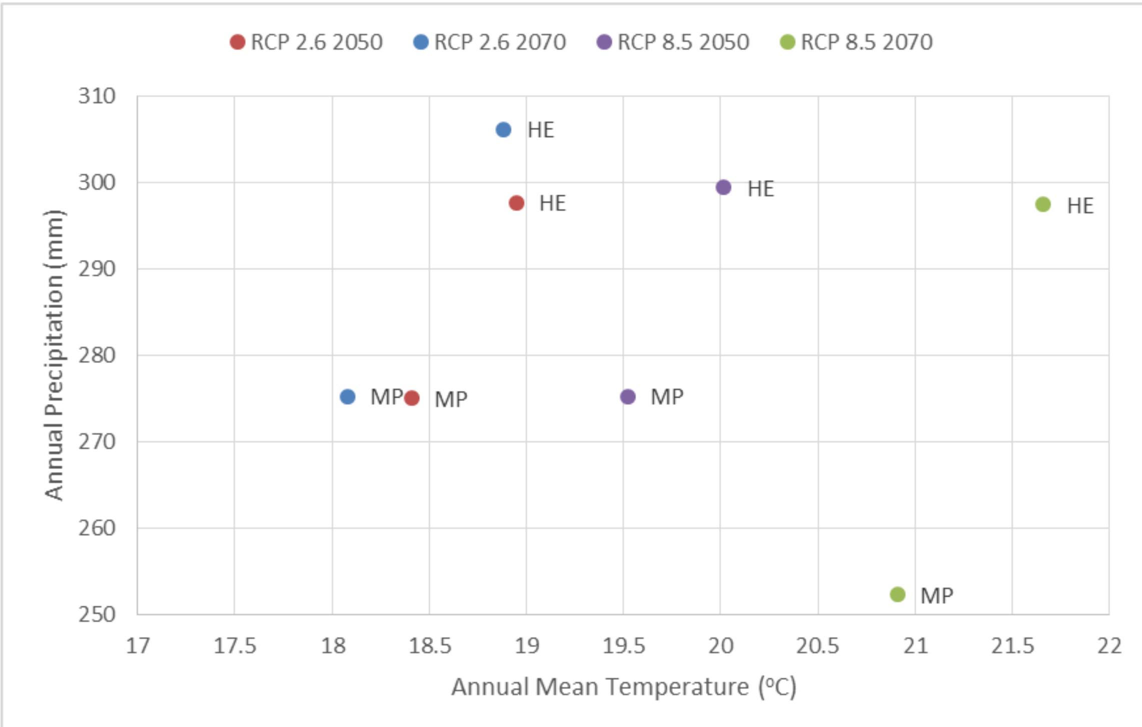
Data on historic (1950-2000) and projected future (2050 - average of 2041-2060; and 2070 - average of 2061-2080) values for 19 bioclimatic variables (http://www.worldclim.org/bioclim) were obtained from

WorldClim (http://www.worldclim.org/current; http://www.worldclim.org/cmip5_30s). The data were then clipped to the Level-III ecoregional boundaries. Annual mean temperature and annual precipitation across the U.S. portion of the ecoregion for 1950-2000 average 16.5 $^{\circ}$C and 304 mm, respectively.

The data for the two future periods consist of downscaled values for two Global Climate Models (GCMs), the Max Planck Institute for Meteorology Earth System Model LR (MPI-ESM-LR) and the Hadley Centre Global Environment Model version 2 Model ES (HadGEM2-ES) and two Representative Concentration Pathways (RCPs), RCP 2.6 and RCP 8.5. These GCMs are two of over 50 models included in the fifth phase of the Coupled Model Inter-comparison Project (CMIP5). CMIP5 involves collaboration of numerous scientists in running GCMs according to various scenarios. These modeling activities are intended to fill important gaps in the current understanding of changes in both historic and future climatic conditions. They are also meant to inform national and international efforts including the Intergovernmental Panel on Climate Change's Fifth Assessment Report (Taylor et al. 2012). Several model runs performed as part of CMIP5 were based on the four RCPs. Some of these runs are for a shorter time period (2035); others go to 2100 and longer. These RCPs are scenarios for future changes in emissions and concentrations of greenhouse gases and in land use. The RCPs are named for the level of radiative forcing, or change in the global energy budget (watts $\cdot$ meter^{-2}) associated with changes in atmospheric composition projected by 2100 compared to preindustrial conditions (Moss et al. 2010, van Vuuren et al. 2011, Taylor et al. 2012, Cubasch et al. 2013). The data for the two future periods consist of downscaled values with a spatial resolution of 30 arc-seconds (roughly 900 m at the equator) based on the historic data (Hijmans et al. 2005).

The two GCMs of interest were selected because they had been found to be relatively unbiased when compared to historical climate data (Sheffield et al 2013). They also have lower values for top of atmosphere energy imbalance and thus were less likely to exhibit long term drift in simulated climatic conditions (Forster et al. 2013). The two RCPs of interest were selected because they bracket the range of expected of greenhouse gas emissions concentrations. RCP 8.5 is the most extreme scenario for projected greenhouse gas concentrations as it entails the highest projected increase in the emission of multiple greenhouse gases to the atmosphere (van Vuuren et al. 2011) and associated increases in global surface temperatures (Knutti and Sedlacek 2012). RCP 2.6 conversely entails the lowest emission of greenhouse gases (van Vuuren et al. 2011) and the lowest level of warming of global surface temperatures (Knutti and Sedlacek 2012). The four GCM by RCP combinations considered here thus represent a realistic range of projected values in both mean annual temperature and precipitation across the U.S. portion of the ecoregion, as shown in Figure 4-1.

Figure 4-1. Average annual mean temperature and annual precipitation projected for the U.S. portion of the ecoregion for two future bi-decadal periods (period means 2050 and 2070) according to two GCMs (MPI-ESM-LR = MP and HadGEM2-ES = HE) and two RCPs (2.6 and 8.5). Historic (1950-2000) values for the U.S. portion of the ecoregion are 16.5°C and 304 mm.



Selecting a subset of GCMs, rather than using an average or other ensemble of all available GCMs, allows for evaluation of several sets of possible future conditions and acknowledges the uncertainty associated with the GCM projections and various RCPs. Given the uncertainty in the forecasts of climate, it is useful to show a range of potential future conditions rather than accepting one average value as the truth (based on Knutti 2010). Comparing the two future bi-decadal periods also is useful. The greenhouse gas concentrations, radiative forcing, and projected global mean temperatures associated with the RCPs are much more similar to each other during the first of the two future periods than they are during the second (van Vuuren and Carter 2014). The comparison allows for consideration of a much wider range of potential future climatic conditions and, as with using multiple GCMs rather than an ensemble, better accounts for the uncertainty associated with the different GCMs and RCPs.

4.1.1.2 Climate Variable Selection

The bioclimatic variables selected for analysis provide information on ecologically relevant characteristics of temperature and precipitation at monthly, quarterly, and annual time steps. These variables are often used in bioclimatic-envelope modeling studies (e.g., Calkins et al. 2012). A subset of six variables that provide information on annual climate and months with highest and lowest temperatures and precipitation were selected for assessing changes in climatic conditions between the historic (1950-2000) and two future bi-decadal periods (period means 2050 and 2070) (Table 4-1). The six variables are annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, annual precipitation, precipitation of the wettest month, and precipitation of the driest month.

4.1.1.3 Conservation Element Spatial Distribution Data

The analysis of the potential impacts of climate change considered only the actual U.S. portion of the ecoregion rather than the somewhat larger analysis extent used for other purposes in the REA. The data on the spatial distributions of terrestrial ecological system and species CEs used in the assessment of the potential impacts of climate change are the same as the data used to map the distributions of these same CEs for other purposes in the REA. However, the analysis of the potential impacts of climate change considered only data on species distribution available in the National Gap Analysis Program (GAP) database to maintain data consistency across all analyses. The analyses also only considered species for which data were available from the GAP at the time the analysis was carried out, in 2015. This limited the analysis of the potential impacts of climate change to a subset of eight species: One individual species CE, Black-tailed prairie dog; all five species of the Grassland Bird Assemblage CE, Arizona grasshopper sparrow, Baird's sparrow, Cassin's sparrow, Chestnut-collared longspur, and Scaled quail; and two species in the Grassland Small Mammal Assemblage, Tawny-bellied cotton rat and Yellow-nosed cotton rat.

The previously described differences between historic and future values for each of the six annual and monthly bioclimatic variables were averaged across the four GCM x RCP combinations for each time period. The distributions of the selected CEs or their constituent species were then used to extract values from these averaged datasets. These extracted values were summarized and mapped in order to provide information on how climatic conditions may change within the current distributions of these species and land cover types of interest for the U.S. portion of the ecoregion.

4.1.2 Results

4.1.2.1 Forecasted Changes in Six Climate Variables

Forecasted changes in the six climate variables were calculated by subtracting the historic average values (1950-2000) from the future bi-decadal average values forecasted for each variable under each of the four selected GCM x RCP combinations, for each future time period (2050 or 2070). Table 4-1 and Figure 4-2 and Figure 4-3 show the resulting differences.

Projected increases in average annual temperatures across the U.S. portion of the ecoregion range from 1.5 to 5.1 °C by the year 2070 according to two different GCM x RCP combinations (Table 4-1). In general, the combination of the MPI-ESM-LR GCM and the RCP 2.6 emissions scenario forecasts the smallest increases in all temperature variables, both annual and monthly and is thus "cooler" compared to the other GCM x RCP combinations. In contrast, the combination of the HadGEM2-ES GCM and the RCP 8.5 emissions scenario forecasts the largest increases in temperatures by 2070 and is thus the "hotter" scenario compared to the other GCM x RCP combinations. The patterns for precipitation are slightly less consistent. The MPI-ESM-LR GCM forecasts the largest declines in annual precipitation and precipitation of the wettest month by both 2050 and 2070, and is thus the "drier" model combination.

In turn, the HadGEM2-ES GCM forecasts the smallest declines in annual precipitation and forecasted an increase in precipitation during the wettest month, and is thus the "wetter" model combination. All GCM x RCP combinations project a small decline in precipitation during the driest month (range from 0.4 to 2 mm for 2070) (Table 4-1).

Table 4-1. Average forecasted changes in six annual and monthly climate variables between the historic period (1950-2000) and two bi-decadal future periods (period means 2050 and 2070) across the U.S. portion of the ecoregion. Blue/Red = smallest/largest change in temperature for a given year. Dark Red/Green = most negative/positive change in precipitation for a given year.

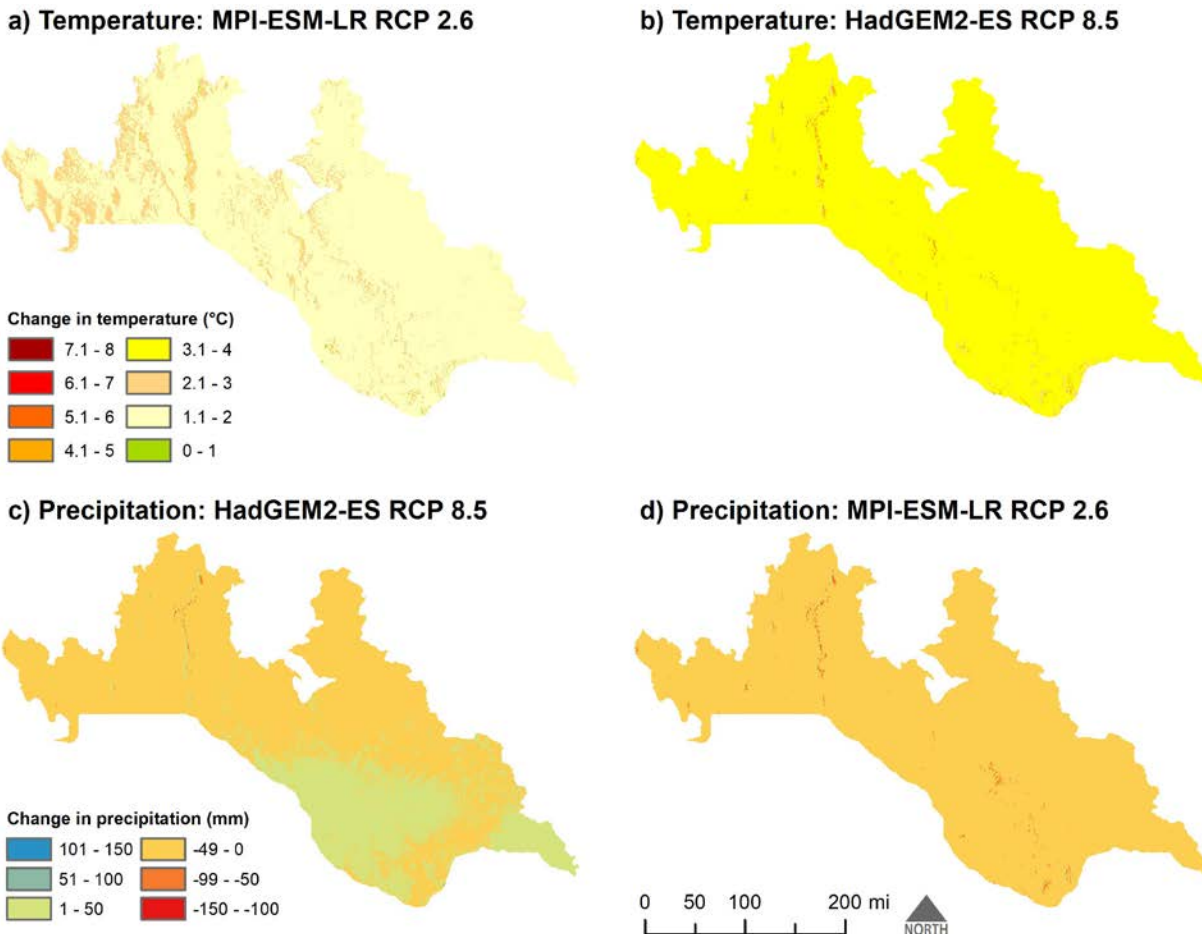
Variable	GCM	RCP	Year	Regional Average
Annual Mean Temperature, °C	HadGEM2-ES	2.6	2050	2.4
Annual Mean Temperature, °C	MPI-ESM-LR	2.6	2050	1.9
Annual Mean Temperature, °C	HadGEM2-ES	8.5	2050	3.5
Annual Mean Temperature, °C	MPI-ESM-LR	8.5	2050	3.0
Annual Mean Temperature, °C	HadGEM2-ES	2.6	2070	2.3
Annual Mean Temperature, °C	MPI-ESM-LR	2.6	2070	1.5
Annual Mean Temperature, °C	HadGEM2-ES	8.5	2070	5.1
Annual Mean Temperature, °C	MPI-ESM-LR	8.5	2070	4.4
Maximum Temperature of Warmest Month, °C	HadGEM2-ES	2.6	2050	2.8
Maximum Temperature of Warmest Month, °C	MPI-ESM-LR	2.6	2050	2.4
Maximum Temperature of Warmest Month, °C	HadGEM2-ES	8.5	2050	3.9
Maximum Temperature of Warmest Month, °C	MPI-ESM-LR	8.5	2050	3.4
Maximum Temperature of Warmest Month, °C	HadGEM2-ES	2.6	2070	2.8
Maximum Temperature of Warmest Month, °C	MPI-ESM-LR	2.6	2070	2.1
Maximum Temperature of Warmest Month, °C	HadGEM2-ES	8.5	2070	5.7
Maximum Temperature of Warmest Month, °C	MPI-ESM-LR	8.5	2070	4.8
Minimum Temperature of Coldest Month, °C	HadGEM2-ES	2.6	2050	1.7
Minimum Temperature of Coldest Month, °C	MPI-ESM-LR	2.6	2050	1.4
Minimum Temperature of Coldest Month, °C	HadGEM2-ES	8.5	2050	2.7
Minimum Temperature of Coldest Month, °C	MPI-ESM-LR	8.5	2050	2.4
Minimum Temperature of Coldest Month, °C	HadGEM2-ES	2.6	2070	1.6
Minimum Temperature of Coldest Month, °C	MPI-ESM-LR	2.6	2070	0.9
Minimum Temperature of Coldest Month, °C	HadGEM2-ES	8.5	2070	3.9
Minimum Temperature of Coldest Month, °C	MPI-ESM-LR	8.5	2070	3.0
Annual Precipitation, mm	HadGEM2-ES	2.6	2050	-6.5
Annual Precipitation, mm	MPI-ESM-LR	2.6	2050	-29.2
Annual Precipitation, mm	HadGEM2-ES	8.5	2050	-4.8
Annual Precipitation, mm	MPI-ESM-LR	8.5	2050	-28.9
Annual Precipitation, mm	HadGEM2-ES	2.6	2070	1.9
Annual Precipitation, mm	MPI-ESM-LR	2.6	2070	-28.9
Annual Precipitation, mm	HadGEM2-ES	8.5	2070	-6.8
Annual Precipitation, mm	MPI-ESM-LR	8.5	2070	-51.9
Precipitation of the Wettest Month, mm	HadGEM2-ES	2.6	2050	2.3

Variable	GCM	RCP	Year	Regional Average
Precipitation of the Wettest Month, mm	MPI-ESM-LR	2.6	2050	-9.3
Precipitation of the Wettest Month, mm	HadGEM2-ES	8.5	2050	9.0
Precipitation of the Wettest Month, mm	MPI-ESM-LR	8.5	2050	-7.2
Precipitation of the Wettest Month, mm	HadGEM2-ES	2.6	2070	9.1
Precipitation of the Wettest Month, mm	MPI-ESM-LR	2.6	2070	-11.5
Precipitation of the Wettest Month, mm	HadGEM2-ES	8.5	2070	9.1
Precipitation of the Wettest Month, mm	MPI-ESM-LR	8.5	2070	-12.4
Precipitation of the Driest Month, mm	HadGEM2-ES	2.6	2050	-0.6
Precipitation of the Driest Month, mm	MPI-ESM-LR	2.6	2050	-0.4
Precipitation of the Driest Month, mm	HadGEM2-ES	8.5	2050	-0.8
Precipitation of the Driest Month, mm	MPI-ESM-LR	8.5	2050	-1.3
Precipitation of the Driest Month, mm	HadGEM2-ES	2.6	2070	-0.9
Precipitation of the Driest Month, mm	MPI-ESM-LR	2.6	2070	-0.4
Precipitation of the Driest Month, mm	HadGEM2-ES	8.5	2070	-2.0
Precipitation of the Driest Month, mm	MPI-ESM-LR	8.5	2070	-1.3

Forecasted spatial patterns in temperature changes by both 2050 and 2070 are fairly consistent among the four GCM x RCP combinations for the smallest (Figure 4-2 (a) and Figure 4-3(a)) and largest (Figure 4-2 (b) and Figure 4-3(b)) changes in average temperature. Temperatures are forecasted to increase more in the northwestern parts of the U.S. portion of the ecoregion than in the southeastern parts, and this is more apparent in the cooler scenario for 2050 (MPI-ESM-LR x RCP 2.6) (Figure 4-2 (a)) and hotter scenario for 2070 (HadGEM2-ES x RCP 8.5) (Figure 4-3 (b)). Temperatures are also forecasted to increase more on the eastern (versus western) sides of several mountain ranges including the Organ, Oscura, and San Andres ranges in New Mexico and the Chinati, Chisos, Davis, Del Norte, Glass and Sierra Diablo Mountains in Texas (Figure 4-2 and Figure 4-3; see Figure 2-3 in Chapter 2 for locations of mountain ranges). The cooler GCM x RCP combination (MPI-ESM-LR x RCP 2.6) forecasts a very small total area in which temperatures actually decline (~23 km^2 for 2050; ~65 km^2 for 2070). These areas are too small to be displayed in the relevant figures (Figure 4-2 (a) and Figure 4-3(a)).

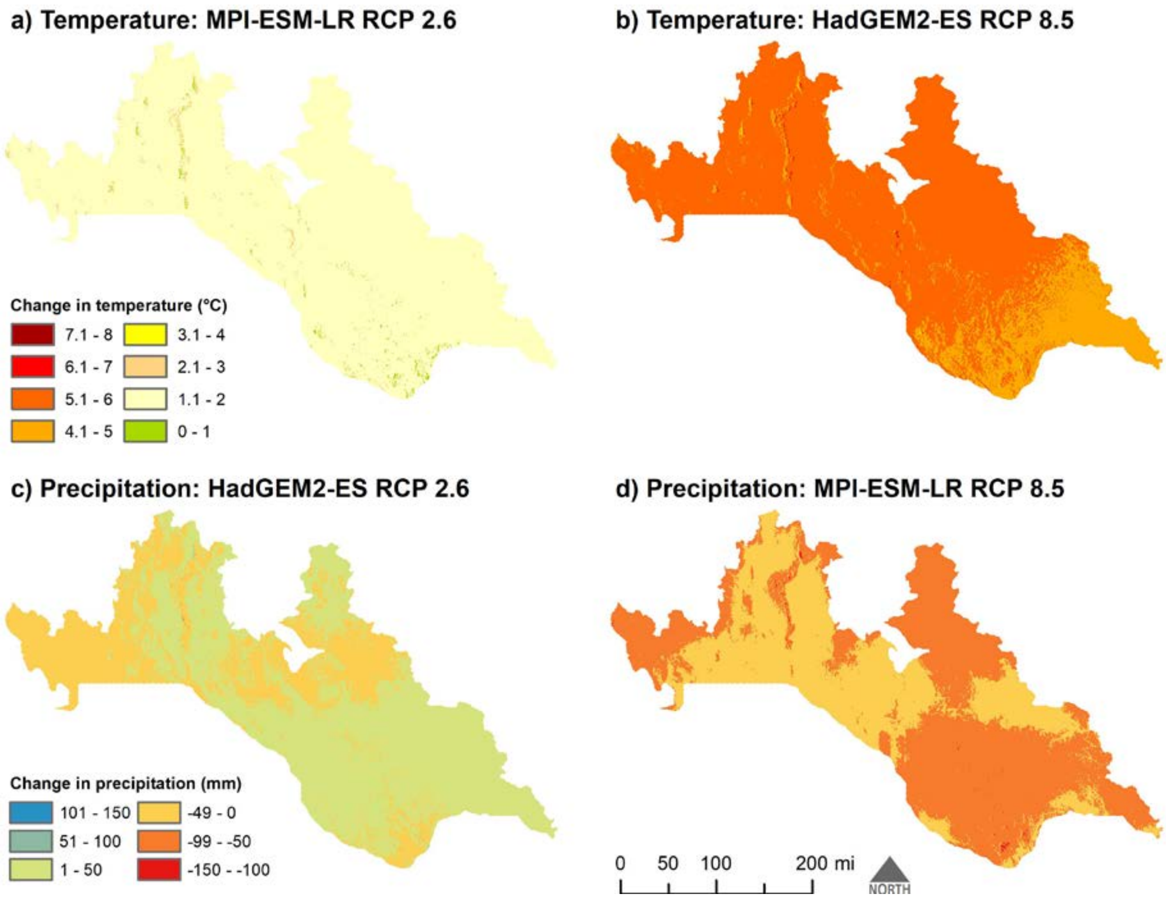
The overall wetter (Figure 4-2 (c) and Figure 4-3(c)) and drier (Figure 4-2 (d) and Figure 4-3(d)) GCM x RCP combinations forecast different patterns of change in annual precipitation by 2050 and 2070. For 2050, the overall wetter model combination shows the northern parts of the U.S. portion of the ecoregion, in New Mexico, becoming drier and the southern parts, in Texas, becoming wetter. It also shows a drying trend on the eastern side and wetter conditions on the western side of the Organ, Oscura, and San Andres Mountains in New Mexico (Figure 4-2 (c)). There is a similar pattern for the Chisos Mountains in Texas and ranges near the Chisos Mountains (Figure 4-2 (c)). The overall drier model combination shows most of the U.S. portion of the ecoregion becoming drier. This includes forecasted drier conditions on the eastern and wetter on the western sides of the previously mentioned mountain ranges in New Mexico and Texas, and also on the eastern versus western sides of the Chinati and Glass Mountains in Texas (Figure 4-2 (d)).

Figure 4-2. Forecasted change in annual mean temperature and precipitation from historic conditions (1950-2000) to 2050 within the U.S. portion of the ecoregion under four GCM x RCP combinations.



For 2070, the wetter model combination forecasts drier conditions in the northwestern parts of the ecoregion, in western New Mexico and eastern Arizona, and around Carlsbad Caverns National on the New Mexico-Texas border (Figure 4-3 (c)). The drier model combination additionally forecasts drier conditions across the area bounded by the Davis Mountains on the north and the Chisos Mountains on the south, and forecasts dry conditions in the central region extending further north (Figure 4-3 (d)). The drier model combination also forecasts drier conditions for 2070 on the eastern sides and wetter conditions on the western sides of several mountain ranges in New Mexico and Texas (Figure 4-3 (c-d)).

Figure 4-3. Forecasted change in annual mean temperature and precipitation from historic conditions (1950-2000) to 2070 within the U.S. portion of the ecoregion under four GCM x RCP combinations.



4.1.2.2 Forecasted Climate Change Impacts on Land Cover and Species CEs

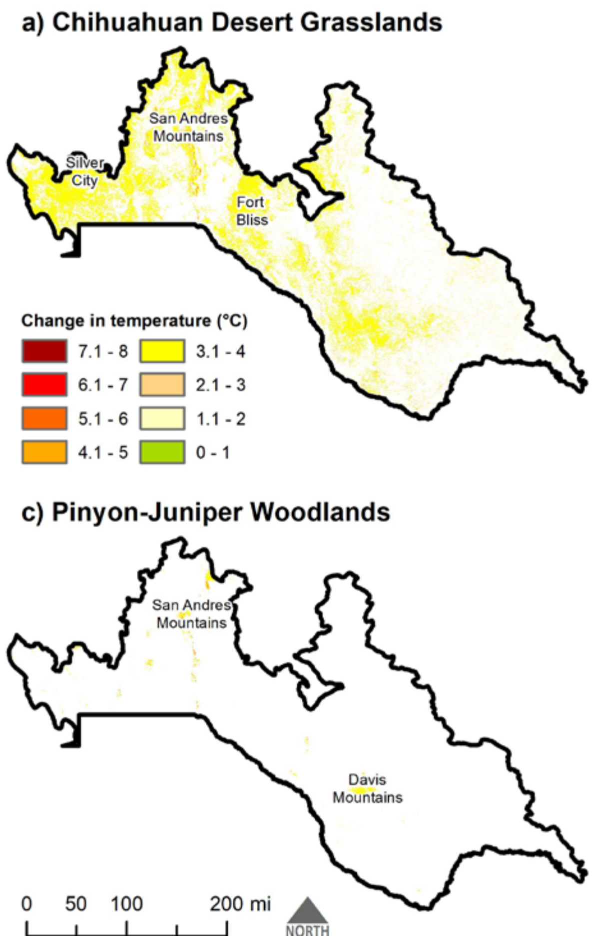
Figure 4-2 shows the average changes in forecasted values for the six selected climatic variables from the historic period (1950-2000) to the two future bi-decadal periods (period means 2050 and 2070) within the current distributions of three terrestrial ecological systems and eight species of interest. Figure 4-4 - Figure 4-9 show the results by climate variable for the same ecological systems and species.

The three terrestrial ecological system CEs are forecasted to experience a relatively narrow range of increases in annual mean temperature, by 2.67 to 2.73 °C by the year 2050 and by 3.3 to 3.4 °C by the year 2070 (Table 4-2, Figure 4-4). The forecasted increases in temperature extremes at the monthly scale for the hottest (maximum) or coldest (minimum) months of the year for the three terrestrial ecological system CEs are equally narrow (Table 4-2). Pinyon-juniper woodlands are forecasted to experience the greatest increases in annual mean temperature, maximum temperature of the warmest month, and minimum temperature of the coldest month for both 2050 and 2070. The other two terrestrial ecological system CEs share the experiencing of the smallest increases in annual mean temperature, maximum temperature of the warmest month, and minimum temperature of the coldest month in 2050 and 2070.

Table 4-2. Average change in six annual and monthly climate variables from the historic period (1950-2000) to two future bi-decadal periods (period means 2050 and 2070) within the current distributions of the three terrestrial ecological system, three small mammals, and five bird species. Blue/Red = smallest/largest changes in temperature for a given period, Dark Red/Green = most negative and most positive changes in precipitation for a given period, with ecological system CEs, small mammals, and birds considered separately.

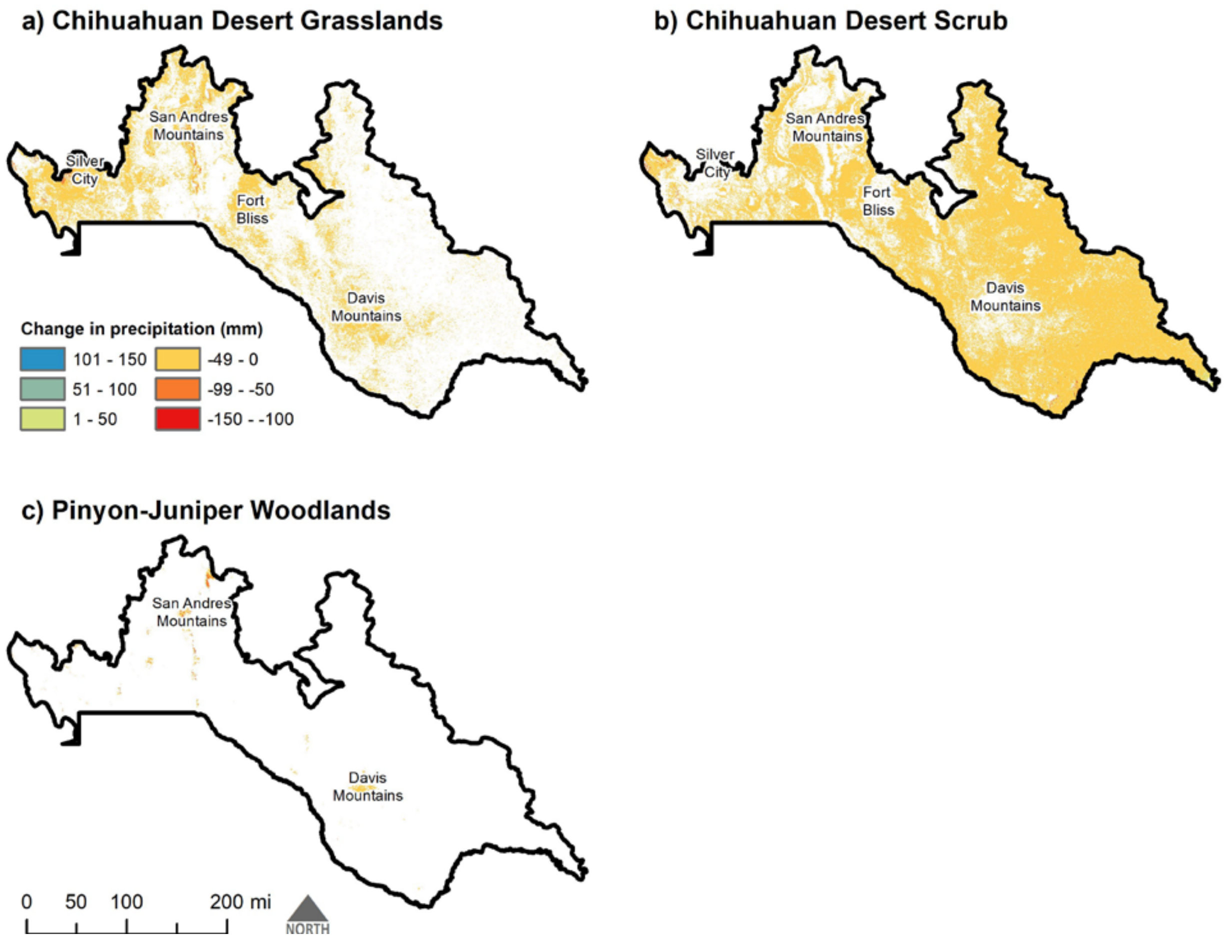
CE or Constituent Species	Year	Annual Mean Temperature, °C	Maximum Temperature of Warmest Month, °C	Minimum Temperature of Coldest Month, °C	Annual Precipitation, mm	Precipitation of the Wettest Month, mm	Precipitation of the Driest Month, mm
Chihuahuan Desert Grasslands	2050	2.718	3.123	2.055	-16.975	-1.264	-0.457
Chihuahuan Desert Grasslands	2070	3.401	3.877	2.350	-25.479	-2.450	-0.803
Chihuahuan Desert Scrub	2050	2.690	3.128	2.039	-17.114	-0.851	-0.413
Chihuahuan Desert Scrub	2070	3.341	3.848	2.363	-19.506	-0.620	-0.711
Pinyon-Juniper Woodlands	2050	2.726	3.135	2.070	-20.791	-1.271	-0.807
Pinyon-Juniper Woodlands	2070	3.411	3.928	2.362	-33.181	-2.756	-1.348
Black-tailed Prairie Dog	2050	2.706	3.146	2.041	-17.458	-0.785	-0.392
Black-tailed Prairie Dog	2070	3.380	3.883	2.344	-22.164	-0.663	-0.777
Tawny-bellied Cotton Rat	2050	2.749	3.097	2.080	-15.616	-2.197	-0.541
Tawny-bellied Cotton Rat	2070	3.454	3.874	2.354	-29.469	-5.749	-0.939
Yellow-nosed Cotton Rat	2050	2.774	3.081	2.105	-19.430	-4.656	-0.992
Yellow-nosed Cotton Rat	2070	3.473	3.853	2.434	-38.588	-8.305	-1.102
Arizona Grasshopper Sparrow	2050	2.694	3.091	2.069	-18.377	-1.009	-0.586
Arizona Grasshopper Sparrow	2070	3.349	3.839	2.402	-24.617	-0.835	-0.737
Baird's Sparrow	2050	2.689	3.113	2.052	-18.328	-0.897	-0.550
Baird's Sparrow	2070	3.344	3.857	2.372	-24.172	-0.814	-0.652
Cassin's Sparrow	2050	2.696	3.127	2.044	-17.302	-0.898	-0.446
Cassin's Sparrow	2070	3.355	3.856	2.363	-21.253	-0.986	-0.765
Chestnut-collared Longspur	2050	2.715	3.151	2.023	-16.773	-1.229	-0.363
Chestnut-collared Longspur	2070	3.399	3.878	2.334	-21.468	-1.708	-0.807
Scaled Quail	2050	2.715	3.151	2.044	-17.221	-1.391	-0.382
Scaled Quail	2070	3.391	3.888	2.348	-23.276	-2.208	-0.790

Figure 4-4. Forecasted changes by 2070 in annual mean temperature for the three terrestrial ecological system CEs.



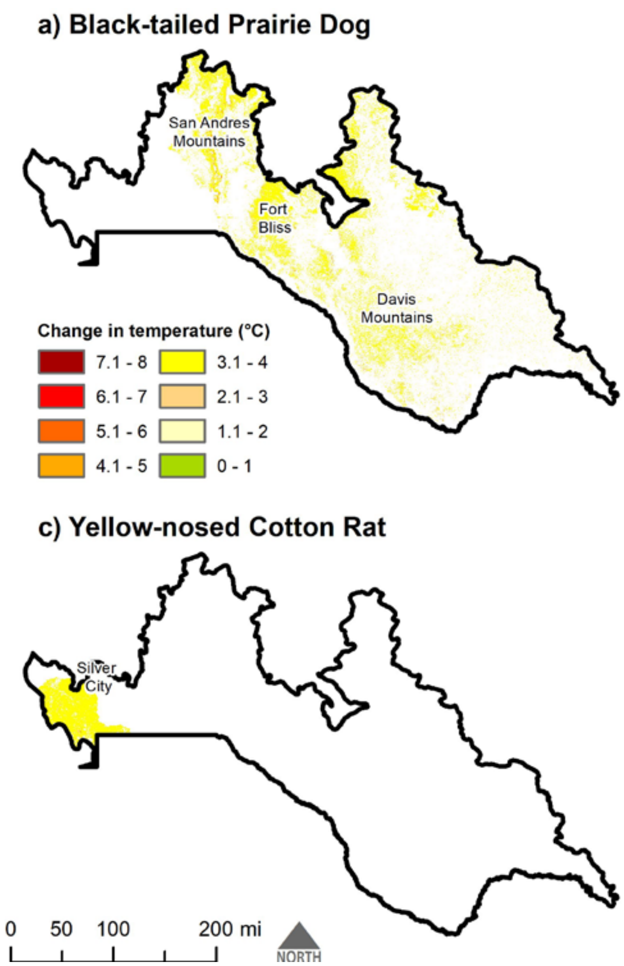
The three terrestrial ecological system CEs are forecasted to experience different severities of reduction in annual precipitation by 2070, with annual precipitation declining by nearly 20 mm on average across the distribution of Chihuahuan Desert Scrub and by more than 33 mm across the distribution of Pinyon-Juniper Woodlands (Table 4-2,Figure 4-5). There are slightly larger forecasted declines in precipitation during the wettest month (up to 2.8 mm by the year 2070) than during the driest month (up to 1.3 mm by 2070). Pinyon-juniper woodlands are forecasted to experience not only to the largest declines in annual precipitation but also the largest declines in precipitation during the driest month and precipitation during the wettest month by 2070. In turn, desert scrublands are forecasted to experience not only to the smallest declines in annual precipitation but also the smallest declines in precipitation during the driest month and precipitation during the wettest month by 2070.

Figure 4-5. Forecasted changes by 2070 in annual precipitation for the three terrestrial ecological system CEs.



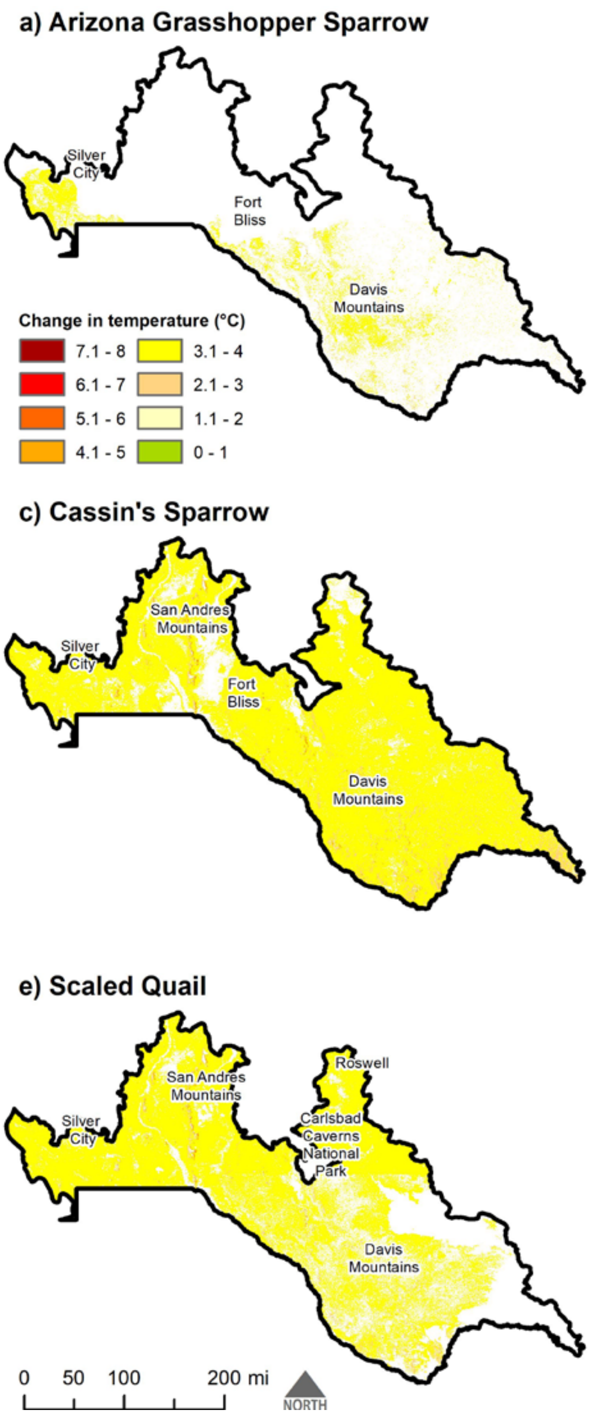
The present geographic distributions of the eight species examined in the analysis of climate change also are forecasted to experience a fairly narrow range of increases in annual mean temperature, by 2.7 to 2.8 °C by the year 2050 and by 3.3 to 3.5 °C by the year 2070 (Table 4-2). They are also forecasted to experience relatively narrow ranges of increases by 2070 in temperature extremes at the monthly scale for the hottest (maximum) or coldest (minimum) months of the year (Table 4-2). Among the mammals examined (Table 4-2, Figure 4-6), the present geographic distribution of the Yellow-nosed cotton rat is forecasted to experience the largest increases in annual mean temperature by 2050 and 2070; Black-tailed prairie dog the lowest. The present geographic distributions of these same two mammal species are forecasted to experience, respectively, the largest and smallest increases in the minimum temperature of coldest month by 2050 and 2070, as well (Table 4-2). In contrast, the present geographic distributions of these same two mammal species are forecasted to experience, respectively, the smallest and largest increases in the maximum temperature of the warmest month by 2050 and 2070 (Table 4-2).

Figure 4-6. Forecasted changes by 2070 in annual mean temperature within the current distributions of three mammalian species.



Among the five grassland birds (Table 4-2,Figure 4-7), the present geographic distributions of the Chestnut-collared longspur is forecasted to experience the largest increases in annual mean temperature by 2050 and 2070; Baird's sparrow the lowest. Among the five grassland birds, the present geographic distribution of Scaled quail is forecasted to experience the largest increase in the maximum temperature of the warmest month by 2050 and 2070; Arizona grasshopper sparrow the smallest (Table 4-2). The present geographic distribution of Arizona grasshopper sparrow is forecasted to experience the largest increase among the five grassland birds in the minimum temperature of the coldest month by 2050 and 2070; Chestnut-collared longspur the smallest (Table 4-2).

Figure 4-7. Forecasted changes by 2070 in annual mean temperature within the current distributions of five grassland bird species.



In contrast (Table 4-2, Figure 4-8 and Figure 4-9), the present geographic distributions of the eight species examined in the analysis of climate change are forecasted to experience a fairly wide range of reductions in average precipitation by 2070, by 22 to 39 mm among the three mammals and by 21 to 25 mm among the five grassland birds. The present geographic distributions of the three mammals are expected to experience reductions in precipitation during the wettest month of the year by 2070, by 0.66 to 8.3 mm, while the present geographic distributions of the five grassland birds are expected to experience reductions in precipitation during the wettest month of the year by 2070, by 0.81 to 2.2 mm (Table 4-2). Finally, the present geographic distributions of the three mammals are expected to experience reductions in precipitation during the driest month of the year by 2070, by 0.78 to 1.1 mm, while the present geographic distributions of the five grassland birds are expected to experience reductions in precipitation during the driest month of the year by 2070, by 0.65 to 0.81 mm (Table 4-2). Among the eight species altogether, the present geographic distribution of the Yellow-nosed cotton rat is forecasted to experience the largest declines by 2070 in annual precipitation, precipitation during the wettest month, and precipitation during the driest month by the year.

Figure 4-8. Forecasted changes by 2070 in annual precipitation within the current distributions of three mammalian species.

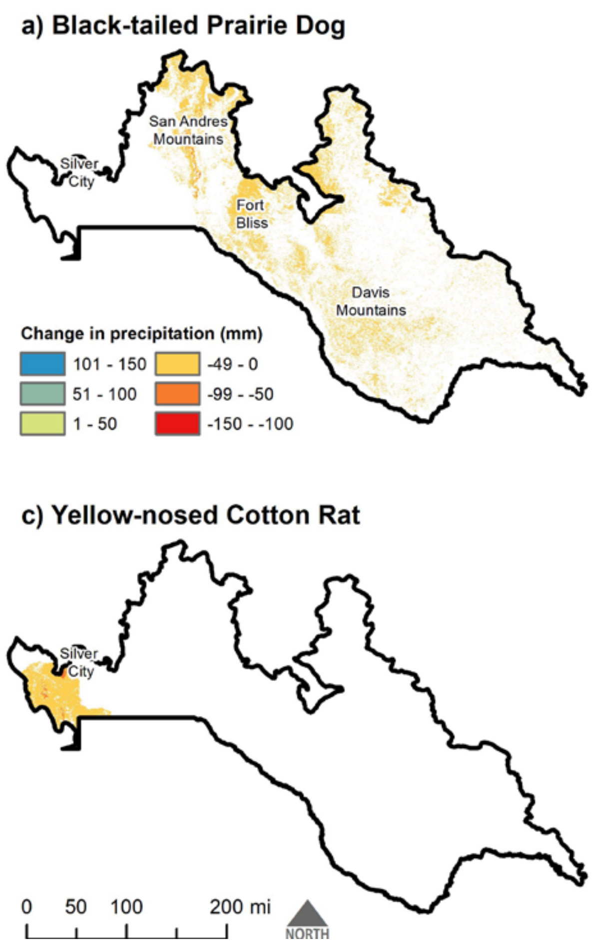
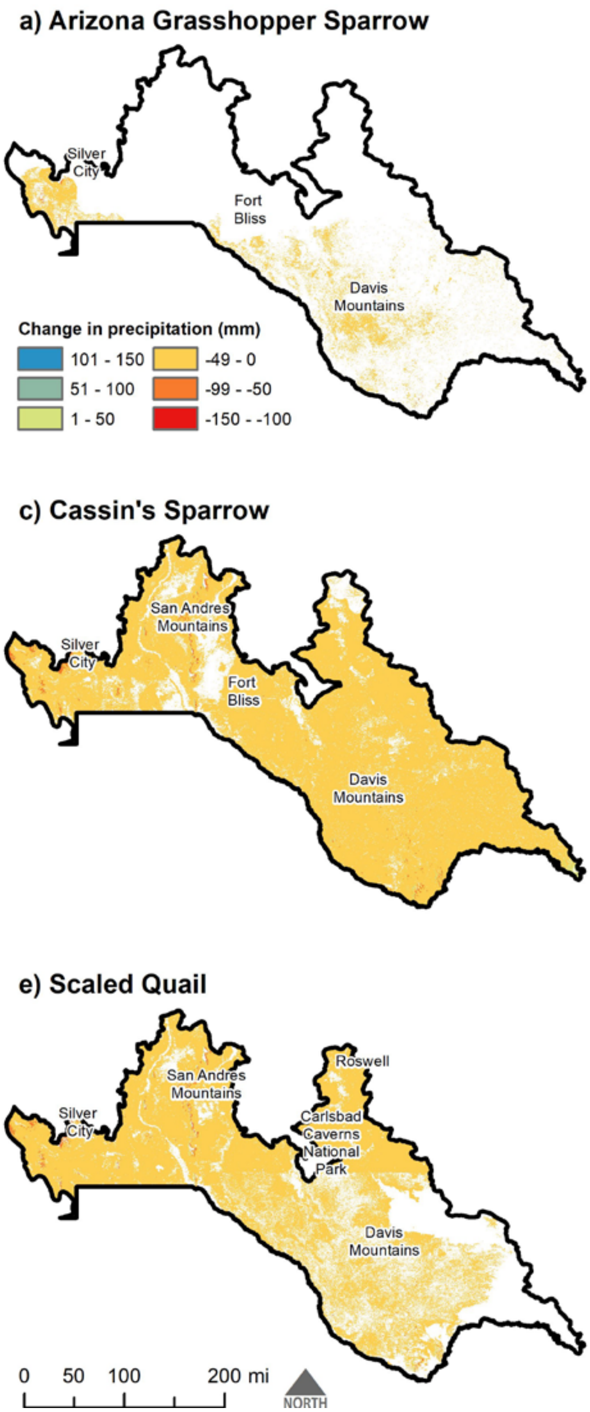


Figure 4-9. Forecasted changes by 2070 in annual precipitation within the current distributions of five grassland bird species.



4.2 Climate Change and Dryland Vegetation Distributions

This section assesses the potential ways in which climate change may affect the relative dominance of grass versus scrub versus woodland species across the U.S. portion of the ecoregion, and consequently the relative distributions of the three terrestrial ecological system CEs. As with the assessment of climate change per se (see above, this chapter), this analysis focused on the Level-III ecoregion rather than the analysis extent.

4.2.1 Introduction

The climate of the U.S. portion of the ecoregion is forecasted to change dramatically by the end of the 21st century. Forecasted changes include increased average annual temperatures (see above) and an increased occurrence of extreme events (e.g., heat waves and droughts; Kunkel et al. 2013a and 2013b, Melillo et al. 2014). The hotter and drier conditions are likely to lead to the occurrence of more and larger wildfires in the Western U.S. (Westerling et al. 2006, Melillo et al. 2014). These and other changes in the climate have already had, and are expected to continue to have, significant impacts on Chihuahuan Desert grasslands, Chihuahuan Desert scrublands, and pinyon-juniper woodlands.

4.2.1.1 Chihuahuan Desert Grasslands and Scrub

Woody plant encroachment, or the increase in density, cover and biomass of native woody plants in grassland areas, has been observed worldwide (van Auken 2000, Ravi et al. 2009, van Auken 2009). This process leads to a shift in vegetation type from grassland to shrubland or savanna to woodland (Archer 1995, van Auken 2000). As discussed in the Chihuahuan Desert REA Pre-Assessment Report, a transition from grassland to shrubland has been observed at various locations in the Chihuahuan Desert, including within the past century (e.g., Humphrey 1958, Gill and Burke 1999, Gibbens et al. 2005, Knapp et al. 2008). In particular, creosote (*Larrea tridentata*) has been spreading into grasslands dominated by grama grass (*Bouteloua* spp.) at the Sevilleta National Wildlife Refuge, situated at the northern edge of the Chihuahuan Desert in central New Mexico (Gill and Burke 1999). Honey mesquite (*Prosopis glandulosa*) has been spreading into grasslands dominated by black grama (*Bouteloua eriopoda*) in southern New Mexico (Hennessy et al. 1983, Gibbens et al. 2005). Creosote has expanded in this area as well (Buffington and Herbel 1965). Shrub cover also has increased at the expense of grasslands at Big Bend National Park in western Texas (White et al. 2008, Leavitt et al. 2010).

There are a number of potential drivers for woody plant encroachment in the southwestern U.S. and the Chihuahuan Desert in particular, many of which are related to climate. These drivers include drought (D'Odorico et al. 2010, Baez et al. 2013), a shift in the seasonality of precipitation towards wetter winters (Brown et al. 1997, Pennington and Collins 2007, Munson et al. 2013), and warmer temperatures especially at night during the winter (D'Odorico et al. 2010). However, warming accompanied by more rainfall during the summer monsoon may favor the stability or spread of a dominant grass species (black grama) in the Chihuahuan Desert (Peters 2002). Further, severe drought accompanied by hot annual and summer maximum temperatures can lead to mortality of encroaching shrubs, including creosote (Bowers 2005, Backlund et al. 2008). Occurrence of extreme cold events may also lead to creosote damage or mortality as a result of freeze-induced cavitation (Pockman and Sperry 1997, Ladwig 2014).

4.2.1.2 Pinyon-Juniper Woodlands

Pinyon-juniper woodlands are potentially dynamic systems, with records of both pinyons (*Pinus edulis*) and junipers (*Juniperus monosperma*) spreading into woodlands dominated by ponderosa pine (*Pinus ponderosa*) in some areas (Allen and Breshears 1998) and of various species of juniper (*Juniperus* spp.) spreading into grasslands and shrublands in others (Johnsen 1962, Miller and Wigand 1994, McKinley and Blair 2008, Sankey and Germino 2008). The spread of juniper and pinyon into a ponderosa pine woodland has been documented just north of the Chihuahuan desert in north central New Mexico (Allen and Breshears 1998). The spread of junipers into grassland areas has been documented in several areas, including southwestern New Mexico (Miller 1999), and northern Arizona (Johnsen 1962) just north of the Chihuahuan Desert, and other areas much further north of the Chihuahuan Desert including southeastern Idaho (Sankey and Germino 2008), and Kansas (McKinley and Blair 2008). Woodland species composition changes have been observed in response to drought and insect-related tree mortality (Breshears et al. 2005, Koepke et al. 2010). Pinyon-juniper woodland boundaries and distributions of the individual tree species are projected to contract in response to future climate change (Rehfeldt et al. 2006).

The effects of several climate-related stressors, especially drought accompanied by high temperatures, have been observed in the southwestern United States (U.S.), including New Mexico and Arizona (Breshears et al. 2005, Koepke et al. 2010, Clifford et al. 2013). Pinyon pine trees appear to be particularly susceptible to carbon starvation during a drought, with drier dry seasons further reducing carbohydrate availability (McDowell et al. 2008, Dickman et al. 2014) and higher temperatures reducing time to mortality (Adams et al. 2009). Model results indicate that delays in the onset of the monsoon season may also increase the probability of mortality in pinyons (Gustafson et al. 2014). Drought-stressed trees are more susceptible to attack by bark beetle (*Ips confusus*) and twig beetle (*Pityophthorus opaculus*; Gaylord et al. 2013). There is evidence that bark beetle survival may increase, development time may decrease, and the occurrence and severity of bark beetle outbreaks may increase in response to warmer temperatures and the occurrence of drought (Raffa et al. 2008, Bentz et al. 2010, Williams et al. 2010). Juniper trees are more drought-tolerant but still experience canopy die back and some mortality if the drought persists (Lajtha and Getz 1993, Linton et al. 1998, Breshears et al. 2005, Gaylord et al. 2013, Dickman et al. 2014). On the other hand, simulations indicate that juniper woodland may expand if rainfall is distributed more evenly throughout the year, rather than being concentrated during the summer monsoon season (Zhou et al. 2013).

4.2.2 Methods and Data

4.2.2.1 Modeling Method

The potential impacts of climate change on the relative dominance of grass versus scrub versus woodland species across the U.S. portion of the ecoregion – and consequently on the relative distributions of the three terrestrial ecological system CEs – were assessed through the development of "niche models." These are models of the environmental conditions suitable for the three terrestrial ecological system CEs – conditions that can be mapped based on current and forecasted future climate spatial variation.

Models of the spatial distribution of species in relation to climate are sometimes termed “bioclimatic-envelope” (e.g., Calkins et al. 2012). However, the models developed here include not only climatic variables but also topographic and geologic variables. The alternative term used here, niche models, recognizes this consideration of a broader suite of variables that affect the spatial distribution of potentially suitable environmental conditions for individual species.

The niche models for the Chihuahuan Desert grasslands, Chihuahuan Desert scrublands, and pinyon-juniper woodlands CEs were developed using two modeling programs linked together: the Software for Assisted Habitat Modeling (SAHM) package for VisTrails (Morisette et al. 2013), and Maxent (Phillips et al. 2006, Phillips and Dudik 2008). Maxent is one of several methods for modeling the suitability of an environment for different species (Phillips et al. 2006). It has been applied to models of suitability for a wide variety of plant species (Franklin et al. 2013) and vegetation types (Alvarez-Martinez et al. 2014). Maxent has been shown to perform better than other, similar methods (Elith et al. 2006, Phillips et al. 2006). The SAHM package for VisTrails was used to develop a workflow that runs Maxent and constrains model development and output to the boundaries of the U.S. portion of the ecoregion.

Data from the historic period (WorldClim; 1950-2000) for fourteen (14) climatic variables – here termed “bioclimatic” variables to emphasize their importance in shaping species distributions – were input directly into the SAHM package for VisTrails, along with data on elevation, slope, and aspect. Information on parent material, bedrock type, and soil texture were added to these climate and topographic variables in separate model runs performed directly in Maxent (Phillips et al. 2006, Phillips and Dudik 2008) as there were technical difficulties incorporating categorical data as input to VisTrails. The input data consisted of data for 1000 random points within each of the current distributions of the three terrestrial ecological system CEs, as described below (see Spatial Data).

4.2.2.2 Climate Forecasts

The niche models were developed using climate data from the historic period, 1950-2000, as described above and projected to four different future climate scenarios (GCM x RCP combinations) for the later of the two bi-decadal forecast periods considered earlier, 2061-2080, period mean 2070. The four selected GCM x RCP combinations are the same as those discussed earlier in this chapter (see Climate Change and Dryland CEs): MPI-ESM-LR and HadGEM2-ES and for the GCMs, and RCPs 2.6 and 8.5 for the emissions scenarios. As with the earlier presentation in this chapter (see Climate Change and Dryland CEs), results are displayed only for two of the four GCM x RCP combinations: HadGEM2-ES x RCP 2.6, which is associated with the smallest increase in temperature and the most rainfall across the region (i.e., cooler and wetter relative to the other GCM by RCP combinations), and MPI-ESM-LR x RCP 8.5, which is associated with the largest decrease in precipitation and a larger increase in temperature (i.e., hotter and drier compared to other future climate scenarios considered), were used.

Maps were generated showing the following for each GCM x RCP combinations:

(1) Changes in the distribution of Chihuahuan Desert grassland between current conditions and the later of the two bi-decadal forecast periods (2061-2080, mean 2070), including areas where the niche models project stability or contraction in the geographic range of suitable climatic conditions and areas where future status of climatic conditions for grassland is uncertain. The analysis did not indicate any areas of grassland expansion.
(2) Changes in the distribution of suitable climatic conditions for Chihuahuan Desert grassland and Chihuahuan Desert scrub by the year 2070, including areas where each vegetation type is projected to be stable, contract, or expand, areas where a shift in vegetation type is possible, and areas where current or future vegetation type is uncertain.
(3) Changes in the distribution of suitable climatic conditions for all three terrestrial ecological system CEs by 2070, including areas of stability, contraction, and expansion for each CE, areas where a vegetation shift is possible, and areas where current or future vegetation type is uncertain.

Areas where current or forecasted future vegetation type is uncertain were separated out into two categories:

(1) The climatic conditions at the location are outside the climatic conditions sampled by the presence/absence data used to generate the niche model, and the results of the model at that location therefore represent an extrapolation to novel conditions and are less reliable (see Section 4.2.2.8, Niche Model Performance Evaluation, below).
(2) The projections of suitable climate under current or forecasted future conditions for two vegetation types overlap at that location, making it uncertain (purely based on model results) which vegetation type is currently present or may be present there in the future.

4.2.2.3 Spatial Data

The niche modeling effort incorporated the same raw spatial data used to map the distributions of the three terrestrial ecological system CEs for this REA. As with the overall analysis of climate change (see above, Climate Change and Dryland CEs, this chapter), the niche modeling effort addressed only the actual U.S. portion of the ecoregion rather than the somewhat larger analysis extent used for other purposes in the REA. As noted elsewhere in this report, the three terrestrial ecological system CEs for this REA consist of suites of individual ecological system types as follows (see the Pre-Assessment Report, Unnasch et al. 2017, Chapters 5-7):

Chihuahuan Desert Grasslands CE

- Apacherian-Chihuahuan Semi-Desert Grassland and Steppe
- Chihuahuan Loamy Plains Desert Grassland
- Chihuahuan-Sonoran Desert Bottomland and Swale Grassland
- Chihuahuan Sandy Plains Semi-Desert Grassland
- Madrean Juniper Savanna

Chihuahuan Desert Scrub CE

- Apacherian-Chihuahuan Mesquite Upland Scrub
- Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub
- Chihuahuan Mixed Desert and Thorn Scrub
- Chihuahuan Mixed Salt Desert Scrub
- Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub
- Chihuahuan Succulent Desert Scrub
- Tamaulipan Calcareous Thornscrub
- Tamaulipan Mesquite Upland Scrub
- Tamaulipan Mixed Deciduous Thornscrub

Pinyon-Juniper Woodlands CE

- Madrean Pinyon-Juniper Woodland
- Southern Rocky Mountain Pinyon-Juniper Woodland (present within the Chihuahuan Desert REA analysis extent but absent from the ecoregion itself)

1000 randomly generated points were selected from the distribution of each of the three terrestrial ecological system CEs. Random point placement was weighted to be proportional to the area represented by each of the three distributions within the total area covered by each of the three terrestrial ecological system CEs (Figure 4-10(a)). Points were constrained to be a minimum of 1000 m from each other (Figure 4-10(b)). The data input into the SAHM and Maxent modeling consisted of data on each of the 1000 sample locations for each of the three terrestrial ecological system CEs, as noted above.

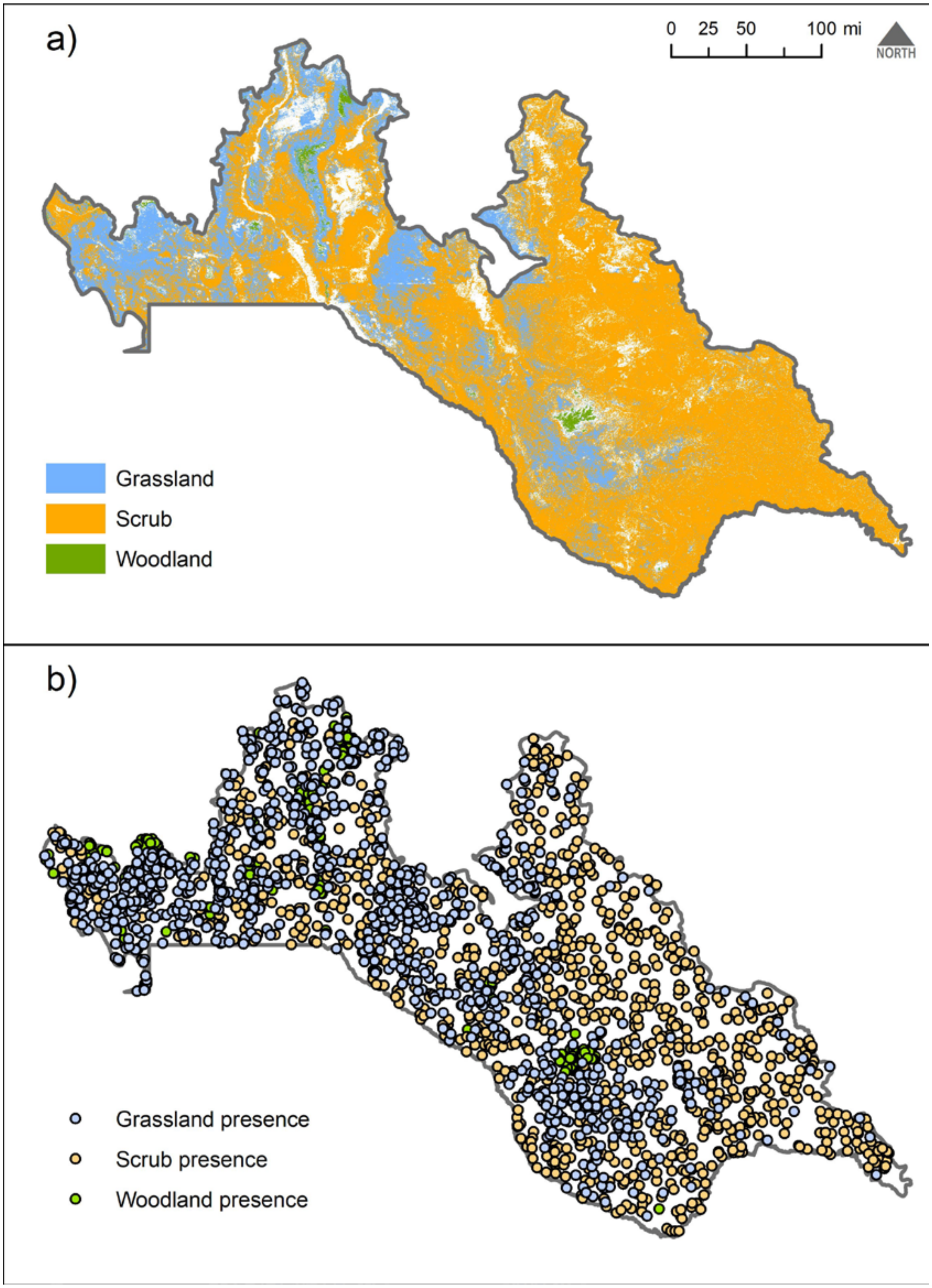
4.2.2.4 Dominant Plant Species

The niche modeling effort also included tabulation of the dominant plant species associated with each of the three terrestrial ecological system CEs, using NatureServe Explorer (http://explorer.natureserve.org/servlet/NatureServe). Table 4-3 shows the results. The resulting information was used to compare the predictions of the modeling results.

4.2.2.5 Soils and Topographic Data

There is evidence that different vegetation types in the Chihuahuan Desert are associated with different soil textures, parent materials, and bedrock types and that soil texture may influence how vulnerable a site is to some kinds of changes in vegetation (Monger and Bestelmeyer 2006, Michaud et al. 2013). The detailed assessment of climate change and its potential impacts on dryland vegetation therefore also incorporated information on soil types and elevation.

Figure 4-10. (a) Distribution of the three terrestrial ecological system CE types; (b) Distribution of sample points used in generating the models of suitable environmental conditions for the three terrestrial ecological system CE types.



The necessary data on soil types and elevation were obtained from the Gridded Soil Survey Geographic (gSSURGO) Database and National Elevation Dataset (NED) at 30 m resolution from the U.S. Department of Agriculture Natural Resources Conservation Service Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/) for the states that intersect the Chihuahuan Desert ecoregion. Data layers on soil texture, specifically particle size distribution of the whole soil (taxonomic family particle size), parent material (parent material modifier and parent material kind combined), and bedrock type (parent material origin) were generated from the gSSURGO data at 10m resolution. Aspect and slope were calculated from the NED using tools in ArcGIS for Desktop 10.2.1. All topographic (aspect, elevation, and slope) and soil variables were aggregated to the resolution of the bioclimatic data. It is important to note that the resolution of the original bioclimatic data (roughly 900 m) drives the resolution of the niche modeling exercise (see below) and is reflected in the spacing (1,000 m) of the occurrence points used as input in those models.

Table 4-3. Dominant plant species by terrestrial ecological system CE.

Grassland	Scrub		Woodland
Achnatherum hymenoides	Acacia berlandieri	Juniperus monosperma*	Juniperus coahuilensis*
Bouteloua curtipendula	Acacia constricta	Koeberlinia spinosa	Juniperus deppeana
Bouteloua eriopoda*	Acacia farnesiana	Larrea tridentata	Juniperus monosperma*
Bouteloua gracilis	Acacia neovernicosa	Leucophyllum frutescens	Juniperus pinchotii
Bouteloua hirsuta	Acacia rigidula	Mimosa warnockii	Pinus cembroides
Bouteloua ramosa	Acacia roemeriana	Muhlenbergia porteri	Pinus discolor
Bouteloua rothrockii	Agave lechuguilla	Nolina microcarpa	Pinus edulis
Flourensia cernua*	Agave parryi	Opuntia engelmannii	Quercus arizonica
Hilaria belangeri	Amyris madrensis	Opuntia imbricata	Quercus emoryi
Juniperus monosperma*	Amyris texana	Opuntia kleiniae	Quercus grisea
Muhlenbergia arenacea	Artemisia filifolia	Opuntia spinosior	Quercus mohriana
Muhlenbergia setifolia	Atriplex canescens	Panicum obtusum	
Pascopyrum smithii	Atriplex obovata	Parkinsonia texana	
Pleuraphis jamesii	Atriplex polycarpa	Parthenium incanum	
Pleuraphis mutica*	Bothriochloa ischaemum	Pennisetum ciliare	
Prosopis glandulosa*	Bouteloua eriopoda*	Pleuraphis mutica*	
Scleropogon brevifolius	Castela erecta ssp. texana	Prosopis glandulosa*	
Sporobolus airoides*	Celtis pallida	Prosopis velutina	
Sporobolus flexuosus*	Distichlis spicata	Psorothamnus scoparius	
Sporobolus wrightii	Eysenhardtia texana	Sophora secundiflora	
	Flourensia cernua*	Sporobolus airoides*	
	Gutierrezia sarothrae	Sporobolus flexuosus*	
	Helietta parvifolia	Urochloa maxima	
	Juniperus coahuilensis*		

Note "*": Species listed as dominant in more than of the three CEs.

4.2.2.6 Bioclimatic Variable Initial Selection

The niche modeling effort began with the nineteen (19) bioclimatic variables included in the WorldClim global climate dataset (http://www.worldclim.org/bioclim; O'Donnell and Ignizio 2012). These 19 bioclimatic variables provide a basis for modeling the effects of climate variation and change on vegetation dynamics (e.g., Calkins et al. 2012). WorldClim and other publications label these 19 bioclimatic variables as follows:

- Bio 1, Annual Mean Temperature
- Bio 2, Mean Diurnal Range (Mean of monthly (max temp - min temp))
- Bio 3, Isothermality (Bio 2/Bio 7) x 100)
- Bio 4, Temperature Seasonality (standard deviation x 100)
- Bio 5, Max Temperature of Warmest Month
- Bio 6, Min Temperature of Coldest Month
- Bio 7, Temperature Annual Range (Bio 5-Bio 6)
- Bio 8, Mean Temperature of Wettest Quarter
- Bio 9, Mean Temperature of Driest Quarter
- Bio 10, Mean Temperature of Warmest Quarter
- Bio 11, Mean Temperature of Coldest Quarter
- Bio 12, Annual Precipitation
- Bio 13, Precipitation of Wettest Month
- Bio 14, Precipitation of Driest Month
- Bio 15, Precipitation Seasonality (Coefficient of Variation)
- Bio 16, Precipitation of Wettest Quarter
- Bio 17, Precipitation of Driest Quarter
- Bio 18, Precipitation of Warmest Quarter
- Bio 19, Precipitation of Coldest Quarter

The niche modeling included all 19 bioclimatic variables as raw inputs, subsequently removing several because of their high correlations with each other in the Chihuahuan Desert dataset (see below).

The niche modeling effort also included a literature review of the bioclimatic variables to identify any that studies have identified as particularly likely to affect the distributions of the dominant vegetation types in the U.S. portion of the Chihuahuan Desert ecoregion. These include variables likely to lead to plant mortality or promote the spread or contraction of particular vegetation types. The information in the reviewed literature (Backlund et al. 2008, Robles and Enquist 2011, Coe et al. 2012, Peterman et al. 2012, Staudinger et al. 2012, Adams et al. 2013, Anderegg et al. 2013, Clifford et al. 2013, Gaylord et al. 2013, Hamerlynck et al. 2013, Munson et al. 2013, Plaut et al. 2013, Zhou et al. 2013, Garfin et al. 2013, Dickman et al. 2014, Gustafson et al. 2014, Hufnagel and Garamvolgyi 2014, Ladwig 2014, Macalady and Bugmann 2014, Melillo et al. 2014) identified fourteen (14) bioclimatic variables that have been identified as particularly likely to affect the distributions of the dominant vegetation types in the U.S. portion of the Chihuahuan Desert ecoregion. The information in these studies was used to assess the nature of the impact (positive, negative, or mixed) of each of these 14 bioclimatic variables. A positive impact is one for which an increase in the bioclimatic variable may have a beneficial impact on the vegetation and potentially lead to its spread. A negative impact is one for which an increase in the bioclimatic variable may lead to the contraction or mortality of the vegetation type. For example, an increase in annual mean temperature may lead to a spread of scrub but a decline of woodland vegetation. Table 4-4 summarizes the results of the literature review for these 14 bioclimatic variables. As noted above, however, the modeling included all 19 bioclimatic variables as raw inputs.

Table 4-4. Bioclimatic variables most likely to affect spatial distributions of the three terrestrial ecological system CEs.

Bioclimatic Variable	Effect on Grasslands	Effect on Scrub	Effect on Pinyon-Juniper Woodlands
Bio 1. Annual Mean Temperature	Mixed (positive at northern end; negative where degraded)	Positive	Negative
Bio 2. Mean Diurnal Range	n/a	Negative	n/a
Bio 5. Max Temperature of Warmest Month	Negative	Negative (when accompanied by drought)	Negative
Bio 6. Min Temperature of Coldest Month	Positive	Positive	Negative
Bio 10. Mean Temperature of Warmest Quarter	Negative	Negative (when accompanied by drought)	Negative
Bio 11. Mean Temperature of Coldest Quarter	Positive	Positive	Negative
Bio 12. Annual Precipitation	Mixed (positive at scrub interface; negative at woodland interface)	Mixed (negative at transition; positive within scrub range)	Positive (within a range)
Bio 13. Precipitation of Wettest Month	Mixed (positive at scrub interface; negative at woodland interface)	Mixed (negative at transition; positive within scrub range)	Positive (within a range)
Bio 14. Precipitation of Driest Month	n/a	n/a	Positive
Bio 15. Precipitation Seasonality	Positive	n/a	Negative
Bio 16. Precipitation of Wettest Quarter	Mixed (positive at scrub interface; negative at woodland interface)	Mixed (negative at transition; positive within scrub range)	Positive (within a range)
Bio 17. Precipitation of Driest Quarter	n/a	n/a	Positive
Bio 18. Precipitation of Warmest Quarter	Positive	Mixed (negative at transition; positive within scrub range)	Positive (possibly within a range)
Bio 19. Precipitation of Coldest Quarter	Negative	Positive	Negative

4.2.2.7 Removal of Highly Correlated Variables

The SAHM package produces a matrix of correlations among the model input variables, and identifies the highest of three coefficients (Kendall, Pearson, and Spearman; Talbert and Talbert 2014) for each pair of variables. The analyst must identify pairs of highly correlated ($r > 0.7$; Dormann et al. 2013) variables and remove one member of each such pair from consideration in the analysis. Without this step, one variable can mask the importance of another variable – or mask the true nature of the relationship of another variable – to the suitability of the environment for the modeled species or community (Phillips 2011). Including non-independent variables therefore can lead to incorrect identification of important variables (Dormann et al. 2013). All non-independent variables were used in a second set of model runs in Maxent to ensure that no important variables were overlooked.

Non-independent variables were culled based on the following three criteria:

1. From each pair of highly correlated variables, the analysis retained the one listed more frequently in the literature (see below, Bioclimatic Variables) as having an effect on the spatial distribution of the vegetation type.
2. When the literature mentioned the two variables equally often as having an effect on the spatial distribution of the vegetation type, the analysis retained the one that had the most appropriate temporal scale for the vegetation type (annual for woodlands and shrublands; seasonal for grassland), or that the literature otherwise indicated was a more useful predictor variable.
3. When a pair of highly correlated variables consisted of a bioclimatic variable and elevation, the analysis retained the bioclimatic variable so that the analysis could better assess the potential impacts of climate change.

The analysis also retained all categorical variables. It is not possible to calculate correlations between categorical variables. As noted above, the analysis input all categorical variables directly into Maxent.

4.2.2.8 Niche Model Performance Evaluation

The performance of the niche models developed using the historic climatic data was evaluated using four different metrics: (1) Area Under the Receiver Operating Characteristic (ROC) Curve (AUC) metric for the test data and (2) the correct classification rate (Fielding and Bell 1997, Warren and Seifert 2011), (3) the True Skill Statistic (TSS; Allouche et al. 2006), and (4) the kappa statistic (Cohen 1960). Only AUC is calculated in Maxent. The continuous probabilities of a given pixel being suitable for a given vegetation type were converted to binary data (suitable, unsuitable) using the sensitivity equals specificity threshold method (Liu et al. 2005, Lobo et al. 2008). Areas where the Multivariate Environment Similarity Surface (MESS) generated by the SAHM package had negative values (Talbert and Talbert 2014) were used to generate a mask that was overlaid on the binary maps and highlighted areas where model results were less certain (Elith et al. 2010). The negative values in the MESS indicate that environmental conditions at a given location are outside the range of values captured by the presence-absence data being used to generate the model. Thus the model output at that location is an extrapolation to novel environmental conditions (Elith et al. 2010, Talbert and Talbert 2014).

Maxent provides information on the extent to which each bioclimatic variable contributes to the modeled relationship between climatic conditions and the distribution of a given vegetation type. It provides both “percent contribution” and “permutation importance” values. The permutation importance values depend on the final model generated by Maxent, rather than the path taken to generate the model (Phillips 2011). Therefore these values were evaluated and used to display information on variable importance in the models rather than the values for percent contribution. Maxent also produces response curves which show the relationship between the modeled climatic suitability for a given vegetation type and each bioclimatic variable in the model. The trends in the response curves for the variables that had a permutation value of at least 10% (based on Rodda et al. 2011) in the niche models for each of the three focal vegetation types were evaluated for their ecological relevancy. This evaluation was based on the findings shown in Table 4-4.

4.2.3 Results

4.2.3.1 Niche Model Performance Metrics

The removal of non-independent variables left twelve (12) bioclimatic and topographic variables in the niche models for the current distributions of the three terrestrial ecological system CEs, as follows:

- Annual Mean Temperature (Bio 1)
- Mean Diurnal Range (Bio 2)
- Isothermality (Bio 3)
- Temperature Seasonality (Bio 4)
- Temperature Annual Range (Bio 7)
- Mean Temperature of Wettest Quarter (Bio 8)
- Annual Precipitation (Bio 12)
- Precipitation Seasonality (Bio 15)
- Precipitation of Wettest Quarter (Bio 16)
- Precipitation of Coldest Quarter (Bio 19)
- Aspect (topography)
- Slope (topography)

Table 4-5 shows the AUC values associated with the test data for the niche models for the current distributions of the three terrestrial ecological system CEs. The models for all three CEs performed well (AUC_{Test} between 0.8 and 0.9) or excellently (AUC_{Test} between 0.9 and 1) (Swets 1988, Talbert and Talbert 2014). AUC values were not improved by incorporating categorical soil data (Table 4-5). Further, no soil variable exhibited a permutation importance value ≥ 10% for any model. Consequently, the most parsimonious models include only bioclimatic and topographic variables. Other studies also have modeled plant species distributions using only bioclimatic and topographic variables (Franklin et al. 2013) or modeled biomes using only climate variables (Rehfeldt et al. 2012).

The three other performance metrics, calculated only for model versions that included bioclimatic and topographic variables but not soil variables, provided similar information to the AUC values. In particular, none of the models have low values for percent of occurrences correctly classified (% Correct <60%; based on Manel et al. 1999, Luck 2002), and all models have kappa statistic values that indicate either a moderate (0.41 to 0.6) or substantial (0.61-0.8) level of agreement between model predictions and true values of vegetation type presence or absence (Landis and Koch 1977, Allouche et al. 2006). The TSS has been presented as an improved measure of model accuracy that, unlike the kappa statistic, does not depend on vegetation prevalence (i.e., proportion of occurrence points for which the vegetation type is present; Allouche et al. 2006). All three models have TSS values in the same or better (0.81 to 1) ranges mentioned above for the kappa statistic (Table 4-5).

Table 4-5. Performance metrics for the niche models including Area Under the Receiver Operating Characteristic Curve for the test data (AUC_{Test}); correct classification rate (% Correct); the True Skill Statistic (TSS); and the kappa statistic. AUC values in parentheses are provided by Maxent for models that include the categorical soil variables.

Vegetation type	AUC_{Test}	% Correct	TSS	Kappa
Chihuahuan Desert Grassland	0.83 (0.69)	76.5	0.53	0.53
Chihuahuan Desert Scrub	0.88 (0.73)	80.5	0.61	0.61
Pinyon Juniper Woodland	0.99 (0.94)	95	0.9	0.79

Table 4-6 identifies all environmental variables retained in the analysis and their permutation importance values. As noted above, permutation importance indicates the extent to which each variable contributes to the modeled relationship between environmental conditions and the distribution of each terrestrial ecological system CE. Three variables have permutation importance values > 10% for the Chihuahuan Desert Grasslands niche model – annual mean temperature, temperature seasonality, and precipitation of the wettest quarter.

Table 4-6. Permutation importance values for the environmental variables included in the final niche models for the three terrestrial ecological system CEs. Values > 10% are shown in bold. NA indicates variables that were not needed for individual CEs.

Permutation Importance (%)➔ Environmental Variable🡻	Grassland	Scrub	Woodland
Annual Mean Temperature	43.60	56.83	62.26
Mean Diurnal Range	1.75	2.69	NA
Isothermality	4.52	0.71	0.88
Temperature Seasonality	11.19	9.59	NA
Temperature Annual Range	NA	NA	2.80
Mean Temperature of Wettest Quarter	1.35	1.93	2.04
Annual Precipitation	NA	6.34	5.46
Precipitation Seasonality	8.72	4.30	4.34
Precipitation of Wettest Quarter	19.56	NA	NA
Precipitation of Coldest Quarter	1.89	14.61	0.72
Aspect	0.50	0.16	0.23
Slope	6.90	2.83	21.25

Only two variables in Table 4-6 have permutation importance values > 10% for the Chihuahuan Desert Scrub – annual mean temperature and precipitation of the coldest quarter – but temperature seasonality only barely falls short of the 10% permutation importance threshold for the same model.

Only two variables have permutation importance values > 10% for the Pinyon-Juniper Woodlands niche model – annual mean temperature and slope.

4.2.3.2 Niche Model Response Curves

Figure 4-11 shows the response curves for all variables with permutation importance > 10% in any one of the three niche models for current distribution.

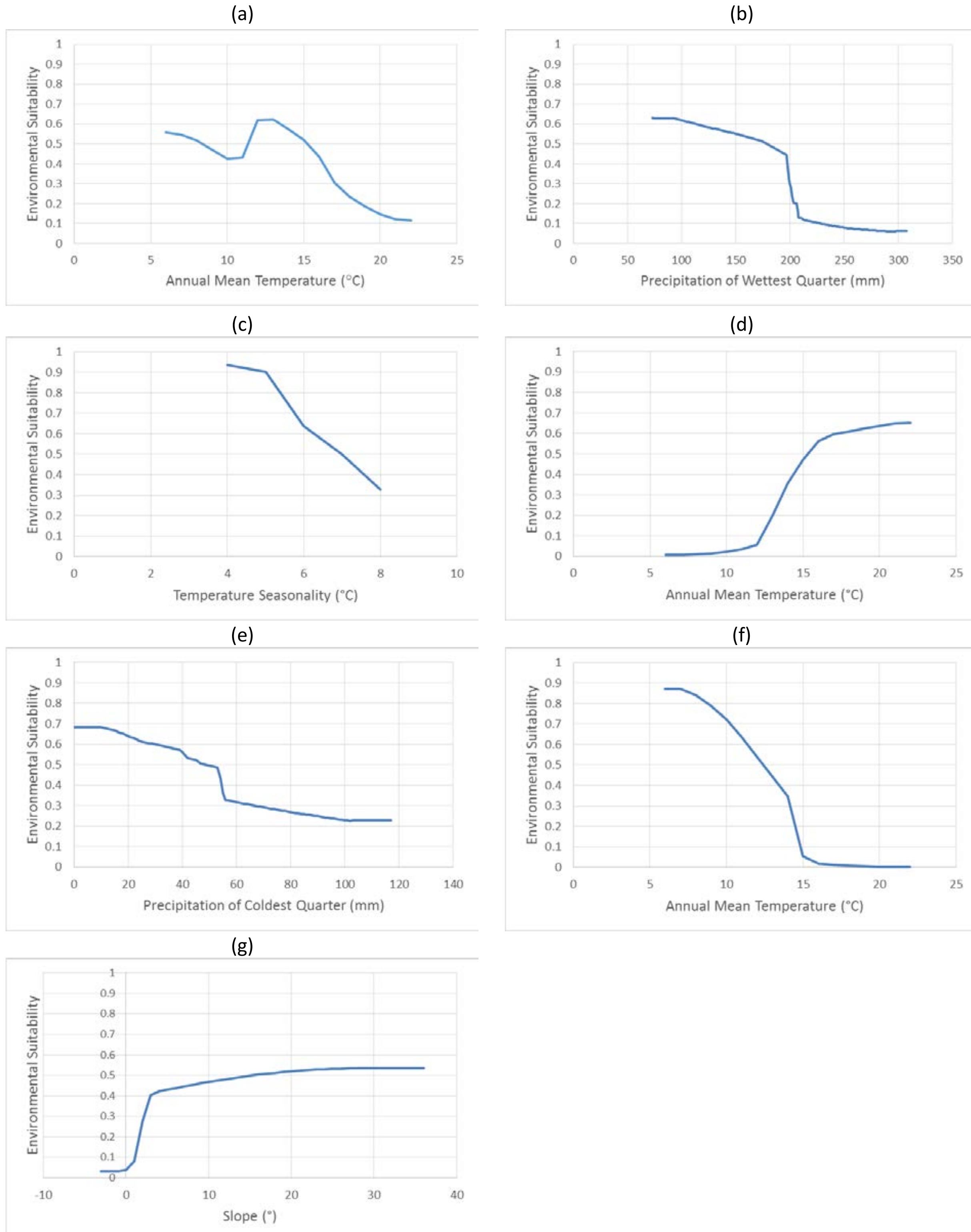
The Chihuahuan Desert Grassland response curve (Figure 4-11(a)) for annual mean temperature shows an overall declining trend with increasing temperature, but with a reversal between 10 and 12 ˚C that results in a distinctive bump between 12 and 16 ˚C. The Chihuahuan Desert Grassland response curves for both precipitation of the wettest quarter and temperature seasonality trend downward (Figure 4-11(b, c)), with a sharp drop in environmental suitability around 200 mm of precipitation in the wettest quarter. The Chihuahuan Desert Scrub response curve for annual mean temperature shows an overall increasing trend with increasing temperature starting around 13 ˚C (Figure 4-11(d)), while the Chihuahuan Desert Scrub response curve for precipitation of the coldest quarter shows a declining trend with a sharp drop around 55 mm (Figure 4-11(e)). The Pinyon-Juniper Woodland response curve for annual mean temperature shows a declining trend that becomes flat above 15 ˚C (Figure 4-11(f)), while the Pinyon-Juniper Woodland response curve for topographic slope (Figure 4-11(g)) shows an increasing trend that spikes up around 3 degrees and levels out around 16 degrees.

The response curves for annual mean temperature for all three conservation elements ((Figure 4-11(a, d, f)) broadly match the expected relationship between each group of ecological systems and mean annual temperature (Table 4-4). The response curve for precipitation of the wettest quarter partly matches expectation for Chihuahuan Desert Grassland (Figure 4-11(b);Table 4-4), while the response curve for precipitation of the coldest quarter does not match expectations for Chihuahuan Desert Scrub (Figure 4-11(e);Table 4-4). The top contributing variables in the models run with the removed environmental variables (i.e., variables with a correlation of r > 0.7 with variables shown inTable 4-6) were highly correlated with annual mean temperature. Since annual mean temperature is the highest contributing variable to each of the three vegetation models, these removed variables do not appear to contribute additional information and they were not evaluated further.

4.2.3.3 Implications of Niche Model Response Curves

Annual mean temperature figures prominently in the niche models for all three terrestrial ecological system CEs. Consequently, forecasted changes in annual mean temperature strongly affect the estimates of the potential effects of climate change on all three CEs. These relationships can be explained in terms of the ecology of these three groups of ecological systems. Overall warmer temperatures, when accompanied by drought, would be expected to favor shrubs over grasses (Backlund et al. 2008). Further, a positive feedback loop appears to exist in the northern portion of the Chihuahuan Desert between increased nocturnal winter temperatures and the spread of creosote into the grasslands in this portion of the ecoregion (D'Odorico et al. 2010).

Figure 4-11. Environmental variables with permutation importance > 10%: Response curves to the niche models for the current distributions of (a-c) the Chihuahuan Desert Grassland, (d-e) Chihuahuan Desert Scrub, and (f-g) Pinyon-Juniper Woodland CEs.



The general declining trend in the response curve for annual mean temperature for Chihuahuan Desert grasslands and increasing trend in the curve for the Chihuahuan Desert scrub discussed above for Figure 4-11 reflect these relationships. Similarly, the increase in suitability (bump) in the Chihuahuan Desert Grassland response curve for annual mean temperatures between 12 and 16 ˚C (Figure 4-11) may be explained by the fact that roughly half (44%) of the area within the U.S. portion of the ecoregion has annual mean temperatures in this range and is dominated by desert grass species (see above,Table 4-3) potentially well adapted to this temperature range. Two dominant desert grass species (black and blue grama, *Bouteloua eriopoda* and *B. gracilis*, respectively) appear to require a minimum temperature of 15 ˚C for germination (Minnick and Coffin 1999). The growing season begins at the hottest time of year (June; Minnick and Coffin 1999), when temperatures should be at the higher end or higher than mean annual temperatures in areas that have suitable germination and establishment conditions for these species. At least one of the dominant shrubs, creosote (for other dominant species, see above, Table 4-3), is susceptible to mortality under drought conditions accompanied by higher temperatures (Bowers 2005, Backlund et al. 2008), which matches the general leveling off of the Chihuahuan Desert Scrub response curve for annual mean temperature. Trees in pinyon-juniper woodlands become more susceptible to drought-induced mortality as temperatures accompanying drought increase (Breshears et al. 2005). Furthermore, higher temperatures may favor bark beetle survival and shorten their development time (Raffa et al. 2008, Bentz et al. 2010). This matches the declining trend of the Pinyon-Juniper Woodland response curve for annual mean temperature.

Patterns in the environmental variables that contributed less to the niche models can also be tied to vegetation ecology. In particular, areas of higher rainfall are likely to be associated with woodland rather than grassland vegetation, which may account for the overall declining trend in the Chihuahuan Desert Grassland response curve for precipitation of the wettest quarter. Pinyon-juniper woodlands typically occur in areas with mean annual precipitation between 250 and 560 mm (Ronco Jr. 1990) and where much of the rain falls during one three month period (i.e., July through September; Sheppard et al. 2002, Peterman et al. 2012). This coincides roughly with the sharp decline in suitability of environmental conditions for grasslands in the study area around 200 mm of rain during the wettest quarter; it is likely that this is the point where vegetation transitions from grassland to pinyon-juniper woodland.

Temperature seasonality refers to the range or variability of temperatures over the course of the annual cycle and is calculated as the standard deviation of monthly temperatures. While this variable did not appear in the literature search as an important variable for any of the three vegetation types (Table 4-4), it was one of the top three contributing variables for the Chihuahuan Desert Grassland niche model (Figure 4-11(c));Table 4-6). It is possible that suitability for the grassland decreases with increasing temperature seasonality because the grassland species are better adapted to the overall lower seasonality in the Chihuahuan Desert than in areas north of the desert. These areas north of the Chihuahuan Desert experience lower minimum temperatures during the coldest month but maximum temperatures during the warmest month are in the same range as in the Chihuahuan Desert.

There is a negative relationship between precipitation of the coldest quarter and environmental suitability for Chihuahuan Desert Scrub: higher rainfall during the winter months is associated with lower suitability for scrub. The direction of this relationship is surprising because it goes against the observation that more winter precipitation may be associated with the spread of shrubs and woody plant encroachment. In particular, values of precipitation above 78 mm have been observed to be associated with an increase in woody vegetation cover (Munson et al. 2013). However, it is possible that the observed negative relationship is driven by the fact that the areas with higher cold quarter precipitation are in mountainous areas and the northern portion of the Chihuahuan Desert in the U.S., where pinyon-juniper woodlands and Chihuahuan Desert grassland currently occur to the exclusion of scrub (Figure 4-10(a)).

The positive association between environmental suitability and topographic slope for pinyon-juniper woodlands matches the observation that these woodlands typically occur at higher elevation than do Chihuahuan Desert grasslands and scrub. Pinyon-juniper woodlands also occur in areas more likely to have steeper slopes, including mountains, rather than the valleys, canyons, and washes where grassland and scrub more often occur. However, pinyon-juniper woodlands do not occur high in the mountains, which may explain the leveling off of the response curve for the Pinyon-Juniper Woodlands niche model for topographic slope at higher values of slope. The tendency for pinyon-juniper woodlands to occur in areas with higher slopes and on mesas and plateaus may be due to these areas having coarser, especially rockier, soils with greater water availability for the trees. It may also be due to these areas having less frequent and severe fires (Ronco Jr. 1990).

4.2.3.4 Potential Future Terrestrial ecological system CE Distributions

The niche models can be combined with forecasts of future climatic conditions to forecast the spatial distributions of conditions suitable for each of the three terrestrial ecological system CEs. As indicated earlier, the present study focused on forecasting these distributions for the later of the two future bi-decadal periods, 2016-2080, period mean 2070, based on two of the four GCM x RCP combinations: HadGEM2-ES x RCP 2.6, which forecasts the smallest increase in temperature and the most rainfall across the region (i.e., cooler and wetter relative to the other GCM by RCP combinations), and MPI-ESM-LR x RCP 8.5, which forecasts the largest decrease in precipitation and a larger increase in temperature (i.e., hotter and drier compared to other future climate scenarios considered).

Figure 4-12 shows the potential distribution of the Chihuahuan Desert Grassland CE in 2070 for each of the two GCM x RCP combinations of interest, estimated based on the Chihuahuan Desert Grassland niche model. Stable areas (blue) are where conditions are suitable for grassland currently and in 2070; and areas of contraction (pink) are where conditions are currently suitable but may not be suitable by 2070. Neither dataset indicated any areas where conditions may become suitable for grasslands by 2070 but are not currently suitable. Un-sampled climate (hatching) indicates areas where the climatic conditions are outside those found at the occurrence points used to generate the niche models and thus where there is less confidence in model results because they are the product of extrapolation.

The two included maps Figure 4-12(a), HadGEM2-ES x RCP 2.6, and Figure 4-12(b), MPI-ESM-LR x RCP 8.5, indicate that climatic conditions may become unsuitable for grasslands across most (Figure 4-12(a)) or all (Figure 4-12(b)) of their current geographic range. The results also indicate that climate change by 2070 will not result in any expansion of grasslands into areas within the U.S. portion of the ecoregion beyond the areas sampled, although a few areas will remain stable as grasslands (blue points inFigure 4-12) to generate the niche model for this CE (hatched areas in Figure 4-12(a, b)).

Figure 4-12. Potential distributions of suitable climatic conditions for the Chihuahuan Desert Grasslands CE in 2070 based on (a) the HadGEM2-ES x RCP 2.6 and (b) MPI-ESM-LR x RCP 8.5 models.

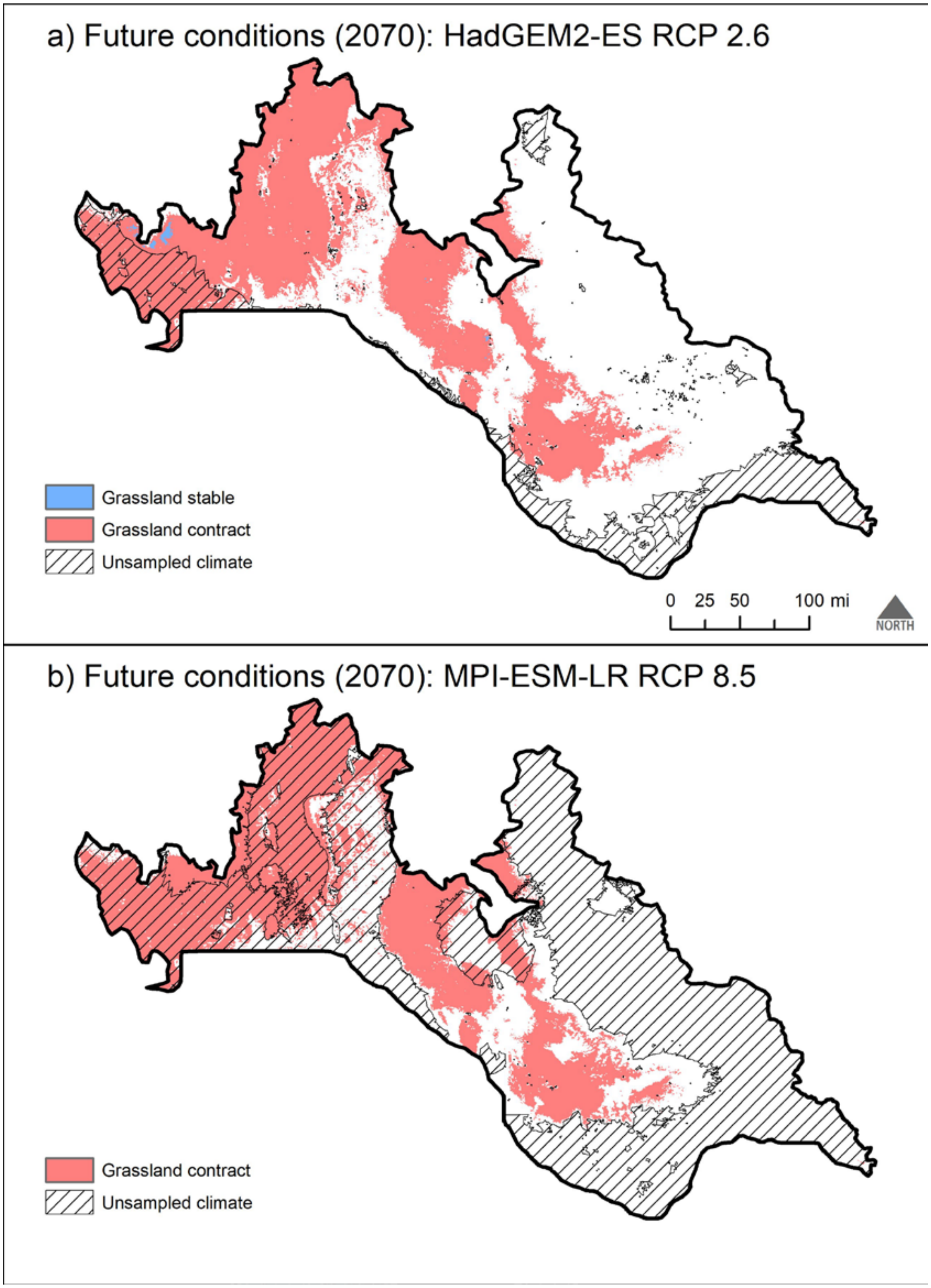


Figure 4-13 and Figure 4-14 show that climate change by 2070 potentially will cause some areas currently more suitable for grasslands to become more suitable for scrub. Stable areas are where climate conditions are currently suitable and may still be suitable by 2070 for each conservation element. Areas of expansion are where climate conditions are currently unsuitable for each conservation element but may become suitable by 2070. Areas of contraction for each conservation element are where climate conditions are currently suitable but may become unsuitable by 2070. Un-sampled climate (hatching) indicates areas where the climatic conditions are outside those found at the occurrence points used to generate the niche models and thus where there is less confidence in model results because they are the product of extrapolation. The estimates based on the Chihuahuan Desert Grassland and Chihuahuan Desert Scrub niche models thus indicate that a large fraction of the U.S. portion of the ecoregion potentially will either remain suitable for scrub (light orange areas in Figure 4-13 and Figure 4-14) or experience an expansion of scrub into areas within the U.S. portion of the ecoregion beyond the areas sampled (magenta points in Figure 4-13 and Figure 4-14) to generate the niche model for this CE (hatched areas in Figure 4-13 and Figure 4-14). Again, the results indicate no areas of grassland expansion and only limited areas of stable grassland.

Figure 4-13. Potential distributions of suitable climatic conditions for the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs in 2070 based on the HadGEM2-ES x RCP 2.6 model.

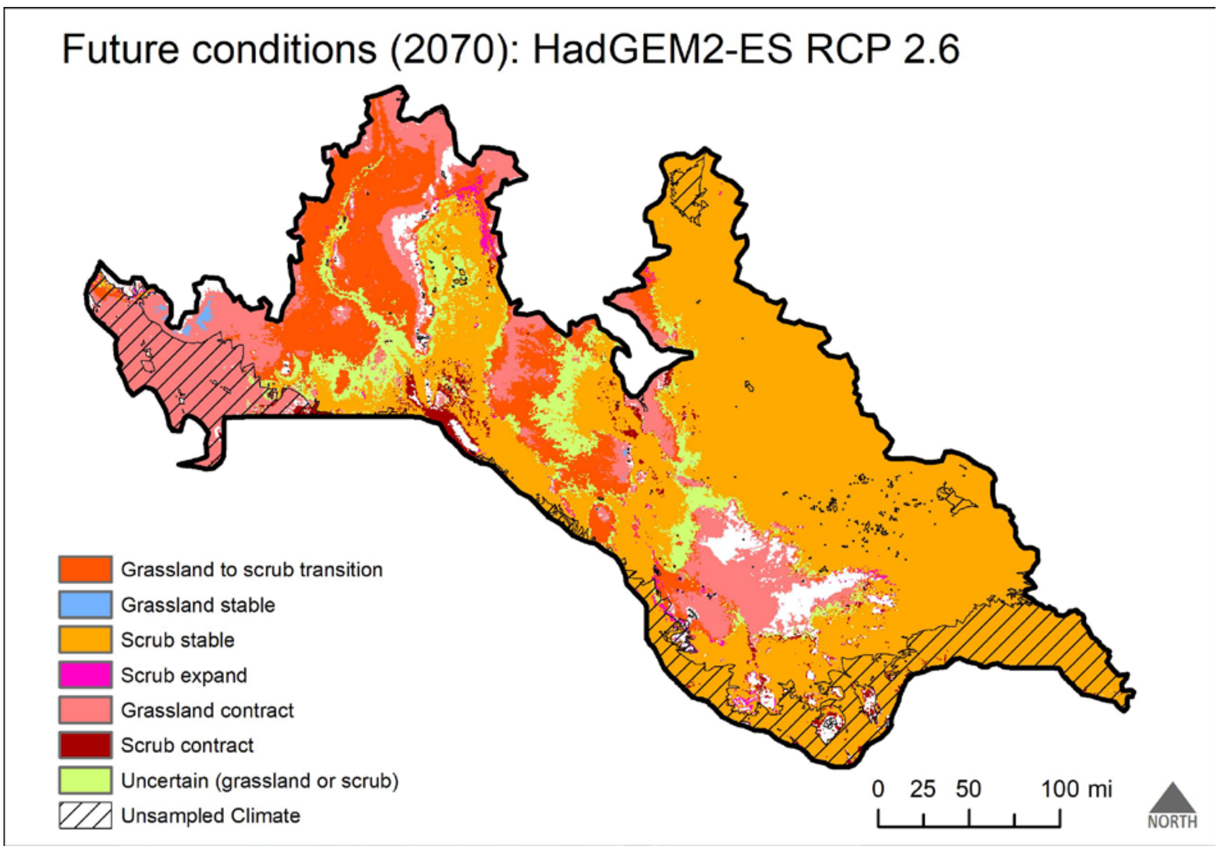
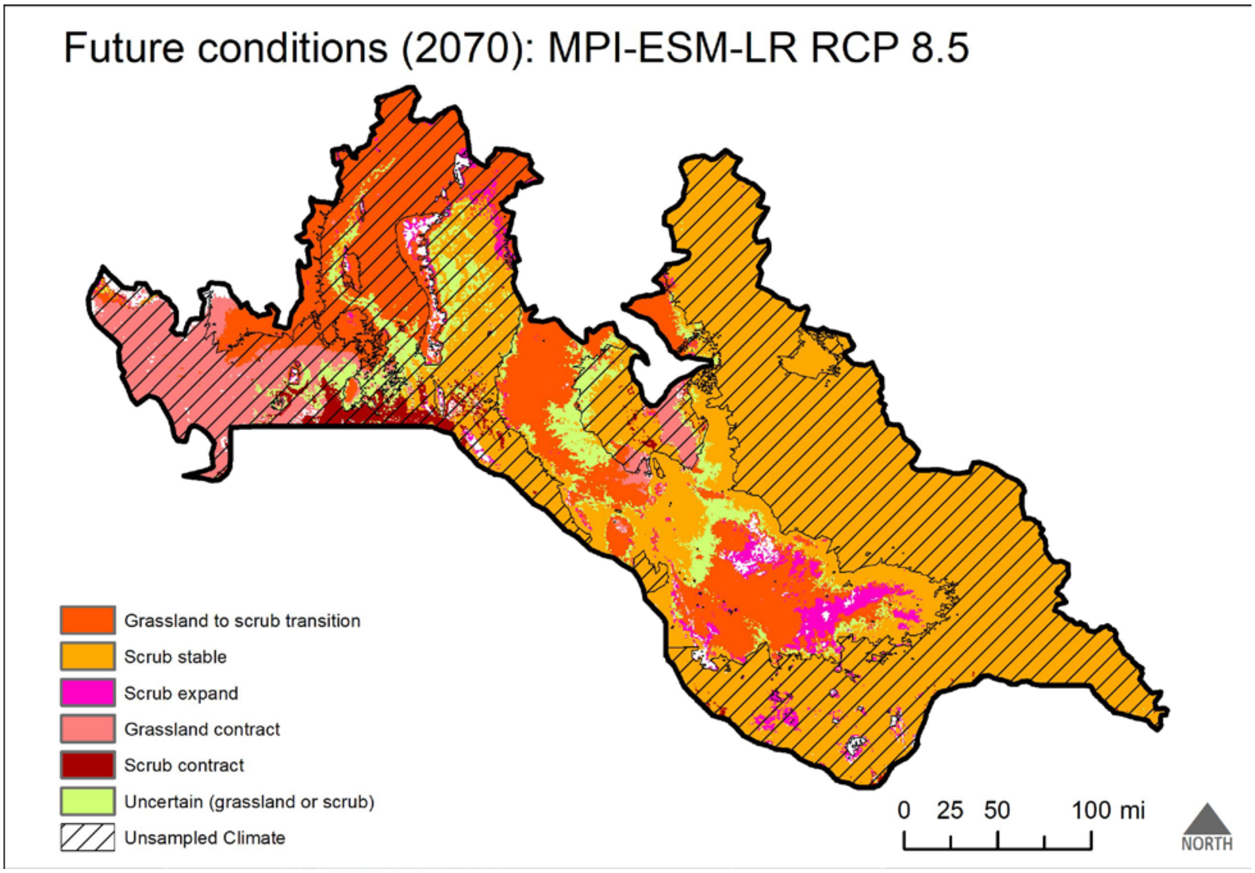


Figure 4-15 and Figure 4-16 show that climate change by 2070 potentially will eliminate most (Figure 4-15) or all (Figure 4-16) areas within the U.S. portion of the ecoregion suitable for pinyon-juniper woodlands. Most pinyon-juniper woodland areas are forecasted to transition to grassland but some may transition to scrub. However, as noted above, many areas are forecasted to experience an expansion of scrub into areas within the U.S. portion of the ecoregion beyond the areas sampled (blue and yellow points in Figure 4-10) to generate the niche model for these two conservation elements (hatched areas in Figure 4-15 and Figure 4-16). Once again, the results indicate no areas of grassland expansion and only limited areas of stable grassland.

Figure 4-14. Potential future distributions of suitable climatic conditions for the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs in 2070 based on the MPI-ESM-LR x RCP 8.5 model.



4.2.3.5 Climate Change and Chihuahuan Desert Grasslands Restoration Potential

The results from applying the Chihuahuan Desert Grasslands niche model to forecasts of climate change indicate that the availability of suitable climatic conditions for Chihuahuan Desert grasslands in the U.S. portion of the ecoregion may decline dramatically by the year 2070 (Figure 4-12 – Figure 4-16). The results using the wetter GCM x RCP combination – HadGEM2-ES x RCP 2.6 – indicate that small pockets of conditions suitable for grasslands may persist in the center and far northwestern corner of the U.S. portion of the ecoregion by 2070 (Figure 4-12(a)). The results using the drier scenario – MPI-ESM-LR x

RCP 8.5 – indicate that no areas suitable for grasslands will remain at all 2070 (Figure 4-12(b)). Under both GCM x RCP combinations, but especially under the drier scenario, a large section of the U.S. portion of the ecoregion is forecasted to have climatic conditions in 2070 that differ significantly in their ecological consequences from current conditions. This is especially true in the northwestern part of the current distribution of suitable climatic conditions for the Chihuahuan Desert grassland (pink areas overlaid with hatching in Figure 4-12(a, b)). More specifically, under the wetter GCM x RCP combination, annual mean temperature in the southeastern section of the U.S. portion of the ecoregion is forecasted to increase; precipitation seasonality (i.e., the coefficient of variation of monthly precipitation, calculated differently than temperature seasonality) in the southern middle section is forecasted to increase; temperature seasonality in the northeastern-most section; and the mean temperature of the driest quarter in the northwestern section is forecasted to increase. For the drier scenario, annual mean temperature across a fairly large area in the southeastern section of the U.S. portion of the ecoregion is forecasted to increase, as is temperature seasonality across much of the northern section and the mean temperature of the driest quarter in the northwestern section, while precipitation of the wettest quarter in the northern central section is forecasted to decrease.

Figure 4-15. Potential distributions of suitable climatic conditions for the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs in 2070 based on the HadGEM2-ES x RCP 2.6 model.

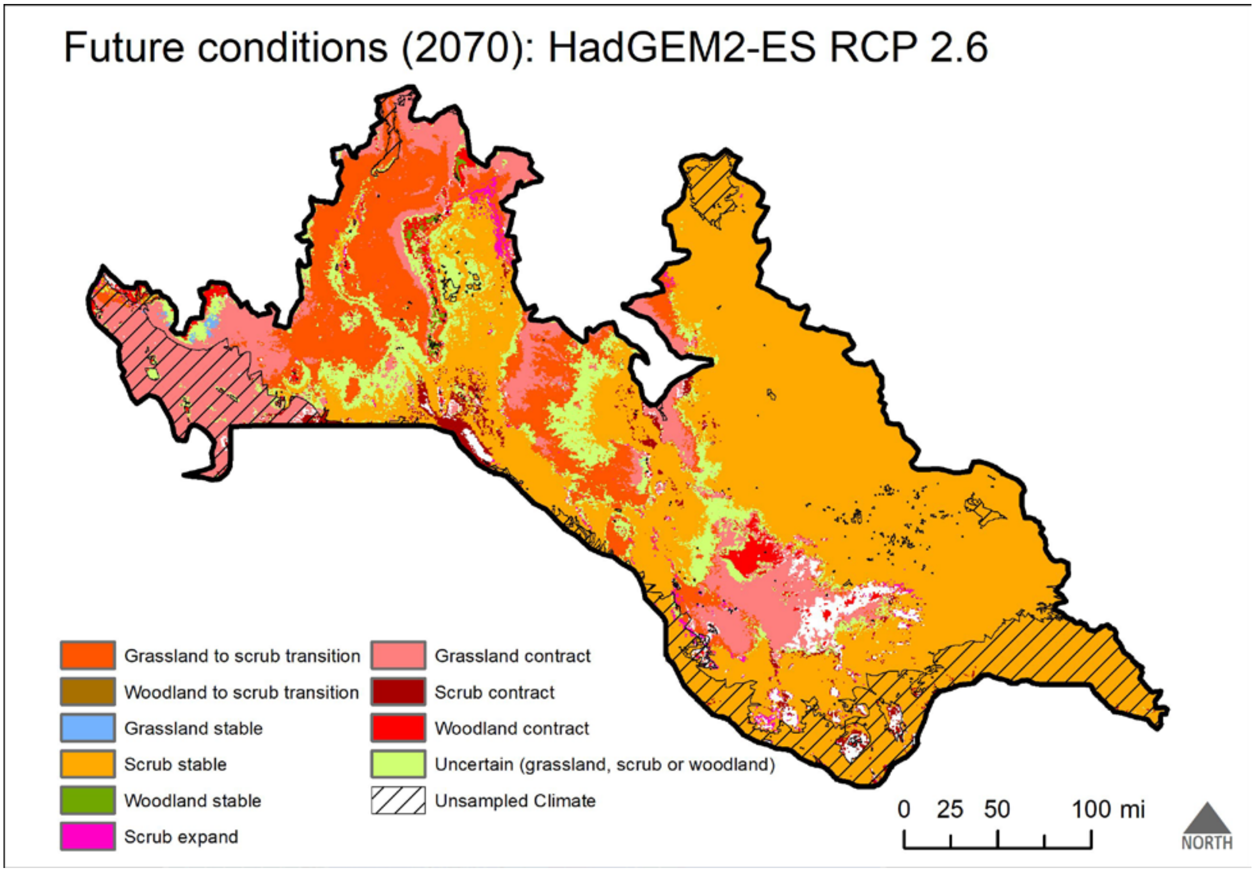
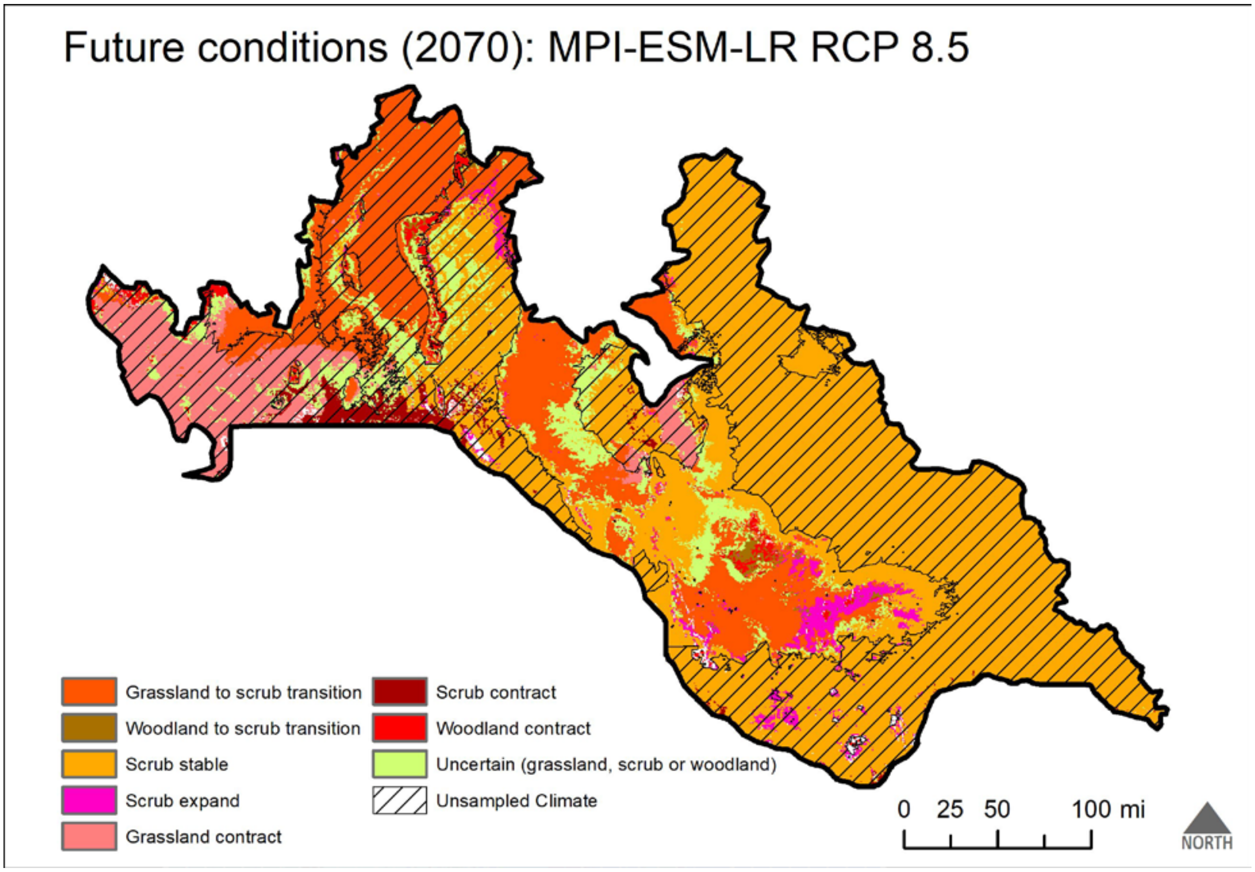


Figure 4-16. Potential distributions of suitable climatic conditions for the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs in 2070 based on the MPI-ESM-LR x RCP 8.5 model.



The results from applying the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub niche models together to forecasts of climate change provide further clarification (Figure 4-13 and Figure 4-14). Some areas that are currently suitable for grassland are forecasted to transition to becoming more suitable for scrub. The forecasted distribution of these potential transition zones differs under the two GCM x RCP combinations considered. Under the wetter GCM x RCP combination, the greatest extent of transition is forecasted to occur in the northwestern portion of the U.S. portion of the ecoregion, largely to the west of the San Andres Mountains and on either side of the Rio Grande (Figure 4-13). Under the drier GCM x RCP combination, the area forecasted to experience this transition extends further south and east into the southeastern corner of New Mexico and western Texas. In particular, there is a large transition zone around and to the southeast of Otero Mesa, two smaller zones south of Roberts Mesa and around Eagle Mountains, and a fourth large zone encircling the Davis Mountains (Figure 4-14). These transition zones may constitute good focal areas for grassland conservation and restoration efforts, especially at sites where a transition is already being observed on the ground or some native shrubs are present but the grassland is still relatively healthy. For example, there is some evidence that early use of prescribed fire may reverse the transition from grassland to scrub vegetation (Sankey et al. 2012).

4.2.3.6 Climate Change and Pinyon-Juniper Woodland Restoration Potential

The distribution of suitable climatic conditions for pinyon-juniper woodlands in the U.S. portion of the ecoregion is forecasted to decline substantially by the year 2070. Under the wetter GCM x RCP combination, small patches of suitable conditions are forecasted to remain in the northwestern section of the ecoregion, specifically in the Oscura, Organ, and San Andres Mountains and near Silver City (Figure 4-15). Under the drier GCM x RCP combination, no climatically suitable areas are forecasted to remain at all (Figure 4-16). Under this drier scenario, scrub may replace pinyon-juniper woodlands in the southeastern section of the U.S. portion of the ecoregion, particularly in the Davis Mountains, and even in the San Andres Mountains in New Mexico. Areas of potential stability of conditions suitable for pinyon-juniper woodlands, and areas of potential transition from pinyon-juniper woodlands to scrub may constitute good focal areas for various habitat management and restoration activities. For example, prescribed fire and thinning may mitigate the occurrence of and mortality associated with future bark beetle outbreaks (Fettig et al. 2013).

4.3 Climate Change and Aquatic/Wetland Conservation Elements

The Chihuahuan Desert REA does not include a quantitative assessment of the potential effects of climate change on the aquatic-wetland CEs. The REA addresses this topic alternatively through the conceptual ecological models for the aquatic-wetland CEs, presented in the Pre-Assessment report (see Chapters 8-11 in Unnasch et al. 2017). The conceptual models for (1) the two perennial stream CEs together, (2) the large river-floodplain systems CE, (3) the spring-emergent wetlands CE, and (4) the playas-playa lakes CE explicitly discuss the ways in which climate change potentially could alter each aquatic-wetland CE. Combined with the forecasts of climate change presented earlier in this chapter, the conceptual models present a consistent forecast of the ways in which climate change will affect the five aquatic-wetland CEs. The following paragraphs summarize the information presented in Chapters 8-11 in the Pre-Assessment report (Unnasch et al. 2017). Numerous publications (e.g., recently, USBR 2013, Friggens and Woodlief 2014, Jaeger et al. 2014, Petrie et al. 2014, Turner et al. 2015, and Eng et al. 2016) address the topic in detail.

As discussed earlier in this chapter, climate change is forecasted to result in generally higher average and seasonal maximum and minimum temperatures in all seasons. The forecasts for annual precipitation include a range of possibilities from a small increase to a large decrease in precipitation. However, the increased temperatures will reduce the frequency and magnitude of snowfall relative to rainfall (e.g., Rango 2006, USBR 2013, Friggens and Woodlief 2014), and increase the extent to which precipitation evaporates as it falls and therefore never reaches the ground at all. The forecasts for annual precipitation indicate that the timing and magnitude (e.g., rainfall intensity) of individual precipitation events also could change.

The effects of these changes in climate on the aquatic-wetland CEs will likely play out along several causal pathways, as discussed in the Pre-Assessment report (Unnasch et al. 2017) conceptual ecological models, beginning with effects on watershed runoff and recharge:

- Changes in the frequency and magnitude of snowfall relative to rainfall, at the higher elevations where snowfall is more common, will affect the magnitude, timing, and temperature of water that runs off from these higher elevations into montane-headwater streams.
- Changes in temperature and precipitation patterns will affect watershed ground cover, as discussed above, this chapter. These changes in vegetation in turn will affect infiltration, diffuse runoff, and evapotranspiration across watershed surfaces, which in turn will affect how much water reaches stream channels, and how quickly following precipitation events, at all elevations.
- Changes in the intensity of rainfall events (e.g., the maximum rainfall rate within a storm) in combination with the changes in watershed vegetation cover will affect the rate and spatial extent of soil erosion caused by individual storm events.
- The forecasted changes in temperatures and precipitation patterns will likely affect runoff water quality by raising the average temperature of water as it flows across the watershed surface and the relative concentrations of soluble matter transported in that diffuse runoff. Changes in air temperature and precipitation patterns will also likely affect the rate at which salts accumulate across soil surfaces as a consequence of natural evaporative processes, and therefore the rate at which such salts are available for dissolution and transport in the diffuse runoff.
- A significant fraction of regional groundwater recharge to takes place at higher elevations across the mountains and foothills of the ecoregion (see Chapter 8, below). The rate of recharge varies with the amount of precipitation received and the amount of water lost to evapotranspiration, which varies with vegetation cover and air temperatures. The rate of recharge also varies depending on whether the precipitation occurs as rain or snow, because melting snow recharges more effectively than does rainfall. Changes in precipitation and air temperatures therefore will affect the rates of mountain recharge.

Such changes in watershed runoff and recharge in turn will affect the hydrology, temperature, and chemistry of the aquatic-wetland CEs themselves, as discussed in the Pre-Assessment report (Unnasch et al. 2017) conceptual ecological models, including the following:

- Changes in watershed runoff patterns will affect the hydrograph shape, magnitude, timing, and duration of the runoff events responsible for high-flow pulses along stream and river channels.
- Changes in mountain recharge will affect baseflow along streams and rivers and discharge at springs. However, groundwater flow-path lengths from mountain recharge zones may be long (see Chapter 8, below), and changes in mountain recharge therefore may not affect groundwater discharge at some springs or along some stream or river reaches for decades to centuries (e.g., Scanlon et al. 2005, Heitmuller and Williams 2006, Webb and Leake 2006, Serrat-Capdevlia et al. 2007, Stonestrom et al., eds. 2007, Wolaver et al. 2008, Magruder et al. 2009, Porter et al. 2009, Kennedy and Gungle 2010, Tillman et al. 2011,USBR 2011a, 2013, Szynkiewicz et al. 2012, 2015a, 2015b, Friggens et al. 2013a, Sheng 2013, Friggens and Woodlief 2014, Jaeger et al. 2014, Eng et al. 2016, Meixner et al. 2016, Sigstedt et al. 2016). On the other hand, baseflow in higher-elevation headwater streams may depend on discharge from relatively small, shallow, local aquifers. The effects of changes in recharge in these settings could take only a few

years to affect baseflow (e.g., Heitmuller and Williams 2006, Webb and Leake 2006, Magruder et al. 2009, Kennedy and Gungle 2010, Theobald et al. 2010).

- Through their effects on the runoff regime, runoff water quality, and watershed erosion, changes in watershed ground cover will affect several critical ecological processes in the water bodies into which the runoff flows. The affected processes will include stream fluvial-alluvial sediment dynamics (e.g., Grant et al. 2003, Schmidt et al. 2003, NMDGF 2006, Hoagstrom et al. 2008, Porter et al. 2009, Theobald et al. 2010, USFWS 2010, Garrett and Edwards 2014, Wohl et al. 2015). The affected processes also necessarily will include stream water quality dynamics, including water temperatures and concentrations of dissolved and particulate organic matter.
- Changes in the frequency and severity of droughts may also affect fluvial network connectivity, which in turn determines fluvial biotic connectivity, for streams and springs that become disconnected from a larger stream network when intermediate stream reaches run dry (e.g., Propst et al. 2008, Gido et al. 2013, Acreman et al. 2014, Bogan et al. 2014, Jaeger et al. 2014, Sabo 2014, Fuller et al. 2015, Murphy et al. 2015).
- Changing precipitation patterns potentially could directly affect playa water quality and soil dynamics by affecting nutrient cycling, moisture retention, and the erosion resistance capacity of playa soils (KellerLynn 2003). Increased thunderstorm activity could also impact playa soil surfaces by diminishing soil crusts and increasing erosion (see also Bennett and Wilder 2009).

The forecasted changes in air temperatures and precipitation also will directly affect the aquatic-wetland CEs at the scale of their individual occurrences, even without intervening effects to watershed dynamics. Some of these direct effects will also affect the hydrology and other characteristics of the waterbodies themselves. For example:

- Changes in air temperature will affect baseflow, low-flow pulse dynamics, and water table elevations along streams and at springs by affecting the rates of evaporation of surface water and evapotranspiration by aquatic, wetland, and surrounding vegetation. (e.g., Scott et al. 2004, 2008, Price et al. 2005, Stromberg et al. 2006, Serrat-Capdevila et al. 2007, Hatler and Hart 2009, Kennedy and Gungle 2010, Friggens and Woodlief 2014). Changes in air temperature and precipitation will both directly and indirectly affect playa inundation regimes. Changes in air temperatures will affect the rates of evaporation of water from playa lake surfaces and wetted soils, and the rates of evapotranspiration by playa vegetation (e.g., Serrat-Capdevila et al. 2007, NPS 2010, Tillman et al. 2011, USBR 2011a, 2013, Friggens and Woodlief 2014).
- Changes in air temperature and precipitation will directly affect riparian-aquatic native-exotic species interactions. Air temperature affects water demand in plants and thermal regulation in land animals, and native species may differ in their abilities to adjust to changes in air temperature patterns compared to non-native species. Similarly, precipitation directly along riparian corridors affects water availability for both plants and land animals along the corridors. Native species may differ in their abilities to adjust to changes in precipitation patterns compared to non-native species (e.g., Price et al. 2005, Enquist et al. 2008, Jones et al. 2010, Nagler et al. 2011, Friggens et al. 2013a, 2013b, Friggens and Woodlief 2014).

Finally, the forecasted changes in climate will affect the aquatic-wetland CEs along another set of causal pathways, by affecting water availability and demand for human use.

- Higher air temperatures will increase evaporative losses from impoundment surfaces, reducing reservoir storage and possibly raising salinity in the impounded waters.
- Higher air temperatures will also result in higher rates of evapotranspiration across irrigated agricultural lands and, potentially, higher rates of accumulation of salts in the irrigated soils, both of which potentially will increase demand for irrigation water unless accompanied by changes in irrigation practices or crop selection.
- Higher air temperatures will also result in increased demand for water for consumption by people and livestock.

These projections emphasize effects on the perennial streams, springs, and playas within the U.S. portion of the ecoregion. The effects of climate change on the three large rivers will be somewhat different, because these three rivers originate outside the U.S. portion of the ecoregion and because, in the case of the Pecos River and the Rio Grande, conditions along these rivers are strongly affected by dams both within and upstream from the ecoregion. (Neither the Gila River nor any of its tributaries are presently dammed or diverted within the U.S. portion of the ecoregion. However, as discussed in Chapter 5, this situation could change.) In particular, the close relationships among water availability, water demand, and the operations of dams, diversions, and return-flow systems along the Pecos River and Rio Grande – and the strong effects of dam, diversion, and return-flow operations on discharge along these two rivers – make it difficult to predict how climate change will affect flow along these two rivers within the ecoregion. However, the combination of demand for water for people and livestock, reduced precipitation inputs, and increased evapotranspiration losses, pose serious threats to water availability for ecological resources and human needs. As quoted in Chapter 2, above, one recent study found that "[t]he Rio Grande offers the best example of how climate-change-induced flow declines might sink a major system into permanent drought" (Dettinger et al. 2015).

Further, the many dams along the Pecos River and Rio Grande within and outside the U.S. portion of the ecoregion trap essentially all the sediment delivered to their impoundments from upstream (e.g., Collins and Ferrari 2000a, 2000b, Ferrari 2013, Hogan 2013, IBWC 2013, Varyu and Fotherby 2015). As a result, changes in watershed ground cover driven by climate change will likely not affect the amount of sediment transported into and along the Pecos River and Rio Grande within the ecoregion. On the other hand, the changes in watershed ground cover driven by climate change both within and outside the U.S. portion of the ecoregion could affect other aspects of water quality along these two rivers such as water temperatures and concentrations of dissolved and particulate organic matter.

5 Development and Grazing

5.1 Introduction

The present chapter presents the assessments of two Change Agents (CAs), development and excessive grazing. Chapter 2 includes a summary of the distribution and potential ecological impacts of development across the U.S. portion of the ecoregion. As noted there and throughout the Pre-Assessment Report, development significantly affects the distributions and condition of species and ecological systems across this landscape. Consequently, development is one of the six CAs addressed in the Chihuahuan Desert REA. It is also one of two CAs for which the REA assesses forecasts of future conditions and their potential impacts; the other forecasted CA is climate change, discussed above in Chapter 4.

Chapter 2 also includes a summary of the distribution and potential ecological impacts of grazing across the U.S. portion of the ecoregion. As noted there and throughout the Pre-Assessment report, grazing also can significantly affect the distributions and condition of species and ecological systems across this landscape. However, as noted in Chapter 3, livestock grazing *per se* does not constitute an ecological stressor. Rather, grazing alters ecological conditions and processes only when its intensity interferes with natural soil and vegetation processes. Consequently, the Chihuahuan Desert REA includes *excessive* grazing as a CA. Unfortunately, the BLM and the Technical Team did not identify any systematic datasets on grazing intensity suitable for inclusion in the REA.

Six Management Questions (MQs) concern or include these two CAs, as follows:

MQ C: What is the current geographic distribution of the impacts of each CA, both in general and in relation to each Conservation Element (CE)?

MQ D: What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?

MQ 6: Where will urban and industrial growth impact intact grasslands or impede their recovery?

MQ 8: How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?

MQ 9: What and where are the aquifers and their recharge zones that support the wet systems?

MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Section 5.2 of the present chapter addresses MQ C specifically with respect to development, assessing its current distribution across the U.S. portion of the ecoregion. Section 5.3 addresses MQs D, concerning forecasts of development across this landscape. Finally, Section 5.4 addresses MQ C specifically with respect to grazing, assessing its current distribution across the U.S. portion of the ecoregion.

Other chapters in the present report address MQs 6, 8, 9, and 13, and additional aspects of MQ C. Chapters 7-10 assess the distributions of development and grazing in relation to the fourteen CEs addressed by the Chihuahuan Desert REA and potential implications of these overlapping distributions. Chapters 7 and 10, respectively, address MQs 6 and 8, concerning the potential impacts of development on grasslands and the grassland bird assemblage. The wording of MQ 9 does not explicitly refer to any CAs. However, given the ecological and economic importance of aquifers and recharge zones in the ecoregion, Chapter 8 includes an assessment of the distribution of development relative to these two resources. Finally, Chapter 7 presents the full assessment of the current geographic distribution of potential impacts of gypsum in the soil and water both in general and in relation to CAs including development and grazing, the subjects of MQ 13.

5.2 Current Development

5.2.1 Methods and Data

The term, "development," covers a wide range of human activities that result in some form of mechanical, chemical, or other direct alteration of soils, vegetation, and water across a landscape. Theobald (2013) presents a classification of the types of development to consider when assessing the impacts of development on ecological conditions across landscapes. Other REAs (e.g., SAIC 2012, Crist et al. 2014) and the New Mexico State Wildlife Action Plan (NMDGF 2016) follow similar typologies. The present REA follows the classification of development types presented by Theobald (2013), with modifications specific to the Chihuahuan Desert. Specifically, the present REA used the following categories to assess development:

- Residential, commercial, industrial, other non-agricultural development
    - Open space, such as the Multi-Resolution Land Characteristics (MRLC) consortium defines for the National Land Cover Database (NLCD) (Homer et al. 2015; https://www.mrlc.gov/nlcd11_leg.php) as "areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes."
    - Low intensity, such as the MRLC consortium defines for the NLCD (Homer et al. 2015; https://www.mrlc.gov/nlcd11_leg.php) as "areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units."
    - Medium intensity, such as the MRLC consortium defines for the NLCD (Homer et al. 2015; https://www.mrlc.gov/nlcd11_leg.php) as "areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units."
    - High intensity, such as the MRLC consortium defines for the NLCD (Homer et al. 2015; https://www.mrlc.gov/nlcd11_leg.php) as "areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover."
    - Landfills

- Military and other secured-area development (when not included in residential, commercial, industrial, other non-agricultural development)
    - Military facilities
    - Border barriers and facilities
    - Correctional facilities
- Agricultural development
    - Annual and perennial non-timber crops
    - Wood and pulp plantation
    - Livestock farming and ranching
- Energy production and mining development
    - Oil and gas production sites
    - Mining and quarrying sites
    - Power generation facilities, including fossil-fuel and nuclear-fuel facilities and associated fuel delivery and waste management infrastructure, geothermal, solar, wind energy and waste-to-energy production sites (hydroelectric facilities: see dams)
    - Waste-to-energy production sites
- Transportation and utility development
    - Airfields
    - Paved roads
    - Dirt & 4-wheel drive roads
    - Railroad infrastructure
    - Utility and service lines
    - Communication tower sites
- Water control development
    - Dams and impoundments
    - Diversion, conveyance, and drainage structures
    - Levees
    - Groundwater wells and pumping facilities

This list does not include other artificial modifications of river and stream channels, such as channel straightening and confinement between artificial banks. Such modifications mostly occur as consequences of or in association with other types of development, including water resources development and residential, commercial, industrial, or agricultural development of floodplains. Floodplain development sometimes also includes the construction of levees. As a result, analysis of the types of development listed above captures most areas where artificial channel modification has taken place. Chapter 8 further assesses the extent of such artificial channel modifications in the ecoregion, through a separate analysis.

Numerous geospatial datasets exist, covering the distribution of various types of development across the analysis extent for the Chihuahuan Desert REA. However, none of these, such as the National Land Cover Database (NLCD; Homer et al. 2015; https://www.mrlc.gov/nlcd11_leg.php), include all of the development types listed above. Energy and water development both have significant footprints in the U.S. portion of the ecoregion, for example, but are generally not fully addressed in the multi-purpose datasets. For this reason, the Technical Team assembled a dataset of development types for the present analysis extent that explicitly incorporated all needed types, using the most recent datasets available. The 2011 NLCD , the U.S. Census Bureau's Topologically Integrated Geographic Encoding and

Referencing (TIGER) database (2016) for Arizona, New Mexico & Texas, and the U.S. Energy Information Administration (USEIA; 2017), U.S. Energy Mapping System (https://www.eia.gov/maps/) provided the data for many development types. Table 5-1 lists the development types and data sources used to compile the map of development for the REA.

Table 5-1. Development types and data sources.

Development Category	**Data Source** (* - A 16-m buffer was added to these point data.)
Residential, commercial, industrial, other non-agricultural development	
Open space	2011 NLCD (30-m raster), Class: "Developed, Open Space" (21).
Low intensity	2011 NLCD (30-m raster), Class: "Developed, Low Intensity" (22).
Medium intensity	2011 NLCD (30-m raster), Class: "Developed, Medium Intensity" (23).
High intensity	2011 NLCD (30-m raster), Class: "Developed, High Intensity" (24).
Landfills	2016 TIGER/Line Area Landmark feature class (polygon) ("Landfill", MTFCC = "C3088"). Not present in the dataset for the analysis extent.
Military and other secured-area development	
Military facilities	2016 TIGER/Line Area Landmark feature class (polygon) ("Military Installation", MTFCC = "K2110"). Not present in the dataset for the analysis extent. However, known military facilities do appear in the NLCD database.
Border barriers and facilities	This feature type is not included in the 2016 TIGER/Line Landmark dataset but is assumed to be captured by the 2011 NLCD database.
Correctional facilities	2016 TIGER/Line Area Landmark feature class (polygon) ("Local Jail or Detention Center", MTFCC = "K1236"; "Federal Penitentiary, State Prison, or Prison Farm", MTFCC = "K1237"; "Other Correctional Institution", MTFCC = "K1238").
Agricultural development	
Annual and perennial non-timber crops	2011 NLCD (30-m raster), Classes: "Pasture/Hay" (81), "Cultivated Crops" (82).
Wood and pulp plantation	Not present in any dataset for the analysis extent.
Livestock farming and ranching	The 2011 NLCD includes buildings and other infrastructure associated with farming and ranching as residential, commercial, or industrial development. Otherwise, this type of land use does not register as a development type.
Energy production and mining development*	
Oil and gas production	Automated Fluid Minerals Support System (AFMSS) oil and gas well dataset (point*), provided by BLM-New Mexico (June 5, 2017).
Mining and quarrying	2016 USGS Mineral Resources Data System (MRDS) data (point*) for mineral resource occurrences in Arizona, New Mexico, and Texas.

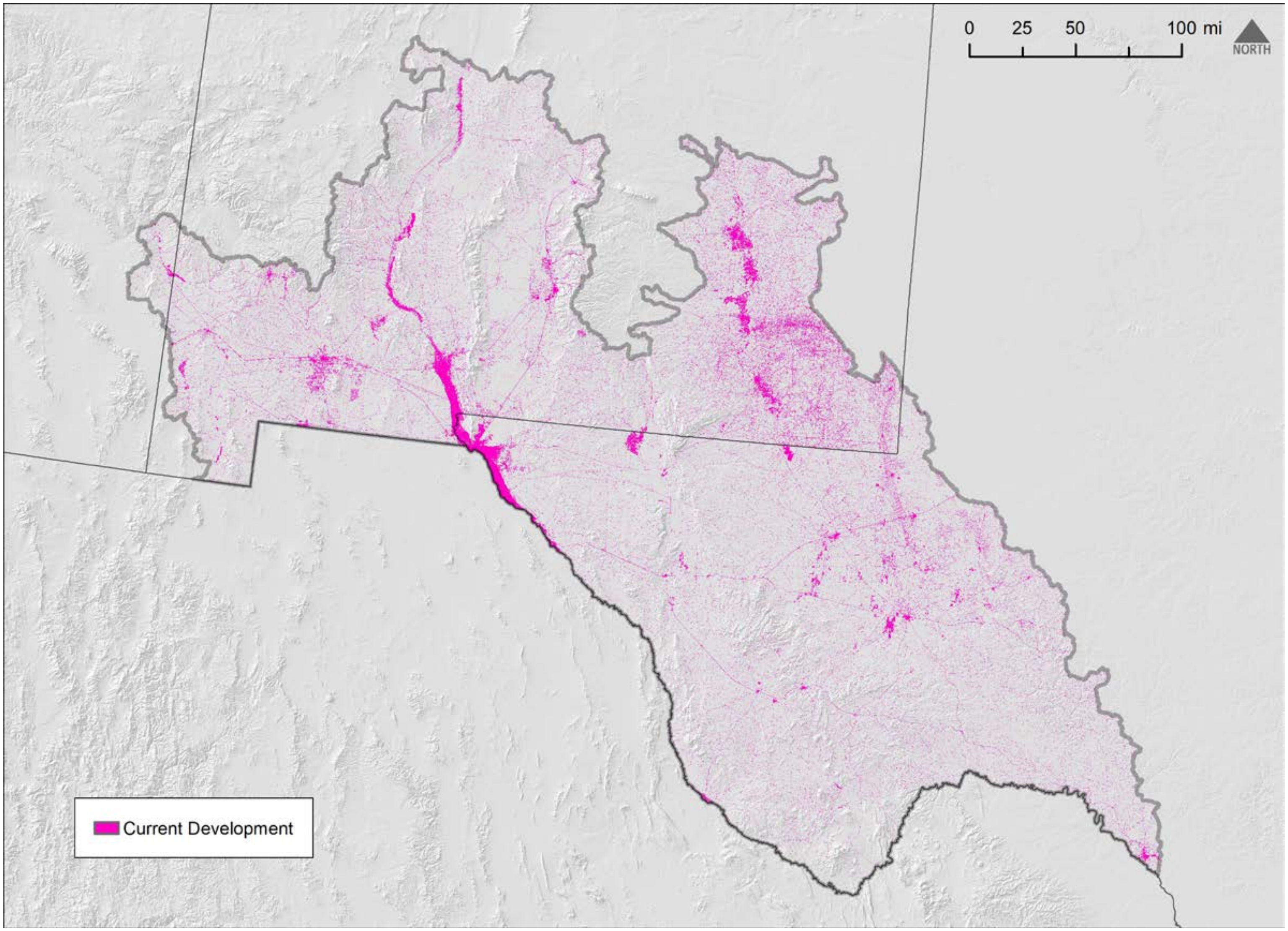
Development Category	**Data Source** (* - A 16-m buffer was added to these point data.)
Power generation facilities	U.S. Energy Information Administration (USEIA; 2017) (https://www.eia.gov/maps/layer_info-m.php). • Crude Oil Pipelines (2017) (line). • Crude Oil Rail Terminals (2014) (line). • HGL Pipelines (2017) (line). • Natural Gas Interstate and Intrastate Pipelines (2017) (line). • Natural Gas Market Hubs (2013) (point*). • Natural Gas Processing Plants (2015) (point*). • Petroleum Product Pipelines (2017) (line). • Petroleum Product Terminals (2016) (point*). • Petroleum Refineries (2017) (point*). • Power Plants. Energy sources include biomass, geothermal, hydroelectric, natural gas, other, petroleum, solar, and wind. (2017) (point*). • Industrial Wind Turbine Locations (2014) (point*).
Transportation and utility development	
Airfields	2016 U.S. Census Bureau TIGER/Line Area Landmark feature class (polygon) ("Airport or Airfield", MTFCC = "K2451") (polygon). Also captured as high-intensity development in NLCD.
All roads	2016 U.S. Census Bureau TIGER/Line All Roads feature classes (line). Ground Transportation Linear Features (GTLF) dataset (line), provided by BLM-New Mexico (June 5, 2017).
Railroad infrastructure	2016 U.S. Census Bureau TIGER/Line National Rails feature class (line).
Utility and service lines	Rights-of-Way (ROW) dataset (line), provided by BLM-New Mexico (June 5, 2017).
Communication towers	2017 Federal Communications Commission's Antenna Structure Registration (ASR) database (point*).
Water control development	
Dams and impoundments	2017 U.S. Geological Survey-National Geospatial Program, National Hydrography Dataset (NHD; NHDWaterbody) (polygon), including waterbodies classified as FType = "Reservoir" (436) or waterbodies with"reservoir" or "tank" in the GNIS_Name.
Groundwater wells and pumping facilities in NM	2017 New Mexico Office of the State Engineer (OSE) Wells dataset (point).
Groundwater wells and pumping facilities in TX	2017 Texas Water Development Board, Groundwater Database Reports, Well Location dataset (point).
Groundwater wells and pumping facilities in AZ	2017 Arizona Department of Water Resources GIS Data - Groundwater Site Inventory dataset (point).

5.3 Results

Figure 5-1 shows the combined distribution of all types of development identified in Table 5-1 for the REA analysis extent. Figure 5-1 represents a 30-m raster and generally does not attempt to represent effects of development features that extend beyond each immediate, physical feature itself. For example, linear features, for which the original data provided only the centerline, occupy only the individual 30-m pixels that intersect the centerline, and most point features are represented as single 30-m pixels. However, the compilation of Figure 5-1 imposed a 16-m buffer around all point data for energy production and mining development features and communication towers, to more accurately represent the physical footprint of such features. As a result, these point locations are represented ideally by four 30-m pixels.

The use of a 16-m buffer for point data nevertheless still potentially underrepresents the sizes of features such as oil or gas drilling sites including among the point data, which average approximately 40 and 160 acres (16 and 65 ha) in the region, respectively (Engler et al. 2012). However, in the absence of measurements of actual feature sizes in the point data, the Technical Team chose a conservative approach to avoid over-representing feature sizes. Methods exist for modeling the severity of impacts of development on surrounding ecological conditions, and the rate of diminution of these impacts with distance from the immediate source (Theobald 2013, Crist et al. 2014), but the present REA did not include such modeling.

Figure 5-1. Current distribution of development.



The most prominent feature in Figure 5-1 is the dense area of residential, commercial, and industrial development in the Las Cruces-El Paso-Ciudad Juarez area, which itself lies within a roughly 75 mile long continuous belt of intensive agriculture along the Rio Grande valley. Other prominent features along the Rio Grande include the inundated areas of Caballo and Elephant Butte Reservoirs and a belt of farming and residential, commercial, and industrial development roughly centered on the city of Socorro. Figure 5-1 also prominently shows the discontinuous belt of dense irrigation farming, residential, commercial, and industrial development, and reservoirs along the Pecos River valley from the vicinity of Roswell, New Mexico, southward to Red Bluff Reservoir, just south of the New Mexico-Texas border.

Patches of less dense residential, commercial, and industrial development mark all the other cities and towns within the analysis extent, including substantial clusters around Deming and Alamogordo in New Mexico and a large cluster in the Pecos River valley in Texas that includes the communities of Kermit, Monahans, Pecos, and Fort Stockton. These clusters include some irrigation farming, as well. Additional areas of intensive irrigation farming include the mainstem Gila River straddling the Arizona-New Mexico border, and the lands surrounding Dell City, Texas. Prominent transportation corridors include Interstate Highways 10, 20, and 25 and other U.S. highways in all three states.

At the opposite end of the scale of visibility, Figure 5-1 exhibits a widespread distribution of small points of development. This peppering of small points of development is particularly dense within and east of the Pecos River valley in both New Mexico and Texas. Many of these latter small points mark oil and gas wells and the network of roads and service features associated with oil and gas production. These points mark the western portion of the highly productive Delaware Basin component of the Permian Basin oil and gas fields. A few oil and gas wells are also present in Otero County, New Mexico. The small points of development across the analysis extent also include numerous small roads and dirt tracks, and numerous groundwater wells and watering tanks.

The few large areas of very low development shown in Figure 5-1 include the higher elevations of all mountain ranges; parts of the Big Bend region in Texas; lands south of Interstate Highway 10 in New Mexico between El Paso, Texas, and Deming, New Mexico; lands within the White Sands Missile Range and Fort Bliss Military Reservation within and south of the Tularosa and Jornada del Muerto valleys in New Mexico; and the western margins of the Rio Grande valley in New Mexico.

5.4 Forecasted Development

5.4.1 ICLUS Forecasts of Development

The U.S. Environmental Protection Agency, Integrated Climate and Land Use Scenarios (ICLUS) project, Version 2 (USEPA 2009, 2016) forecasts development across the continental U.S. The project forecasts population, residential development, and impervious surface cover changes by decade to the year 2100, relative to conditions in 2010. The forecasts are spatially explicit models that take into account the existing distribution of population within the U.S., national fertility and immigration, patterns of migration of people between counties, and patterns of land use including their spatial relationships to transportation systems. Population distributions within and among counties are assessed by metro- and micro-politan statistical areas defined by the U.S. Census Bureau. Rates of migration between counties are estimated based in part on statistical patterns in the ways in which differences in climate between any two counties – termed “climate amenities” – affect migration between the two. ICLUS v2 addresses two climate variables as climate amenities: average monthly humidity-adjusted temperature and average seasonal precipitation for both summer and winter (USEPA 2009, 2016).

The ICLUS methodology assesses nineteen (19) categories of land use, with a spatial resolution of 90 m, delineated in the U.S. National Land Use Dataset (Theobald 2014). Nine of these categories represent “developed” land uses, while nine others represent land use/land cover categories that can be converted into developed land uses. One category covers open water. Table 5-2 lists the ICLUS land use categories.

Table 5-2. ICLUS land use categories.

Land Use Group	Land Use Code	Land Use Class Name
Water	0	Natural water
	1	Reservoirs, canals
	2	Wetlands
Protected	3	Recreation, conservation
Working/production	4	Timber
	5	Grazing
	6	Pasture
	7	Cropland
	8	Mining, barren land
Developed	9	Parks, golf courses
	10	Exurban, low density
	11	Exurban, high density
	12	Suburban
	13	Urban, low density
	14	Urban, high density
	15	Commercial
	16	Industrial
	17	Institutional
	18	Transportation

ICLUS V2 forecasts take into account climate change for its effects on climate amenities and on immigration. ICLUS V2 takes climate change into account by examining the results from multiple Global Circulation Models (GCMs) under a range of Representative Concentration Pathways (RCPs). The most current ICLUS V2 datasets are for two GCMs: the HadGEM2-ES (UK National Meteorological Service, Hadley Center, Global Environment Model version 2, Earth System model) and the GISS-E2-R (National Aeronautics and Space Administration, Goddard Institute for Space Studies, Atmospheric Model E combined with the Russell Oceanic Model). The ICLUS program selected these two GCMs because they are considered “high sensitivity” versus “low sensitivity” climate models, respectively. The ICLUS V2 datasets available incorporate the climate forecasts from the HadGEM2-ES and GISS-E2-R climate models run under the RCP 4.5 and RCP 8.5 scenarios. RCP 4.5 assumes that efforts to curb annual global emissions of greenhouse gases are effective, such that emissions peak around 2040 and then decline. RCP 8.5 assumes that emissions continue to rise throughout the 21st century. These four combinations of GCMs and RCPs bracket the range of the entire suite of GCMs and RCPs examined by the ICLUS V2 effort.

The ICLUS V2 forecasts also take into account possible future variation in demographics, human development, economy and lifestyle, policies and institutions, technology, and the environment. The forecasts accomplish this by running the models under different plausible scenarios, termed "Shared Socioeconomic Pathways" (SSPs), for how these variables may play out (Samir and Lutz 2014, Van Vuuren and Carter 2014). The ICLUS V2 forecasts available specifically incorporate SSP2 and SSP5. SSP2 is known as the "middle of the road" SSP scenario. It assumes that recent global trends will continue with respect to economic development, reductions in resource and energy intensity, and reductions in fossil fuel dependency combined with an intermediate forecast for global population growth. SSP5 is a more extreme SSP scenario. Compared to SSP2, SSP5 assumes more rapid economic and technological growth, reactive rather than proactive environmental policies, less direct governance of global markets, and higher rates of migration among countries, but similar rates of population growth. As with the two GCMs and two RCPs available from the ICLUS V2 efforts, these two SSPs bracket a range of possibilities.

In combination, the two GCMs, two RCPs, and two SSPs represent a range of possible futures. Specifically, the ICLUS V2 datasets available for the present REA consist of the following:

1. The HadGEM2-ES climate model run under the RCP 4.5 combined with the SSP2. This combination represents a scenario with reduced greenhouse gas emissions by 2040, a global climate system that responds more rapidly to changes in emissions, and middle-of-the-road changes in the global economy and global population growth.
2. The HadGEM2-ES climate model run under the RCP 8.5 combined with the SSP5. This combination represents a scenario with no reductions in greenhouse gas emissions, a global climate system that responds more rapidly to changes in emissions, and more rapid global economic development with little regulation but a similar rate of global population growth.
3. The GISS-E2-R climate model run under the RCP 4.5 scenario combined with SSP2. This combination represents a scenario with reduced greenhouse gas emissions by 2040, a global climate system that responds less rapidly to changes in emissions, and middle-of-the-road changes in the global economy and global population growth.
4. The GISS-E2-R climate model run under the RCP 8.5 combined with the SSP5. This combination represents a scenario with no reductions in greenhouse gas emissions, a global climate system that responds less rapidly to changes in emissions, and more rapid global economic development with little regulation but a similar rate of global population growth.

The present analysis focuses on the ICLUS forecasts for 2050 and 2070, relative to 2010. These time increments correspond to the forecast periods used in the assessment of the potential impacts of climate change, discussed in Chapter 4, above.

Figure 5-2. ICLUS v2.1 development forecasts to 2050 and 2070, HadGEM2-ES x RCP 4.5 x SSP2.

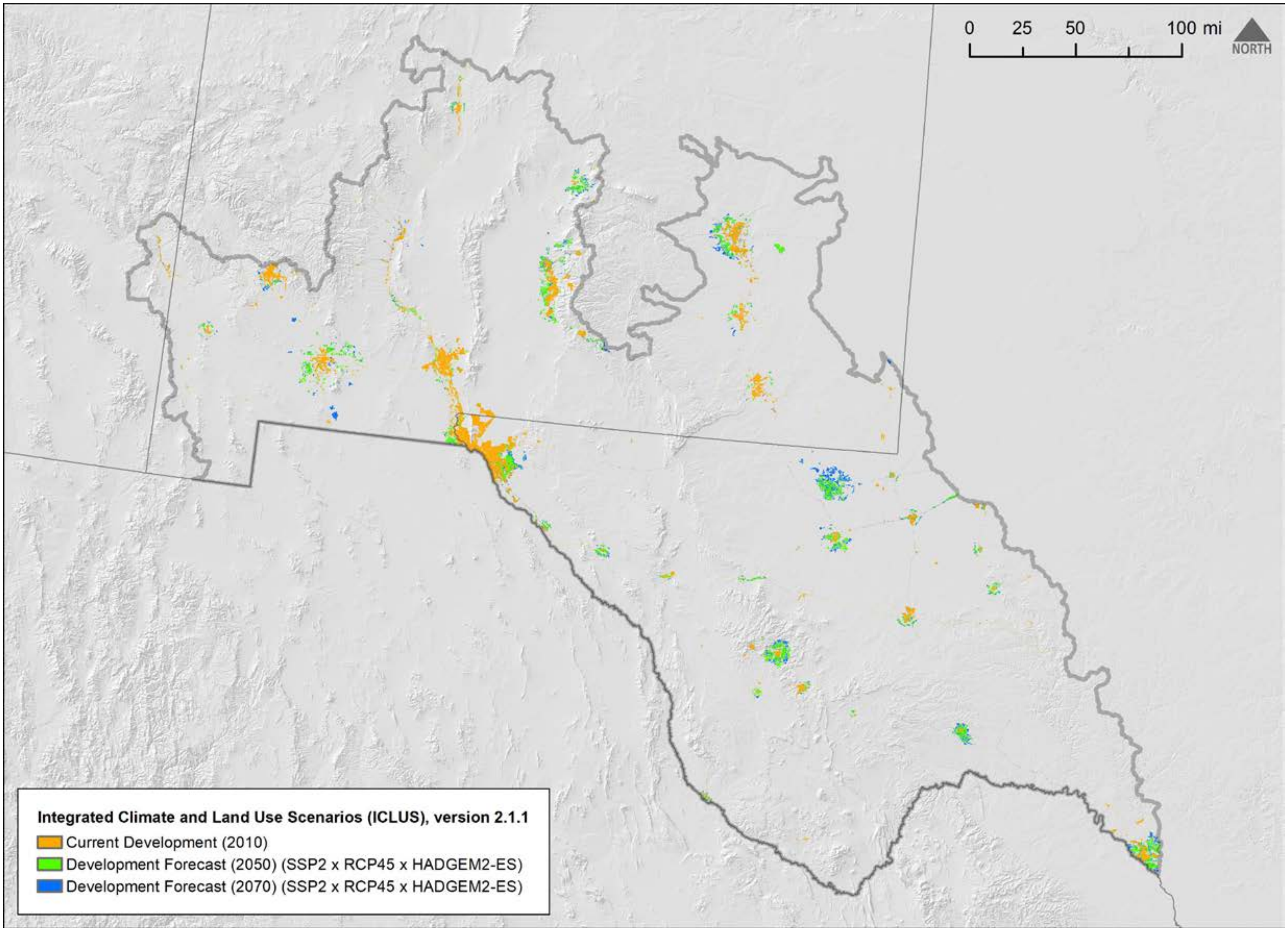


Figure 5-3. ICLUS v2.1 development forecasts to 2050 and 2070, HadGEM2-ES x RCP 8.5 x SSP5.

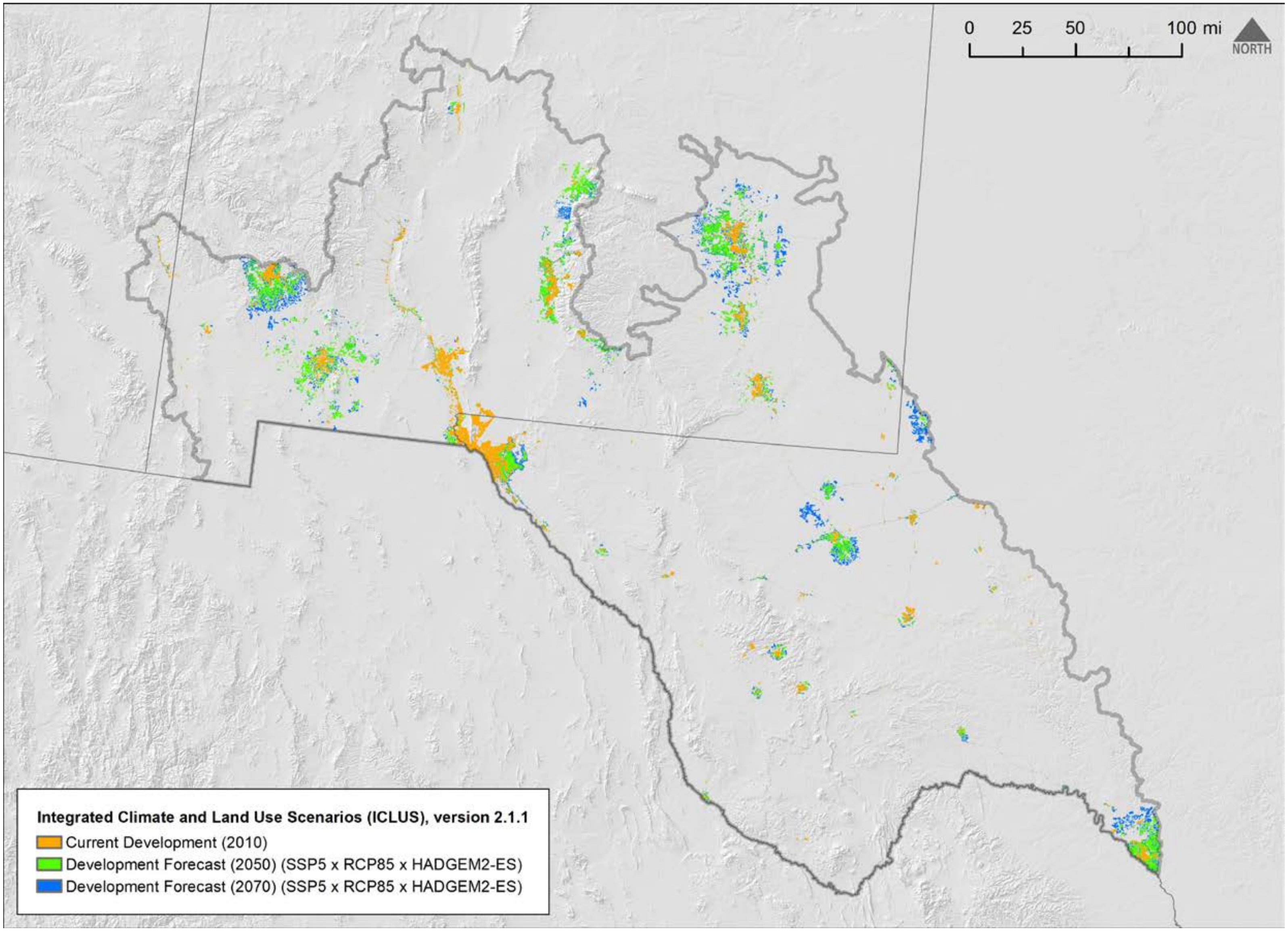


Figure 5-4. ICLUS v2.1 development forecasts to 2050 and 2070, GISS-E2-R x RCP4.5 x SSP2.

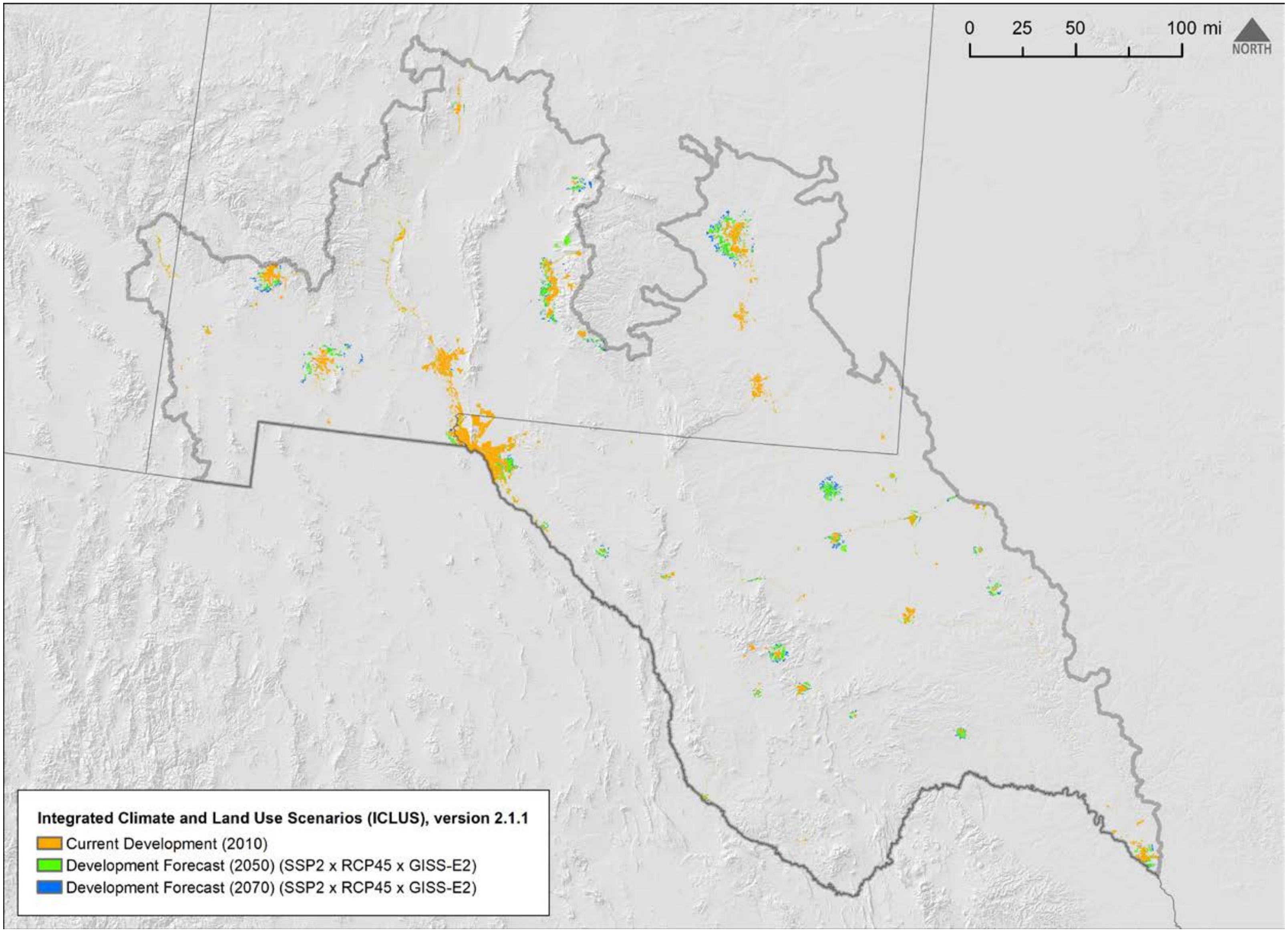
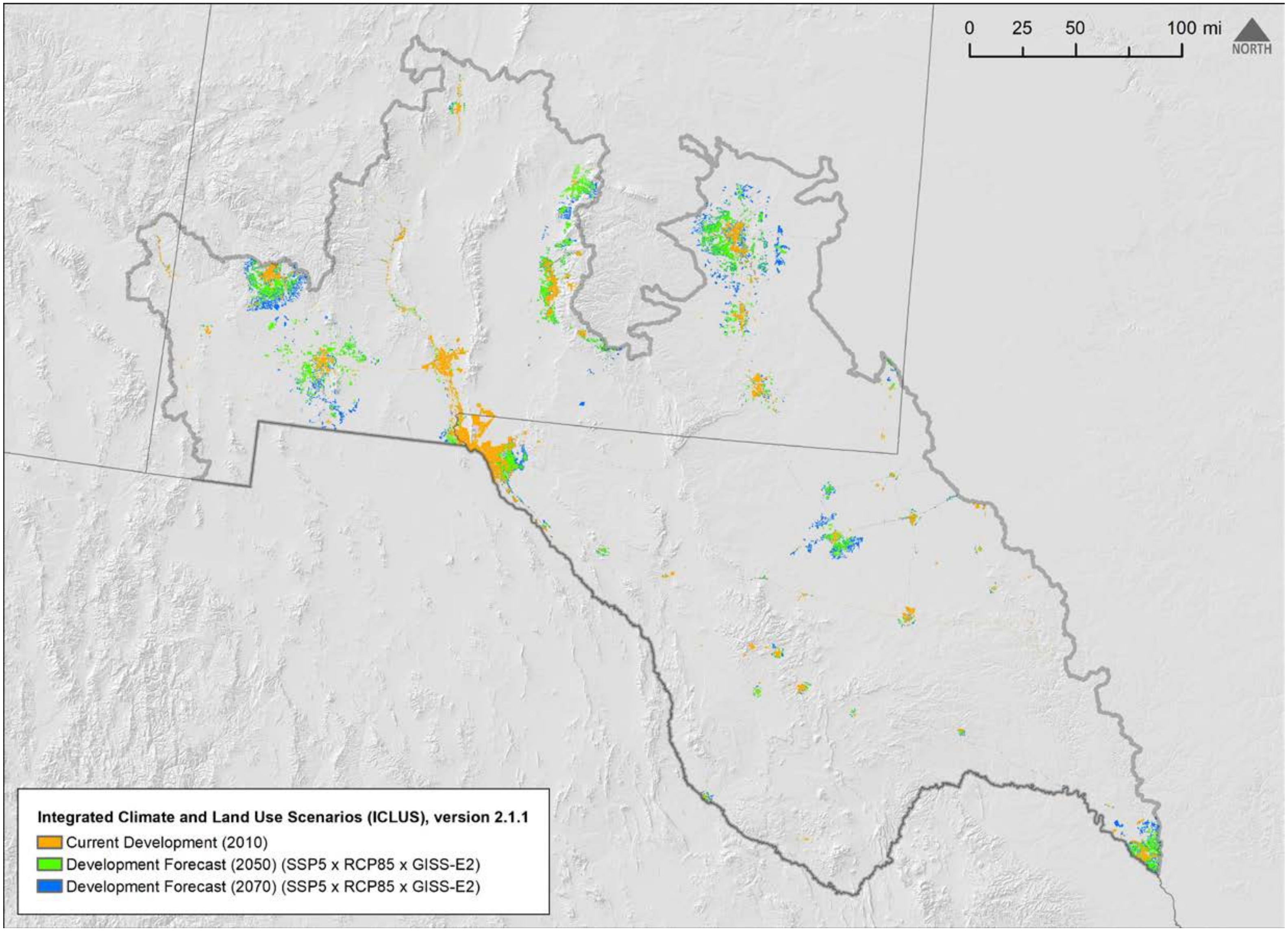


Figure 5-5. ICLUS v2.1 development forecasts to 2050 and 2070, GISS-E2-R x RCP 8.5 x SSP5.



Further, the present analysis focuses on the ICLUS forecasts for all developed land use categories listed in Table 5-2 except "Institutional" land use (code=17). This category includes military reservations, and represents all lands within military reservations as "developed." The U.S. portion of the Chihuahuan Desert ecoregion includes several large military reservations, including the White Sands Missile Range and Fort Bliss Military Reservation. Most lands within these reservations are undeveloped and used for military exercises. The ICLUS datasets include all buildings, roads, and other infrastructure within these reservations under their appropriate land use categories. Excluding "Institutional" land use from the present analysis therefore results in datasets that correctly represent all forms of development within the military reservations that could affect ecological conditions, other than the effects of military exercises *per se*.

Figure 5-2 – Figure 5-5 show the ICLUS V2 forecasts for development within the REA analysis extent for 2050 and 2070, compared to 2010. These four figures are based on, respectively, (1) the HadGEM2-ES climate model run under RCP 4.5 combined with the SSP2, (2) the HadGEM2-ES climate model run under RCP 8.5 combined with the SSP5, (3) the GISS-E2-R climate model run under RCP 4.5 combined with SSP2, and (4) the GISS-E2-R climate model run under RCP 8.5 combined with SSP5.

Figure 5-3 (HadGEM2-ES x RCP 8.5 x SSP5) shows the greatest extent of expansion of development by 2050 and by 2070. Expansion of development under this scenario combination is forecasted to results in substantial sprawl around Silver City, Deming, Alamogorda, Carrizozo, and Roswell, New Mexico, and around El Paso, Pecos, and Del Rio, Texas. Figure 5-3 also shows areas of development by 2050 and by 2070 located in areas completely beyond the immediate radii of existing (2010) areas of development. Figure 5-5 (GISS-E2-R x RCP 8.5 x SSP5) shows a similar pattern of significant expansion, even with the less sensitive GCM. This similarity suggests that the results under these two scenarios are determined primarily by the combination of RCP 8.5 and SSP5.

Figure 5-2 (HadGEM2-ES x RCP 4.5 x SSP2) and Figure 5-4 (GISS-E2-R x RCP 4.5 x SSP2) both show less expansion around areas of existing (2010) development, compared with the RCP 8.5 x SSP5 combinations. However, they differ from each other in other respects. For example, Figure 5-4 shows a much greater spatial extent of development in an area north of Pecos, Texas, in the vicinity of the present small town of Mentone, Texas; and also shows development along the north-south corridor between Alamogorda and Carrizozo, New Mexico, similar to that shown in Figure 5-3.

In sum, all four GCM x RCP x SSP combinations forecast substantial expansions of developed land between 2010 and 2050 within the analysis extent, with modest further expansions between 2050 and 2070. Overall, the ICLUS V2 forecasts predict increasing development around existing urban areas, with the potential for substantial sprawl in some areas and/or development of presently small towns located at the intersections of major transportation routes.

5.4.2 Oil and Gas Production Forecasts

The ICLUS V2 forecasts do not address all forms of potential development for the region. Specifically, as noted above, the ICLUS V2 forecasts address only the several types of "developed" land use listed in

Table 5-2, with the exception of "Institutional" land use (code=17). Further, the "Industrial" land use category in Table 5-2 (code=16) does not include oil and gas production, which fall under the general land use category of "Mining" (code=8). However, as discussed earlier in this chapter and in Chapters 2 and 3, above, oil and gas production are substantial components of the economy of the U.S. portion of the ecoregion in New Mexico and Texas, with a highly visible land-use footprint that includes drilling sites and their access roads, pipelines, and waste disposal and pumping facilities. The REA therefore sought information on forecasts of oil and gas production for the region, for their bearing on the possible future footprint of these activities within the analysis extent. The information acquired is not sufficient to support a quantitative analysis to complement the ICLUS forecasts, but is sufficient to document a broad scenario and its geographic implications.

As noted in Chapters 2 and 3, above, the land-use footprint of oil and gas production in the U.S. portion of the ecoregion has increased throughout recent decades (Ruhlman et al. 2012), driven in part by the increased and enhanced use of horizontal drilling and hydraulic fracturing (*aka* "fracking") in the most recent two decades (Engler et al. 2012, Engler and Cather 2014, USEIA 2014, 2015, 2016, Texas General Land Office 2015, NMEMNRD 2016). The relative paces of expansion and evolution of oil versus gas production have varied, driven both by improvements in technology and changes in oil versus gas supplies and prices (Engler et al. 2012). However, both oil and natural gas remain in high demand, reserves remain large, and additional reserves continue to be discovered or brought into production using new technologies. As a result, the Permian Basin, straddling the New Mexico-Texas border, is expected to remain one of the most intensively developed areas of oil and gas production in the U.S., with associated land development and demands on fresh water for fracking (Figure 5-6).

The U.S. Energy Information Administration (USEIA 2017) identifies four geologic stratigraphic units or "plays" as the likely foci of expanding oil and gas production within the Permian Basin, within the analysis extent: the Abo-Yeso, Bone Spring, Glorieta-Yeso, and Delaware plays. Figure 5-6 shows the locations of these four plays and indicates their relative depths within the basin. Engler and others (Engler et al. 2012, Engler and Cather 2014) forecast that these four plays have high to very high potentials for continuing development through the drilling of additional wells combined with the use of CO_2-enhanced oil recovery and other advanced extractive technologies. (Their forecast for the Abo-Yeso play specifically focuses on the Leonard group within this larger play). These authors further forecast that the rate of drilling activity in the Pecos BLM District alone (for map of BLM districts, see Chapter 2) for the period 2010-2020 will continue at the 2010 rate of approximately 800 new well completions per year. Their forecast indicates that this drilling activity most likely will take place within the geographic limits of the present distributions of wells in each of the four plays, a process termed "in-filling." Engler et al. (2012, see also Engler and Cather 2014) also note that waste handling, including for produced water, will require increasing space as well, in pace with the increased drilling and production.

Engler et al. (2012, see also Engler and Cather 2014) also identify several plays with moderate potentials for new or continuing development in southeastern New Mexico, including the Artesia sandstone group, San Andres Central Basin Platform, and Wolfcamp plays. The boundaries of these stratigraphic units all fall within the boundaries of the four larger plays noted above.

Figure 5-6. Oil and gas wells, and shale gas and oil plays.

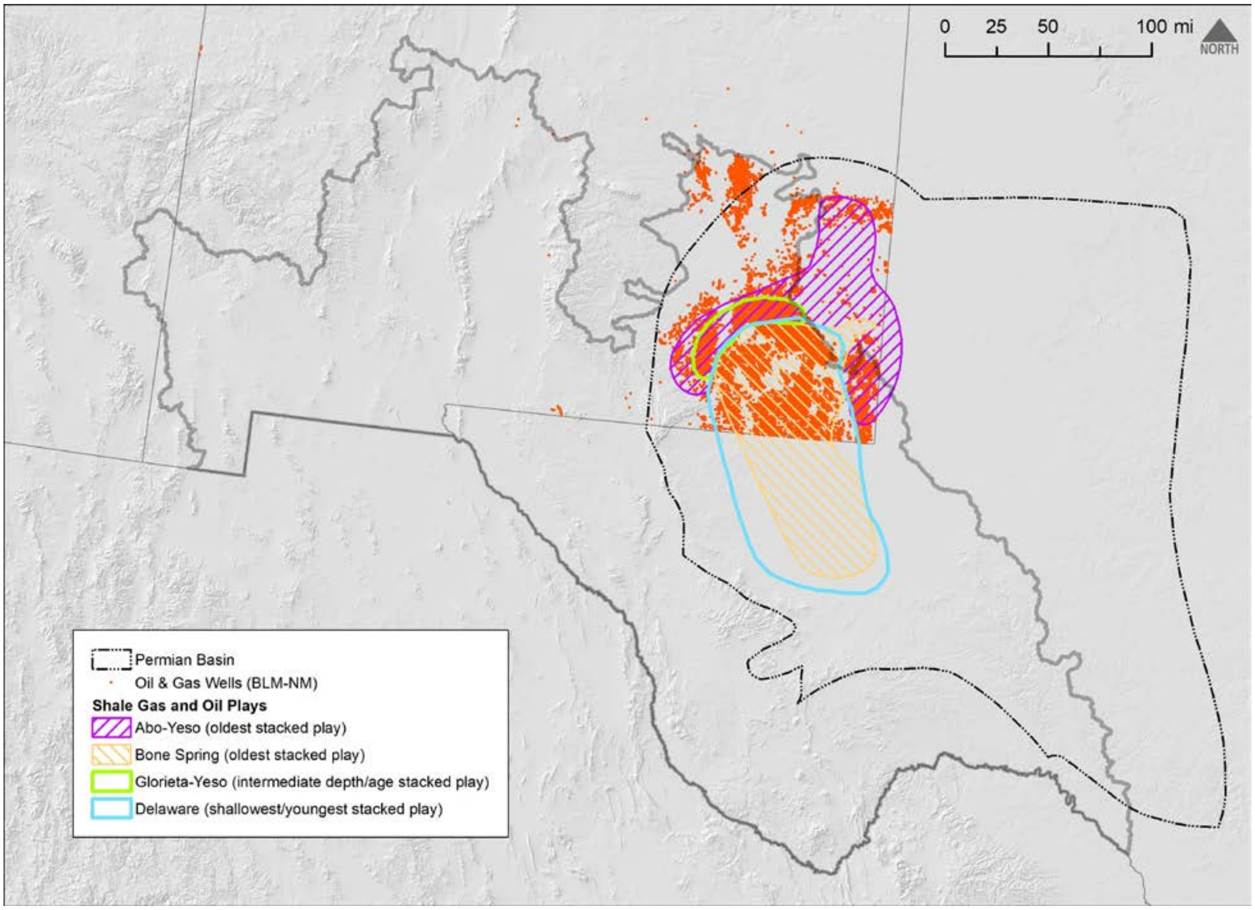


Figure 5-6 also shows the locations of all oil and gas well permits issued by the BLM in New Mexico within the analysis extent. These well locations are included in the data used to construct Figure 5-1, above (see Table 5-1). The BLM does not maintain comparable data for Texas. Figure 5-1 uses alternative data on oil and gas wells in Texas, not shown in Figure 5-6 because they did not figure in the forecasts developed by Engler et al. (2012, see also Engler and Cather 2014).

The BLM well data for New Mexico, shown in Figure 5-6, indicate the following: First, significant numbers of wells are located outside the four oil and gas plays identified in the U.S. Energy Information Administration data (USEIA 2017), including a significant number outside the boundaries of the Permian Basin itself, particularly north of Roswell, New Mexico. Second, in-filling within the boundaries of the Bone Spring, Glorieta-Yeso, and Delaware plays, and across the western extension of the Abo-Yeso play, largely will take place in areas with already high densities of wells. Third, in-filling across the eastern portion of the Abo-Yeso play and a small eastern extension of the Bone Spring play will take place in areas with currently low densities of wells. These latter two areas lie beyond the boundaries of the present analysis extent, but development in these two areas presumably could affect conditions within the analysis extent related to the overall concentration of oil and gas production and waste management across the region.

5.4.3 Water Infrastructure Forecasts

The ICLUS V2 forecasts also do not address development of water management infrastructure (see Table 5-1). No geospatial forecasts were located for water infrastructure development within the analysis extent. However, as noted in Chapter 2, above, efforts are ongoing to permit construction of a large diversion facility somewhere along the mainstem immediately upstream from the present analysis extent, under the terms of the New Mexico-Arizona Water Settlement Act of 2004 (New Mexico Interstate Stream Commission 2017). The locations of this facility and its associated distribution system have not yet been determined.

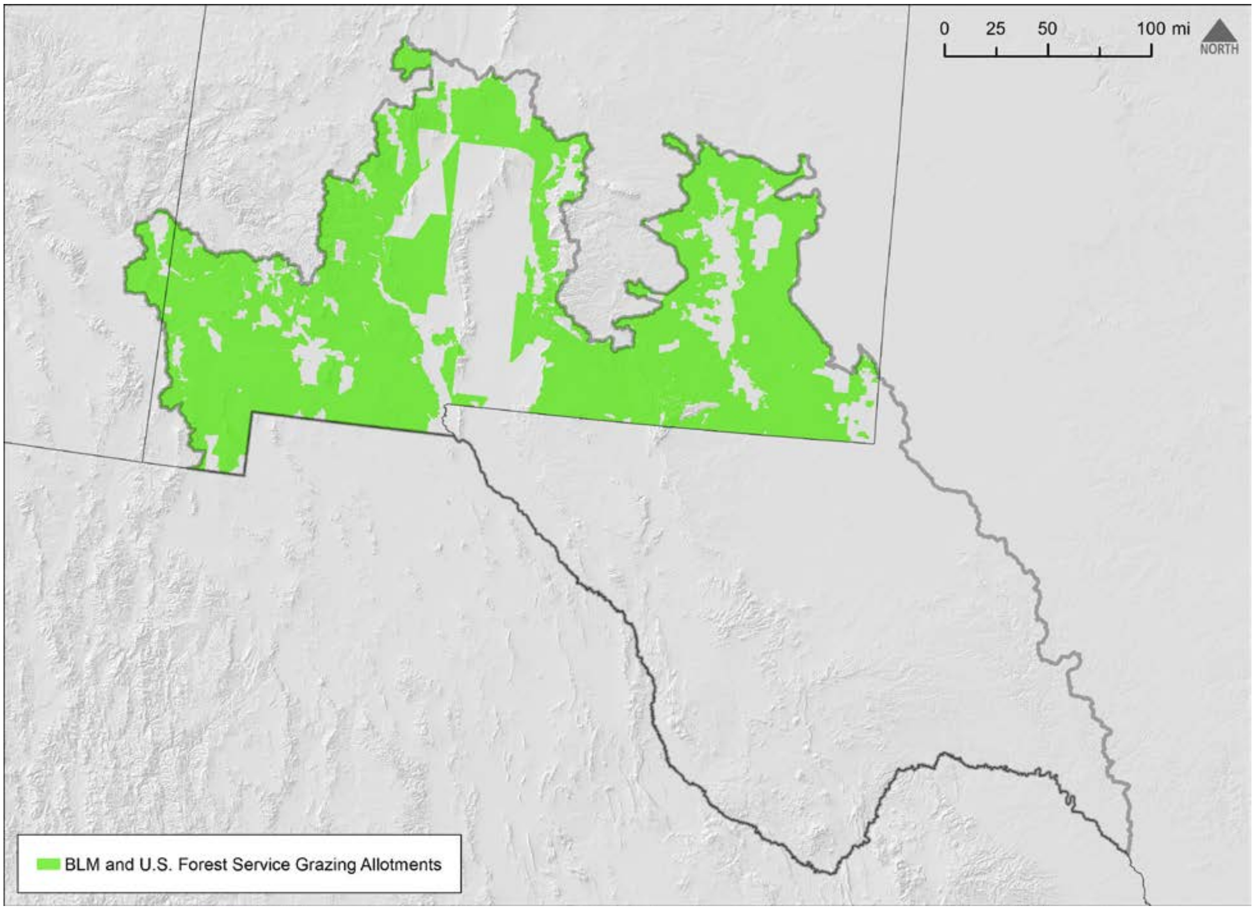
5.5 Grazing

Livestock ranching in the U.S. portion of the ecoregion focuses on cattle ranching, with some sheep and goat ranching as well (NASS 2011, NMDGF 2016). Most grazing in Arizona and New Mexico takes place on public lands administered by the U.S. Forest Service and BLM, which control the spatial distribution and intensity of grazing through permits and leases for grazing on specifically designated lands, termed "allotments." The present analysis uses data on the locations and boundaries of grazing allotments in Arizona and New Mexico managed by the U.S. Forest Service and BLM within the analysis extent for the REA. Figure 5-7 shows the distribution of U.S. Forest Service and BLM grazing allotments across the analysis extent. Most lands in Texas within the analysis extent are privately owned. Although these lands also are grazed, no systematic data are available on the spatial distribution of the grazing.

U.S. Forest Service and BLM grazing allotments cover almost the entire analysis extent across Arizona and New Mexico (Figure 5-7). Notable exceptions include military reservations, publicly protected areas, developed lands, and reservoirs (compare to Figure 5-1, above), and private lands (see Chapter 2, above; NMDGF 2016). Grazing allotments generally do not exclude other compatible land uses, such as oil and gas production or wind and solar electrical generation.

Data on actual grazing intensity are not systematically available for the allotments shown in Figure 5-7. As a result, the REA could not directly assess the distribution of excessive grazing. Chapter 7, below, discusses the availability of estimates of rangeland condition in general. However, these estimates take into account the combined impacts of all stressors, including altered wildfire regimes, from which it is not possible to separate out information on the impacts of grazing alone.

Figure 5-7. Distribution of U.S. Forest Service and BLM grazing allotments.



6 Invasive Species, Wildfire, and Landscape Restoration

6.1 Introduction

The present chapter presents the assessments of three Change Agents (CAs); invasive species, uncharacteristic wildfire, and landscape restoration. Chapter 2 includes a summary of the ecological impacts of invasive species across the U.S. portion of the ecoregion, and the conceptual ecological models in the Pre-Assessment Report provide extensive discussions of the impacts to individual Conservation Elements (CEs). Chapter 2 and the conceptual ecological models for the three terrestrial ecological system CEs in the Pre-Assessment Report also discuss the importance of wildfire disturbance as a natural process across the U.S. portion of the ecoregion. As noted in Chapter 3, wildfire disturbance *per se* does not constitute an ecological stressor. Rather, alterations to a landscape that cause wildfire frequency or intensity to depart significantly from their natural ranges of variation can interfere with natural soil and vegetation processes. Consequently, the Chihuahuan Desert REA includes *uncharacteristic* wildfire as a CA. Finally, landscape restoration is not a stressor but an intentional counter-measure against some stressors. However, landscape restoration can bring about significant changes in an ecoregion – changes that are of interest to the BLM and other land management agencies in the U.S. portion of the present ecoregion. For this reason, the present REA includes landscape restoration as a CA.

Seven (7) Management Questions (MQs) concern or include these three CAs, as follows:

MQ C: What is the current geographic distribution of the impacts of each CA, both in general and in relation to each Conservation Element (CE)?

MQ 1: Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?

MQ 3: Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?

MQ 4: What areas of potential black-tailed prairie dog habitat would support restoration?

MQ 6: Where will urban and industrial growth impact intact grasslands or impede their recovery?

MQ 12: Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?

MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Section 6.2 of the present chapter addresses MQ C specifically with respect to invasive species, assessing their current distributions across the analysis extent for the REA. Similarly, Section 6.3 addresses MQ C specifically with respect to wildfire. Chapter 2 also includes a summary of the historic importance of wildfire in the ecological dynamics of the U.S. portion of the ecoregion, as noted there and throughout the Pre-Assessment Report (Unnasch et al. 2017). However, as described in Chapter 3, wildfire per se does not constitute an ecological stressor. Rather, changes in wildfire frequency and intensity, brought about by land-use practices and climate change, can alter natural soil and vegetation processes.

Consequently, the Chihuahuan Desert REA includes uncharacteristic wildfire as a CA. Finally, Section 6.4 addresses MQ C specifically with respect to landscape restoration. Section 6.4 also addresses MQ 1, which overlaps with MQ C and concerns the status (e.g., success rate) of landscape restoration efforts in the ecoregion. Unfortunately, the available geospatial datasets do not provide systematic information on the effectiveness of restoration efforts.

Other chapters in the present report address MQs 3, 4, 6, 12, and 13. Chapter 7 addresses MQ 6, concerning the potential impacts of development on grasslands. Chapter 7 also presents the full assessment of the current geographic distribution of potential impacts of gypsum in the soil and water both in general and in relation to CAs including invasive species and uncharacteristic wildfire, both subjects of MQ 13. Chapter 8 addresses MQ 3, concerning areas where uncharacteristic wildfire potentially could increase sedimentation to aquatic-wetland ecological systems, and MQ 12, concerning the distribution and implications of tamarisk beetle activity. Finally, Chapter 9 addresses MQ 4, concerning areas of potential black-tailed prairie dog habitat that might support restoration.

6.2 Invasive Species

The conceptual ecological models for the three terrestrial ecological system CEs, Chapters 5-7 in the Pre-Assessment Report for the present REA (Unnasch et al. 2017), identify specific invasive plants that have significant ecological effects in the Chihuahuan Desert ecoregion. Table 6-1 lists these species or groups of closely related species, along with three species subsequently specifically identified by the AMT as management concerns, African rue (*Peganum harmala*), Malta starthistle (*Centaurea melitensis*), and yellow starthistle (*Centaurea solstitialis*). The conceptual ecological models for the five aquatic-wetland ecological system CEs, Chapters 8-11 in the Pre-Assessment Report for the present REA (Unnasch et al. 2017), similarly identify specific invasive plants and animals that have significant ecological effects in the Chihuahuan Desert ecoregion. Table 6-1 also lists these species or groups of closely related species. Table 6-1 lists tamarisk (aka salt cedar) (*Tamarix* spp.) twice, as an invasive species in terrestrial *and* aquatic-wetland CEs. The lists for the terrestrial and aquatic-wetland CEs in Table 6-1 are not comprehensive. Rather, they focus on species that the literature or the AMT identify as ecologically particularly problematic, because of the ways in which they interact with native species or because they significantly alter natural ecological processes such as, for example, wildfire, soil stability, hydrology, or water chemistry.

Table 6-1 lists five species for which the REA did not locate systematic distribution data. The data sources used for mapping invasive terrestrial plants (see below) did not record any occurrences of fineleaf fumitory or prickly Russian thistle within the analysis extent for the REA. Similarly, the data sources used for mapping invasive aquatic-wetland plants (see below) did not record any observations of the giant reed (*Arundo donax*) within the analysis extent for the REA, although it does occur further downstream along the Rio Grande. Phragmites is common along streams and in wetlands in the ecoregion, but published records do not indicate whether these stands consist of native, non-native, or hybrid plants – a common difficulty throughout North America (Saltonstall 2002). Finally, no systematic geospatial dataset was located for the distribution of the golden alga (*Prymnesium parvum*).

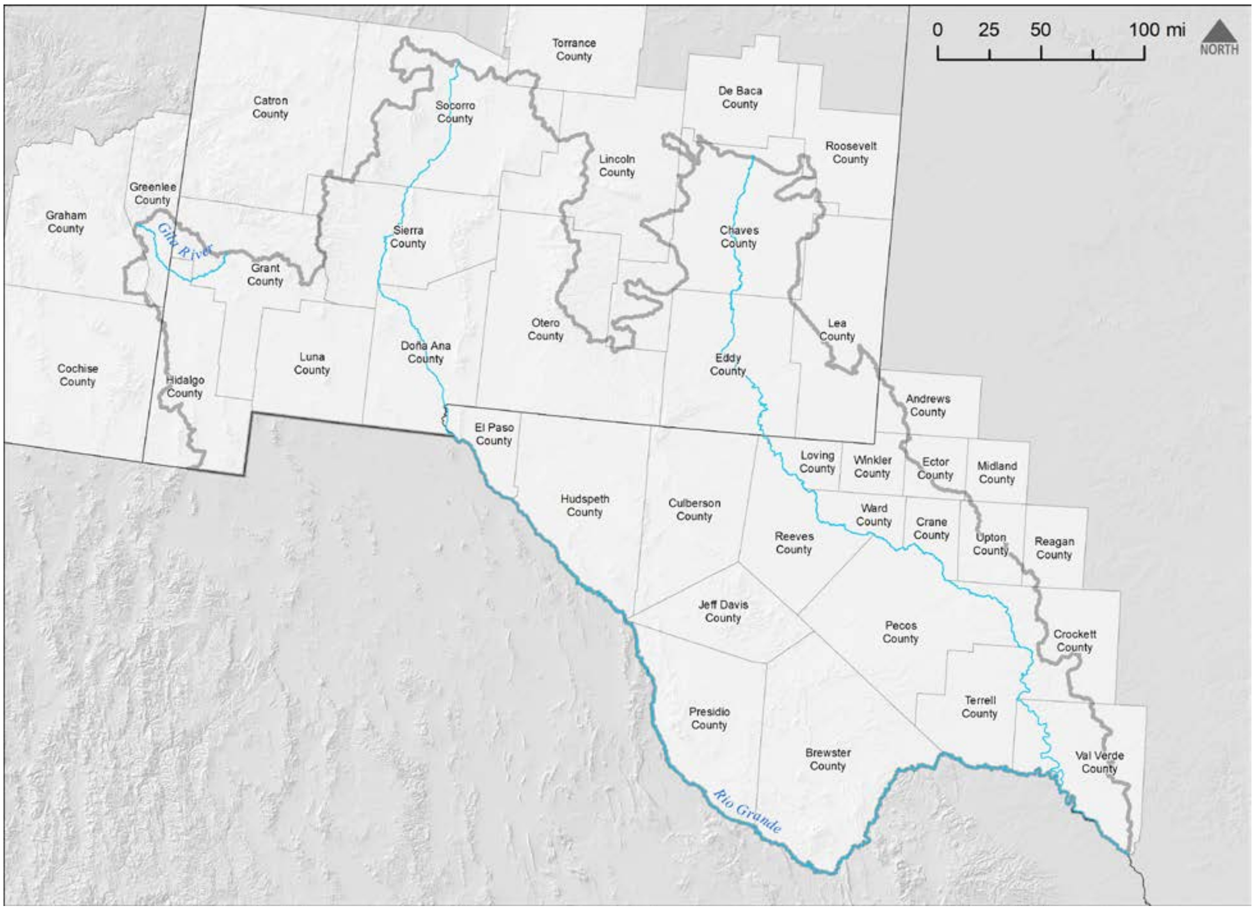
Table 6-1 also does not include the numerous non-native fishes introduced into the ecoregion for sport or as bait or forage for sport fishes. REAs conventionally do not include sport fish in their analyses. However, Table 6-1 does include flathead catfish, a species native to the rivers east of the Continental Divide that today also occurs in the Gila River basin where it is invasive and ecologically problematic. Other fish species transplanted from east of the Continental Divide into the Gila River, where they are considered problematic, include western mosquitofish, channel catfish, black bullhead, fathead minnow, and largemouth bass (Gori et al. 2014). The present analysis focuses on flathead catfish to represent the scope of the east-to-west invasion.

Table 6-1. Invasive plants of regional ecological concern.

Species or Species Group	Data Source
Invasive Plants in Terrestrial Ecological System CEs	
Common burdock (*Arctium* spp.)	University of Georgia, Center for Invasive Species and Ecosystem Health, Early Detection and Distribution Mapping System (EDDMapS 2017; www.eddmaps.org)
Burningbush or Mexican fireweed (*Bassia scoparia*)	
Cheatgrass (*Bromus tectorum*)	
Malta starthistle (*Centaurea melitensis*)	
Yellow starthistle (*Centaurea solstitialis*)	
Stinkgrass (*Eragrostis cilianensis*)	
Lehmann lovegrass (*Eragrostis lehmanniana*)	
Redstem stork's bill (*Erodium cicutarium*)	
African rue (*Peganum harmala*)	
Buffelgrass or African buffelgrass (*Pennisetum ciliare*)	
Russian thistle (*Salsola* spp.)	
London rocket (*Sisymbrium irio*)	
Tamarisk or salt cedar (*Tamarix* spp.)	
Cocklebur (*Xanthium* spp.)	
Fineleaf fumitory (*Fumaria parviflora*)	Not mapped; see text
Prickly Russian thistle (*Salsola tragus*)	
Invasive Plants in Aquatic-Wetland Ecological System CEs	
Russian olive (*Elaeagnus angustifolia*)	University of Georgia, Center for Invasive Species and Ecosystem Health, Early Detection and Distribution Mapping System (EDDMapS 2017; www.eddmaps.org)
Purple loosestrife (*Lythrum salicaria*)	
Tamarisk or salt cedar (*Tamarix* spp.)	
Hydrilla (*Hydrilla verticillata*)	U.S. Geological Survey, Nonindigenous Aquatic Species database (USGS-NAS 2017; https://nas.er.usgs.gov)
Giant reed (*Arundo donax*)	Not mapped; see text
Phragmites (*Phragmites* spp.)	
Golden alga (*Prymnesium* parvum)	
Invasive Animals in Aquatic-Wetland Ecological System CEs	
Asian clam (*Corbicula fluminea*)	U.S. Geological Survey, Nonindigenous Aquatic Species database (USGS-NAS 2017; https://nas.er.usgs.gov)
American bullfrog (*Lithobates catesbeianus*)	
Nutria (*Myocastor coypus*)	
Flathead catfish (*Pylodictis olivaris*), native east of Continental Divide; invasive in Gila River basin	

Distribution data for most of plants listed in Table 6-1 come from the EDDMapS (2017) database. Although this database includes point data on field observations, the majority of observations in the database simply identify the counties where the species occur. The present analysis uses the county data. The plant species involved are highly invasive, and their presence anywhere in a county can reasonably be taken as evidence of their widespread presence. Nevertheless distributions mapped by county likely over-represent the extent of species distribution, simply because a species present in a county may not occur “edge to edge” within the county. Figure 6-1 provides a County map for reference.

Figure 6-1. County reference map.



Distribution data for one plant species and all of the animal species listed in Table 6-1 consist of point data from the USGS-NAS (2017) database. These point data represent locations where a trained observer has recorded the presence of a species. In contrast with the county data, therefore, point data may underrepresent the actual distribution of a species.

Figure 6-2 – Figure 6-9 show the county distributions for, respectively, common burdock and Mexican fireweed; cheatgrass and Malta starthistle; yellow starthistle and stinkgrass; Lehmann lovegrass and redstem stork's bill; African rue and buffelgrass; Russian thistle and London rocket; tamarisk and cocklebur; and Russian olive and purple loosestrife. Figure 6-10, in turn, shows the point distributions of the animal species and single plant species based on the USGS-NAS (2017) database.

Figure 6-2. County distributions of common burdock (top) and Mexican fireweed (bottom).

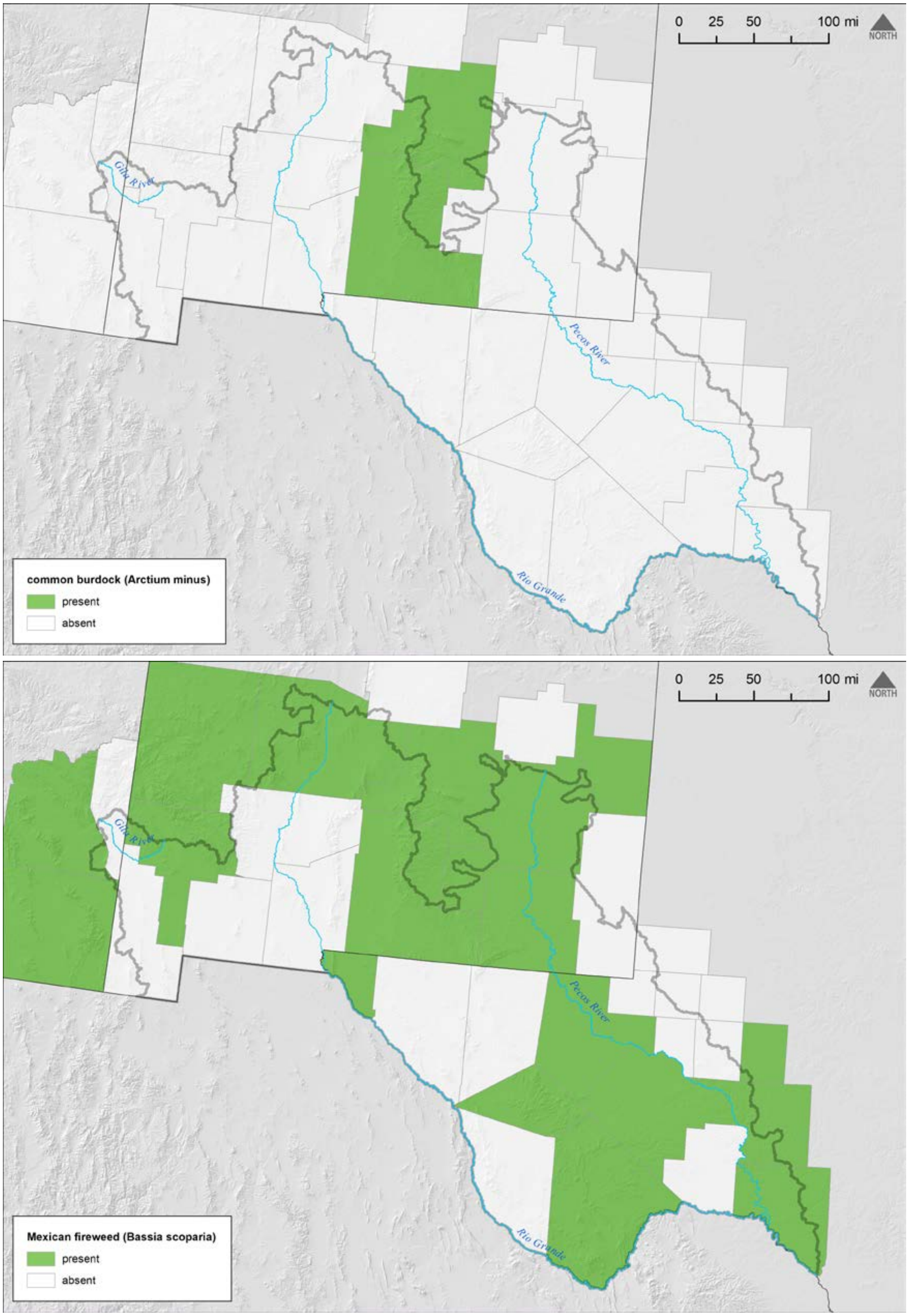


Figure 6-3. County distributions of cheatgrass (top) and Malta starthistle (bottom).

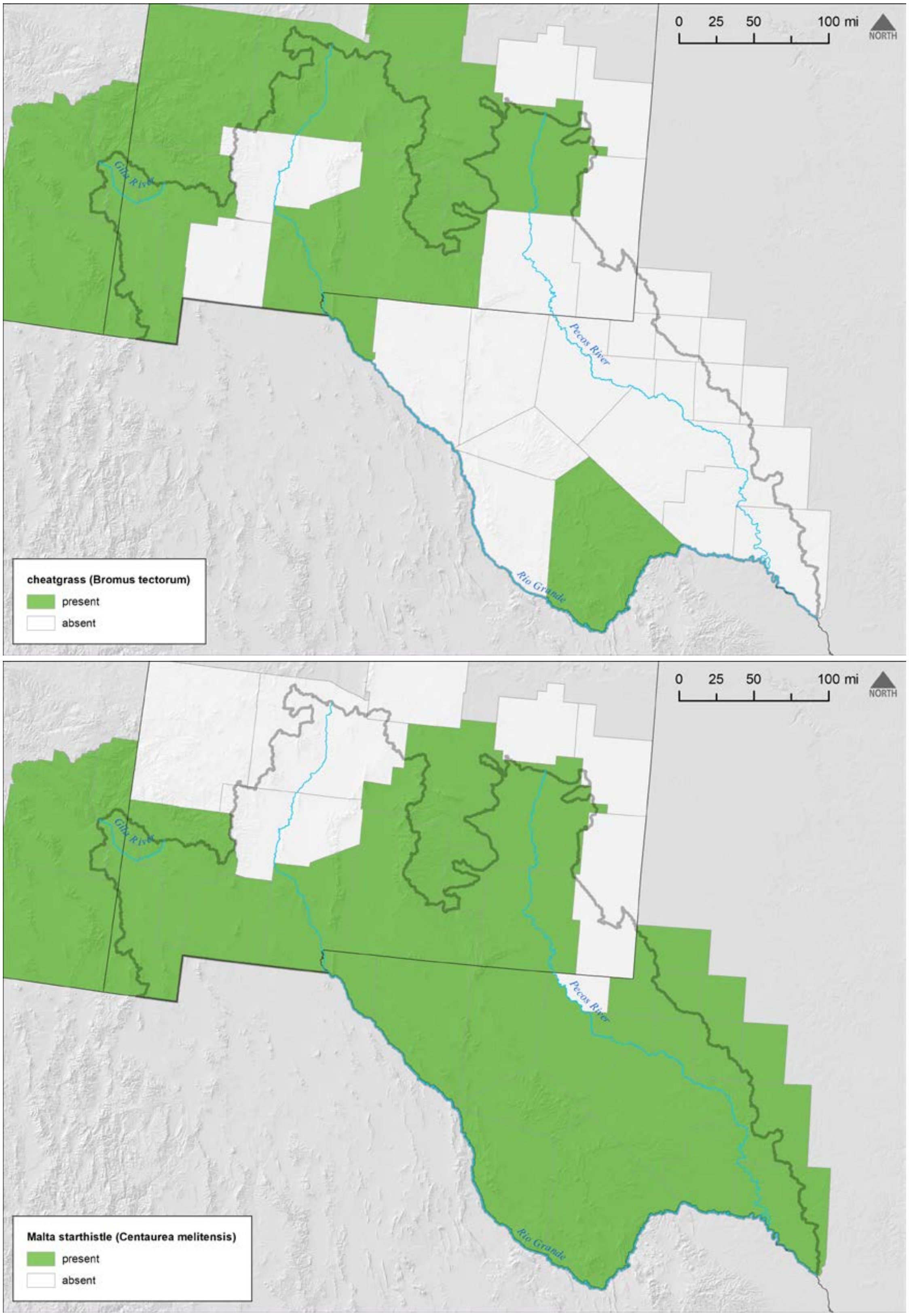
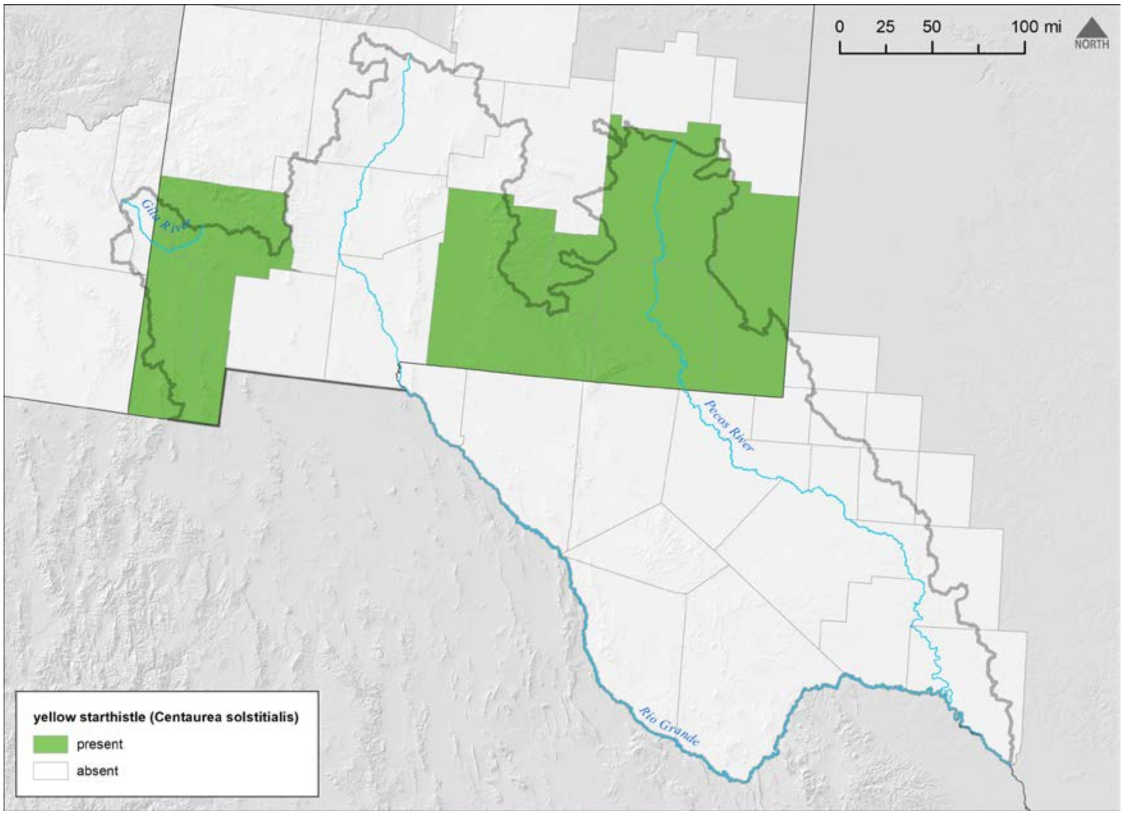


Figure 6-4. County distributions yellow starthistle (top) and stinkgrass (bottom).



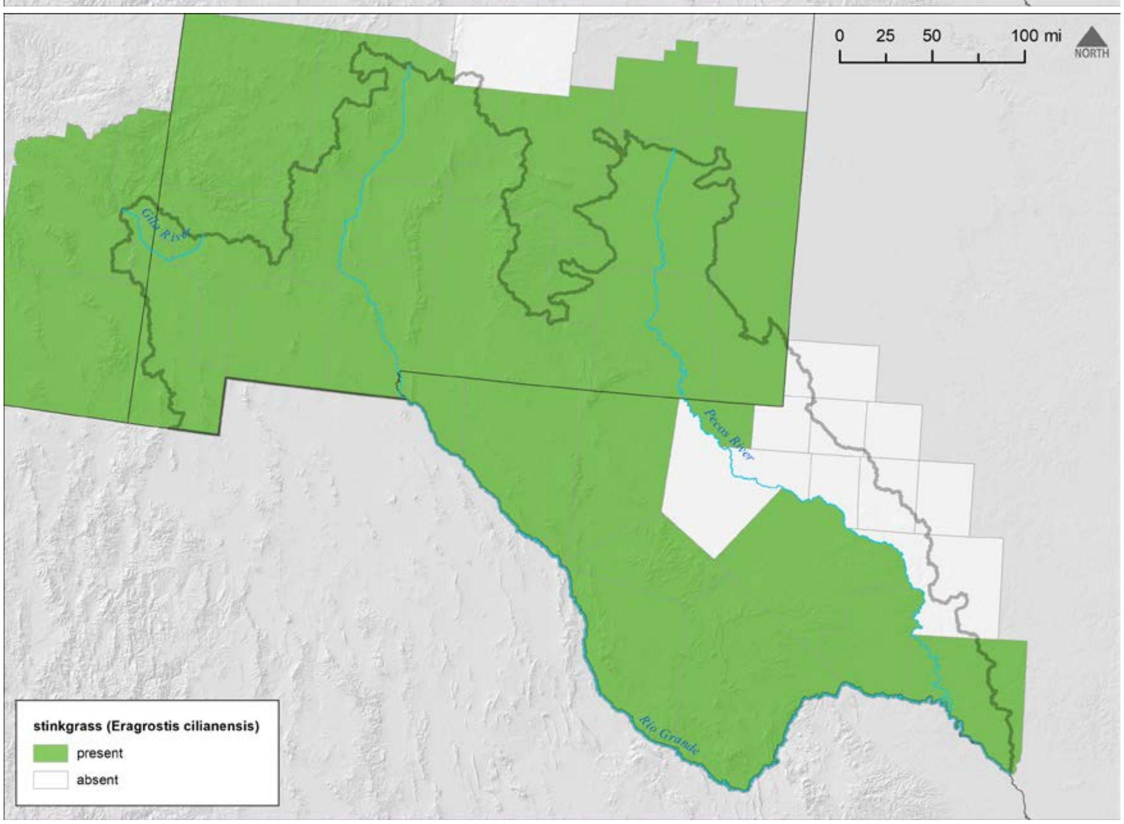


Figure 6-5. County distributions Lehmann lovegrass (top) and redstem stork's bill (bottom).

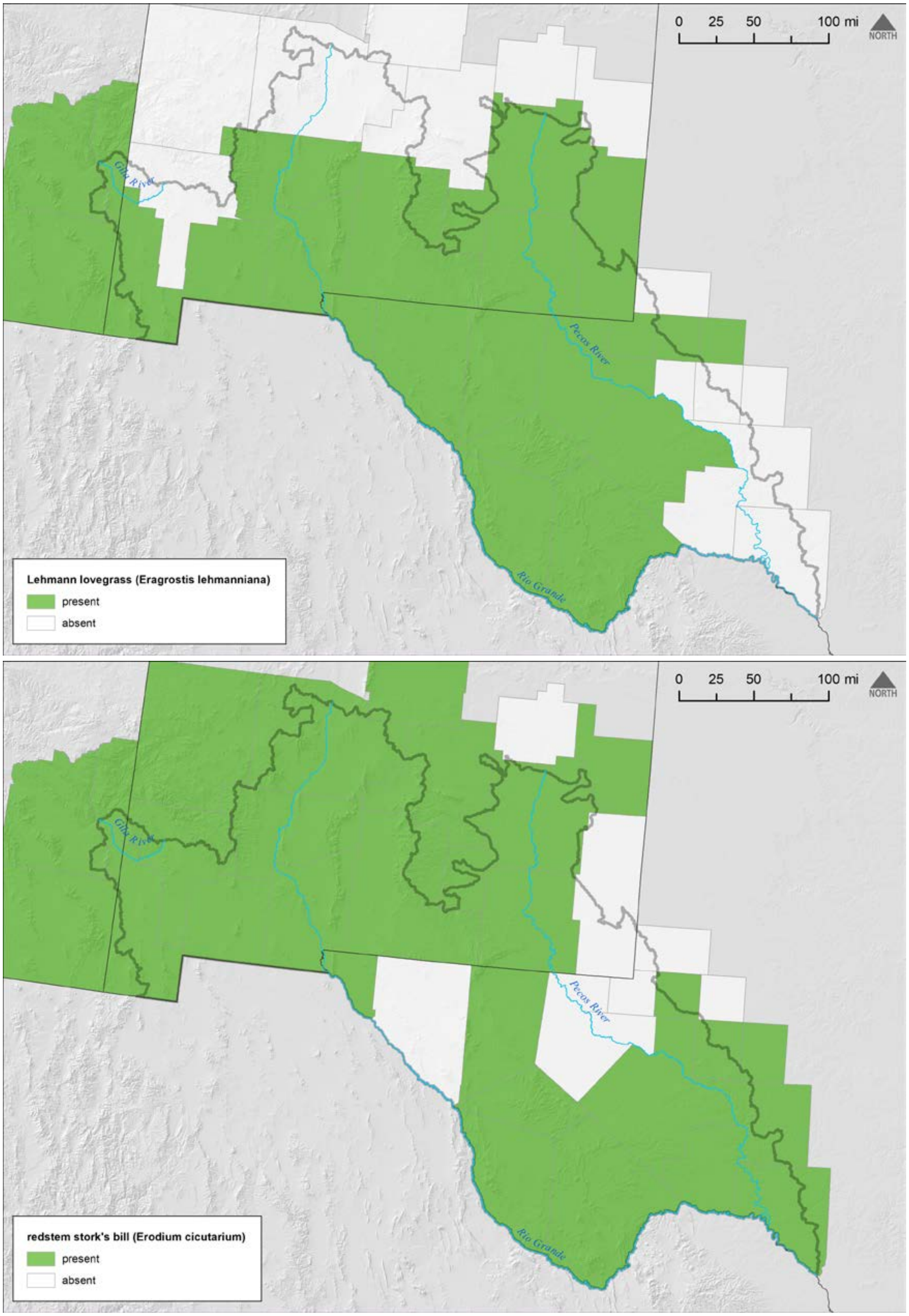


Figure 6-6. County distributions of African rue (top) and buffelgrass (bottom).

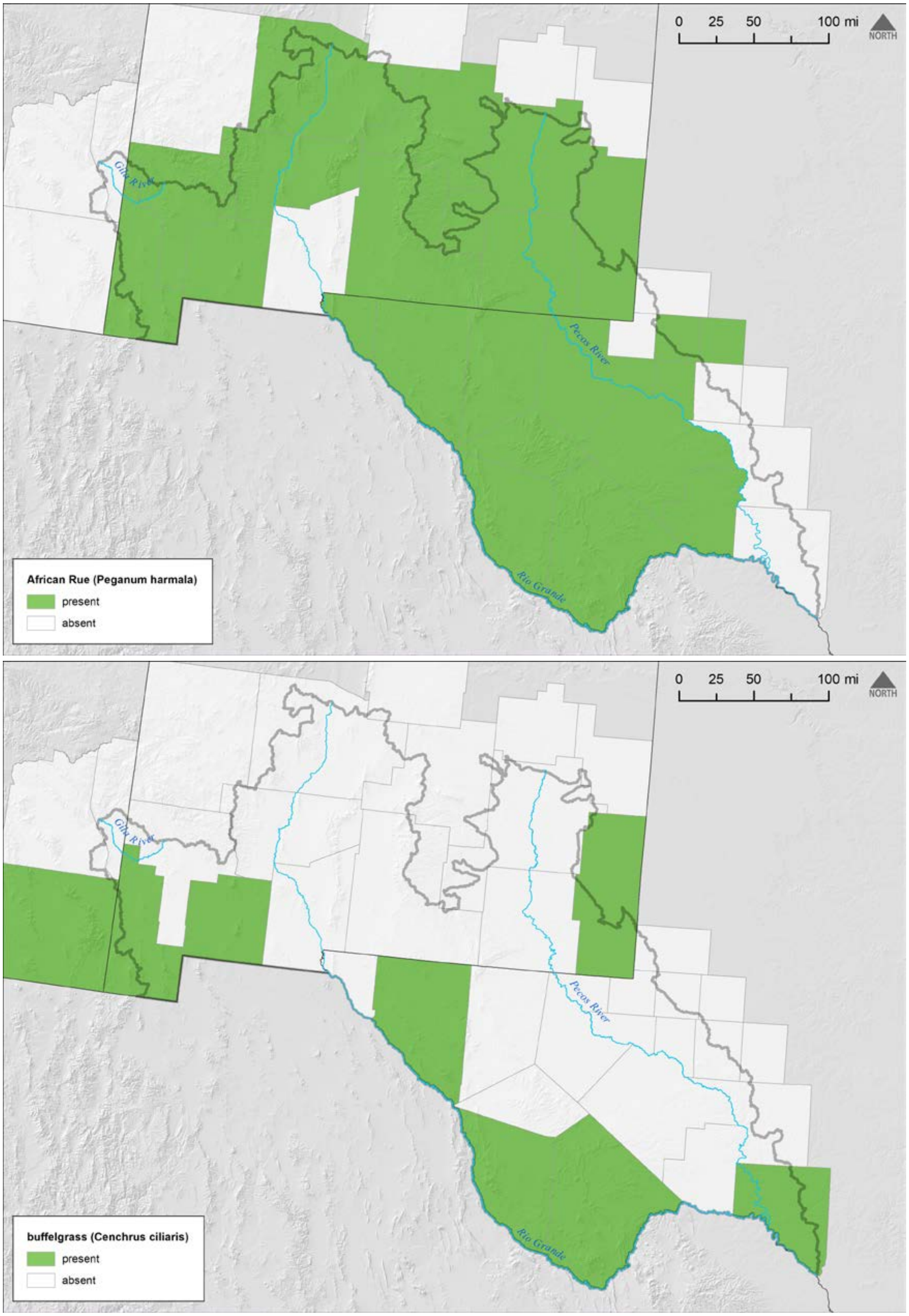


Figure 6-7. County distributions of Russian thistle (top) and London rocket (bottom).

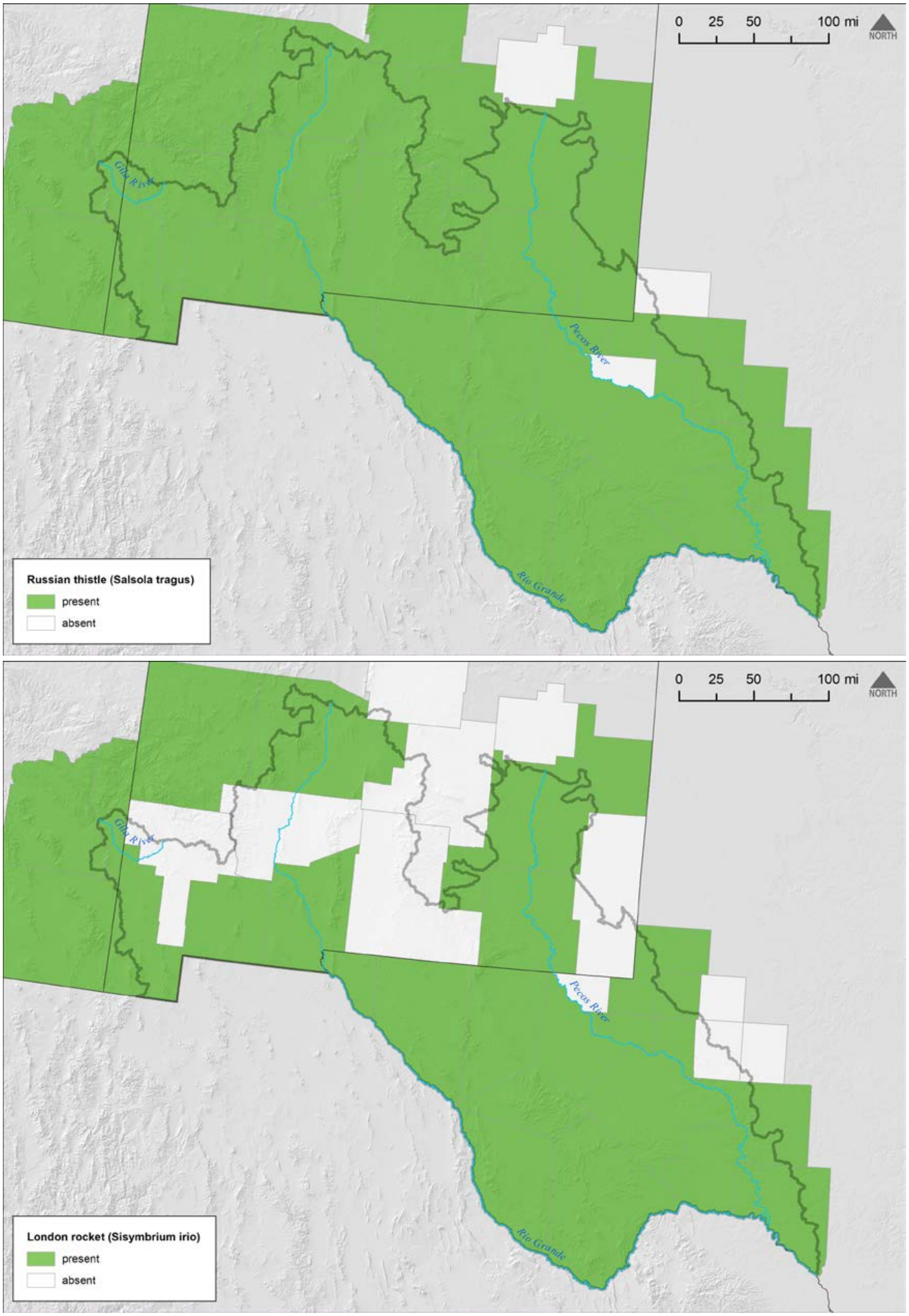
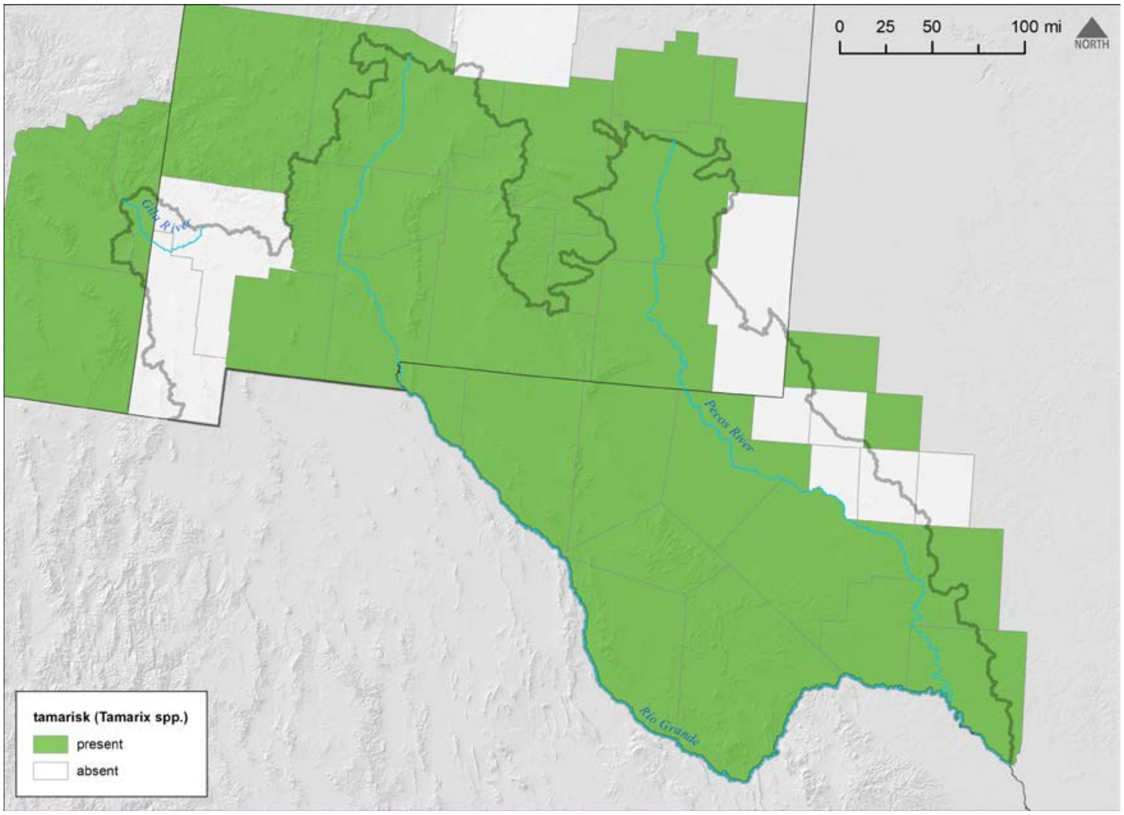


Figure 6-8. County distributions of tamarisk (top) and cocklebur (bottom).



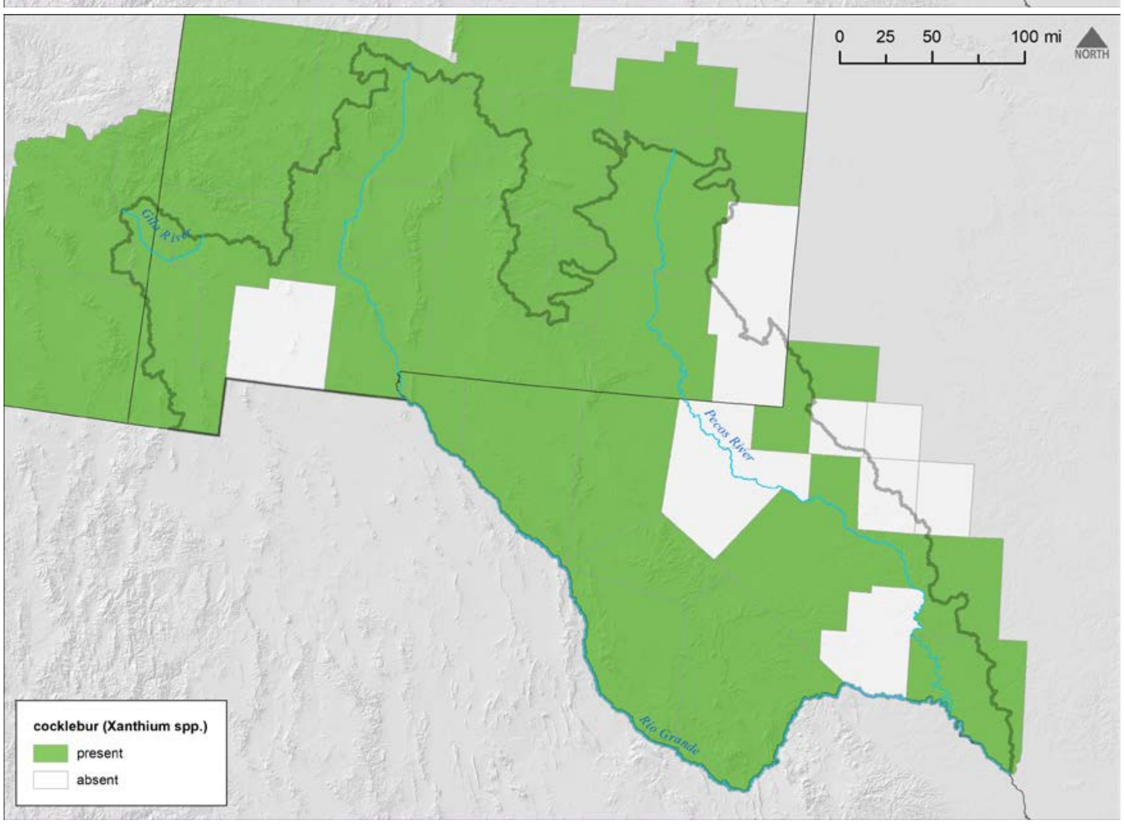


Figure 6-9. County distributions of Russian olive (top) and purple loosestrife (bottom).

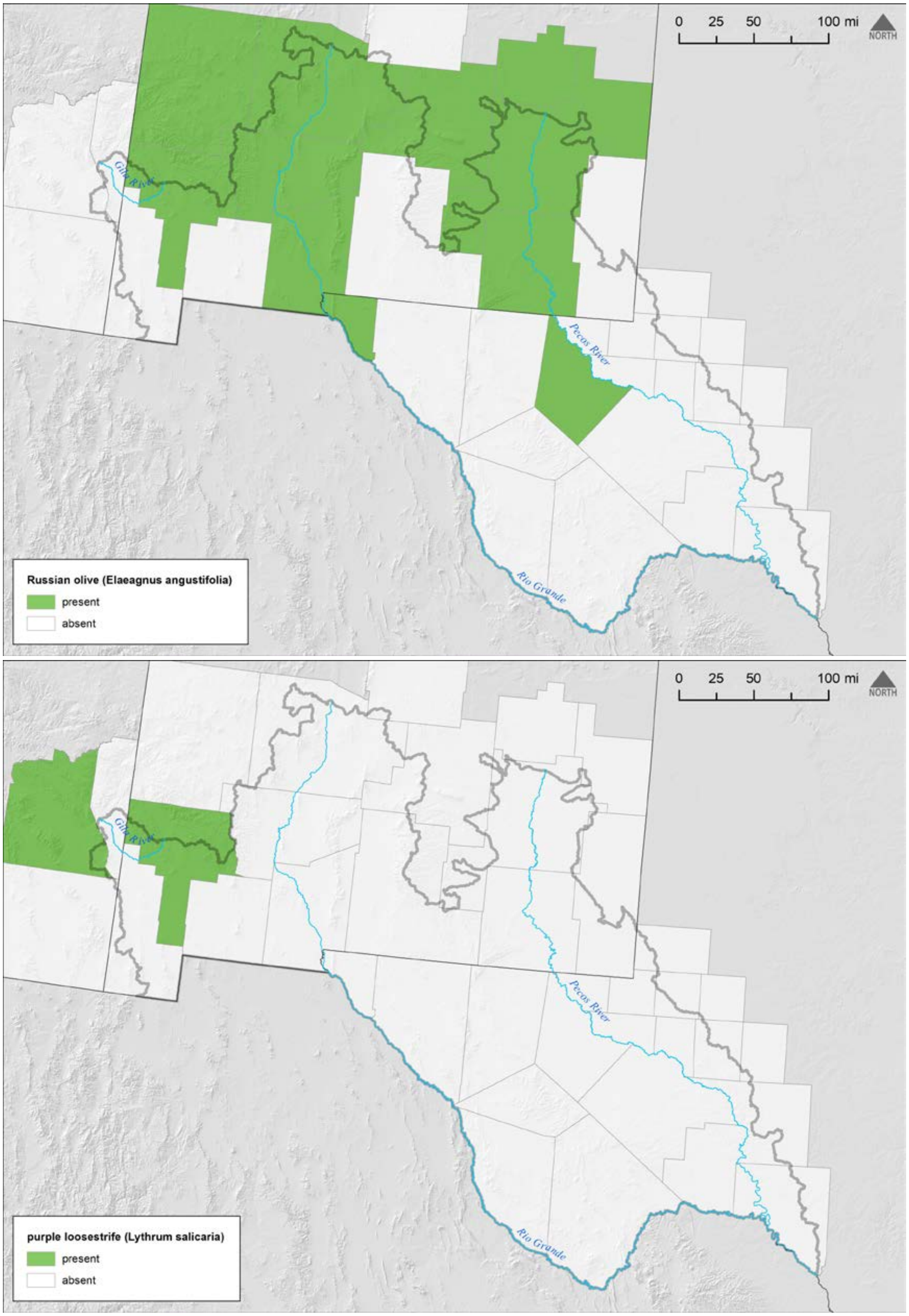


Figure 6-10. Point observations of invasive animals and a plant (*Hydrilla*) in aquatic-wetland ecological system CEs.

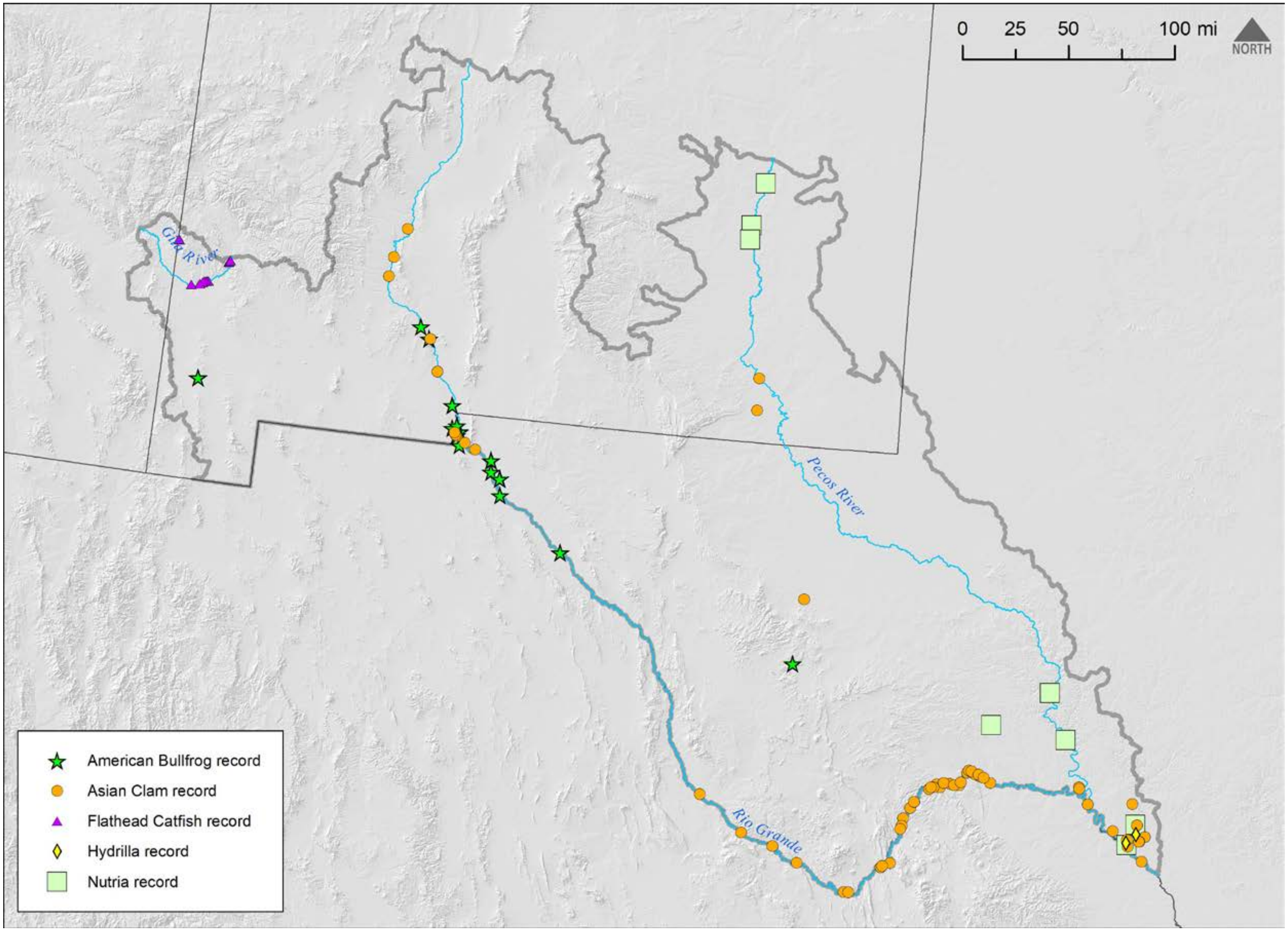


Figure 6-2 – Figure 6-9 indicate that invasive plants affecting the three terrestrial ecological system CEs occur in every county within or overlapping the analysis extent for the REA. For example, among three invasive grasses most often mentioned in the Pre-Assessment Report (Unnasch et al. 2017) as affecting the Chihuahuan Desert Grassland CE, buffelgrass is reported only along the eastern, western, and southern margins of the analysis extent; Lehman lovegrass everywhere except the northernmost and southeastern-most counties, and cheatgrass mostly across the northern counties but also in the Big Bend region. Together, these three species alone cover the entire analysis extent. Only one terrestrial invasive plant species, common burdock, has a more limited distribution than buffelgrass.

Figure 6-8 and Figure 6-9 also shows the county distributions of two woody species that are also invasive in aquatic-wetland ecological system CEs in the ecoregion, tamarisk (salt cedar) and Russian olive, respectively. Tamarisk is reported across the analysis extent in all but three counties in New Mexico and all but five comparatively small counties in western Texas. Russian olive occurs almost entirely in New Mexico alone. Figure 6-9 also shows that purple loosestrife, an herbaceous plant invasive in aquatic-wetland ecological system CEs in the ecoregion, is reported only in counties that contain portions of the Gila River mainstem.

Figure 6-10, in turn, shows that the Asian clam occurs commonly along the Rio Grande in both New Mexico and Texas, at only two scattered locations along the Pecos River in New Mexico, and at a handful of other locations that could be springs or could merely represent incorrect spatial coordinates. Flathead catfish appears only along the Gila River mainstem. Observers have reported nutria at multiple locations along the Pecos River in both New Mexico and Texas, and at one location that could be a spring or represent incorrect spatial coordinates. American bullfrog is reported at multiple locations along the Rio Grande in both New Mexico and Texas, and at two other locations that could be springs or represent incorrect spatial coordinates. However, the NAS data for this bullfrog species may significantly underrepresent its distribution, based on anecdotal reports of its widespread occurrence, for example, in the Gila River watershed, noted by the AMT. Finally, hydrilla is reported only along the Rio Grande at the southeastern-most extent of the U.S. portion of the ecoregion, in the vicinity of Amistad Reservoir.

6.3 Uncharacteristic Wildfire

Wildfire historically and still today plays a significant role in shaping the land cover of the U.S. portion of the ecoregion, as discussed throughout the Pre-Assessment report (Unnasch et al. 2017) and in Chapters 2 and 3, above. As discussed in detail in the Pre-Assessment report conceptual ecological models for the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs (see Chapters 5-7 in Unnasch et al. 2017), fire frequency and intensity strongly shape vegetational succession, affect seed vitality among fire-adapted plant species, and affect nutrient cycling in all three terrestrial ecological system CEs. Changes to wildfire regimes among these three CEs therefore have the potential to bring about significant changes in their compositions and distributions.

The present REA examines wildfire patterns in the U.S. portion of the ecoregion using data on: (1) the distribution of individual fires since 1985, both overall and in relation to each of the three terrestrial ecological system CEs; (2) vegetation departure from conditions expected under a historic fire regime, both overall and in relation to the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs; and (3) wildfire hazard potential overall.

Figure 6-11 shows the perimeters of all wildfires recorded within the analysis extent for the REA, from 1985 through 2016, based on data from two sources: The interagency Monitoring Trends in Burn Severity (MTBS), National MTBS Burned Area Boundaries Dataset for 1985-2015, May 2017 update (MTBS 2017; http://mtbs.gov/nationalregional/burnedarea.html), and the Geospatial Multi-Agency Coordination historic fire dataset for 2016, update of March 13, 2017 (GeoMAC 2017; https://www.geomac.gov/). Figure 6-12 and Figure 6-13 are similar to Figure 6-11 but include raster data on the spatial extent of each burn within its perimeter in relation to in relation to the three terrestrial ecological system CEs. Figure 6-12(bottom) and Figure 6-13 are similar to Figure 6-12(top) but show the burns associated separately with each of the the three terrestrial ecological system CEs.

Figure 6-12 and Figure 6-13 show numerous wildfires throughout the analysis extent between 1985 and 2016. A large proportion of the burns covered both grasslands and adjacent pinyon-juniper woodlands within the same perimeter. Some of these perimeters also include areas of scrub. However, several large and small burns involved scrub areas alone, particularly in the upper Pecos River valley and across a wide belt extending from the Chinati Mountains eastward to the REA boundary. Overall, between 1985 and 2016, 3% of the area of the Chihuahuan Desert Scrub CE, 7% of the Chihuahuan Desert Grasslands, and 12% of the Pinyon-Juniper Woodlands CE experienced one or more burns.

Figure 6-11. Wildfire perimeters, 1985-2016.

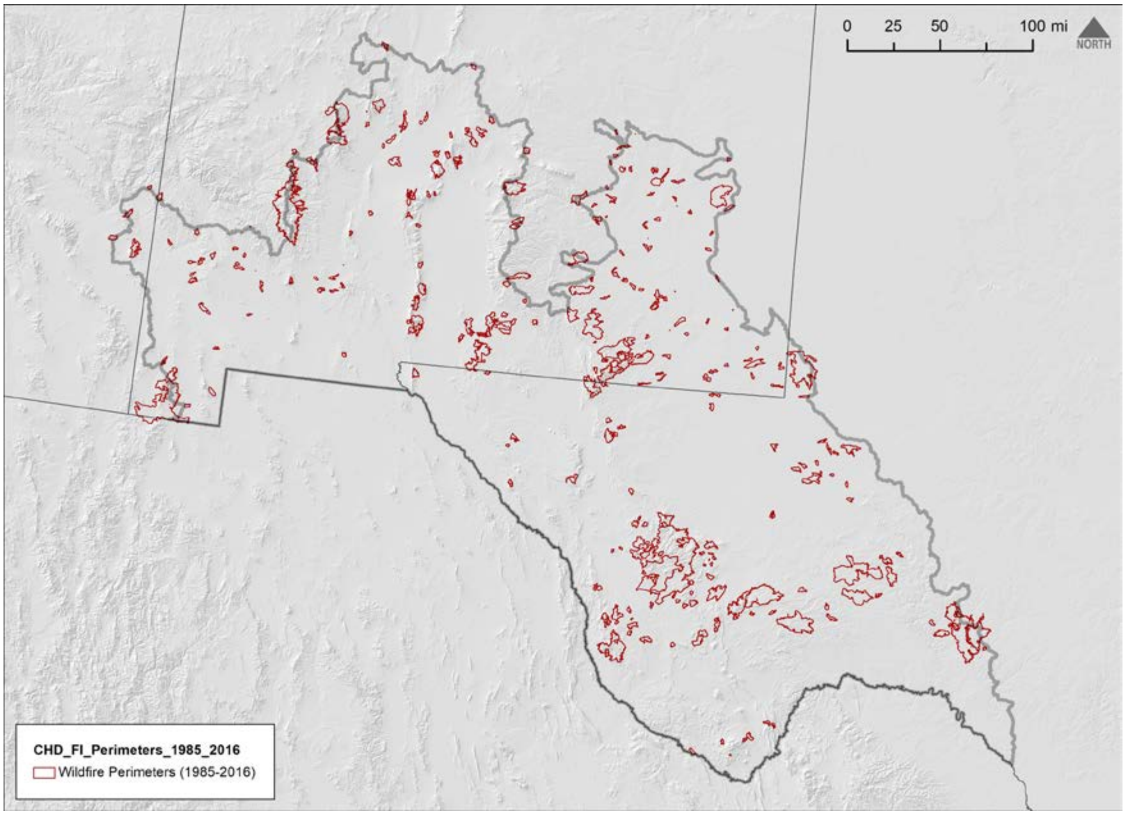
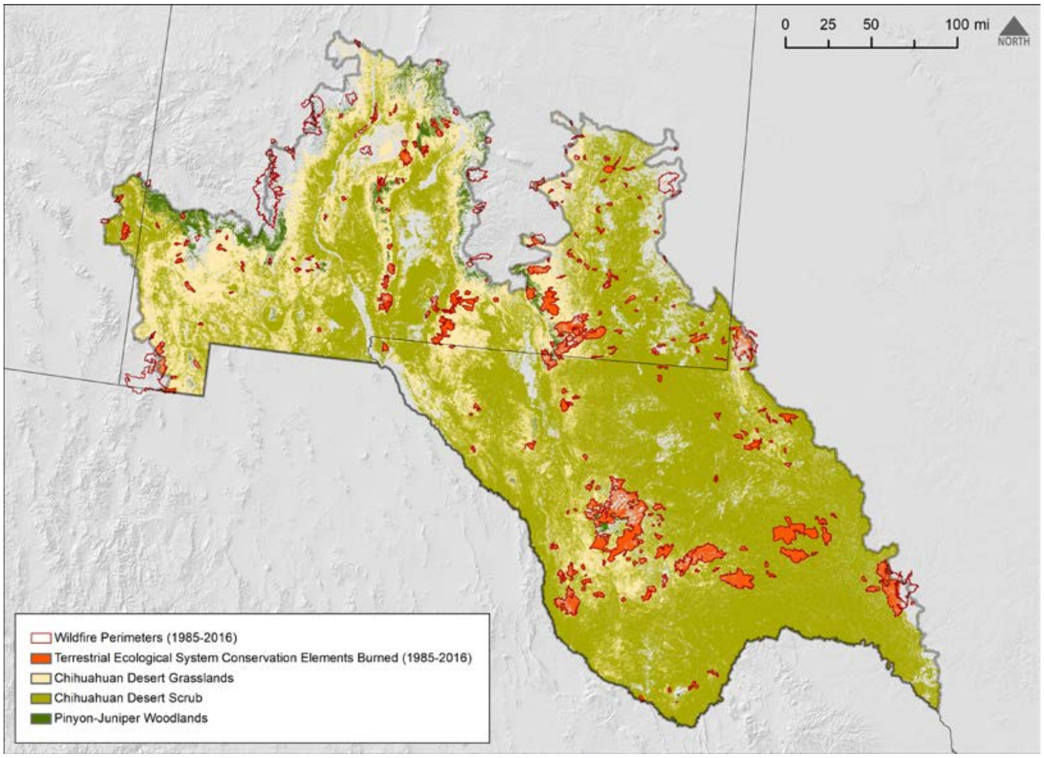


Figure 6-12. Wildfires, 1985-2016, in relation to the three terrestrial ecological system CEs (top) and to the Chihuahuan Desert Grassland CE (bottom).



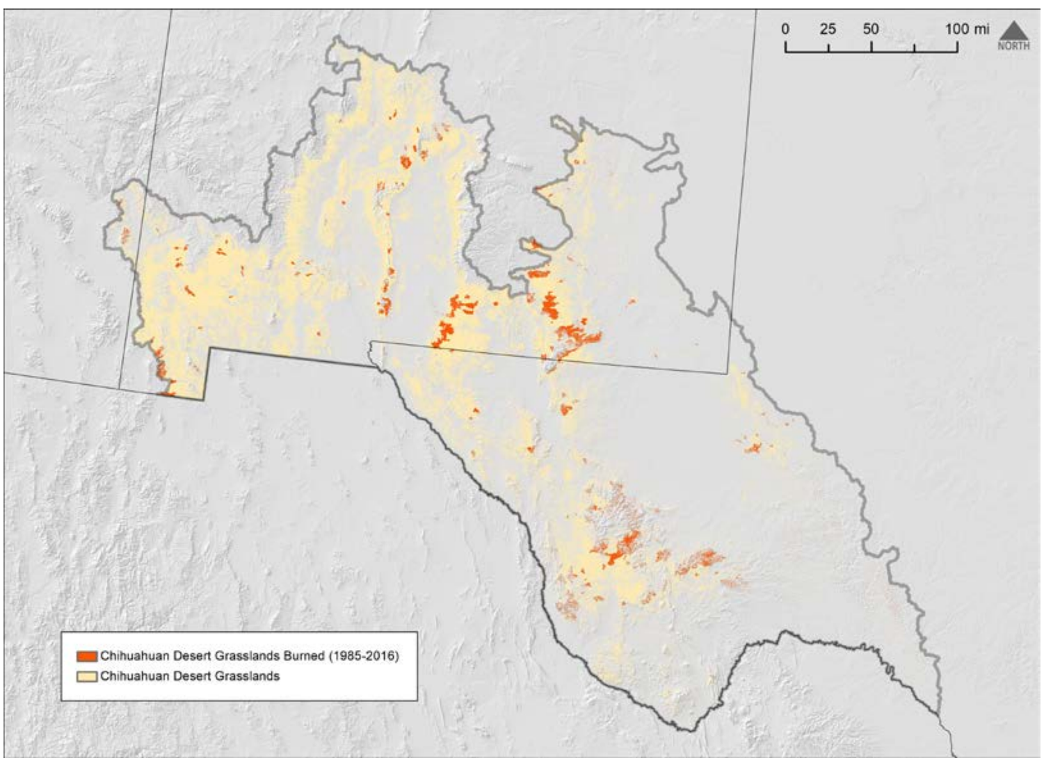
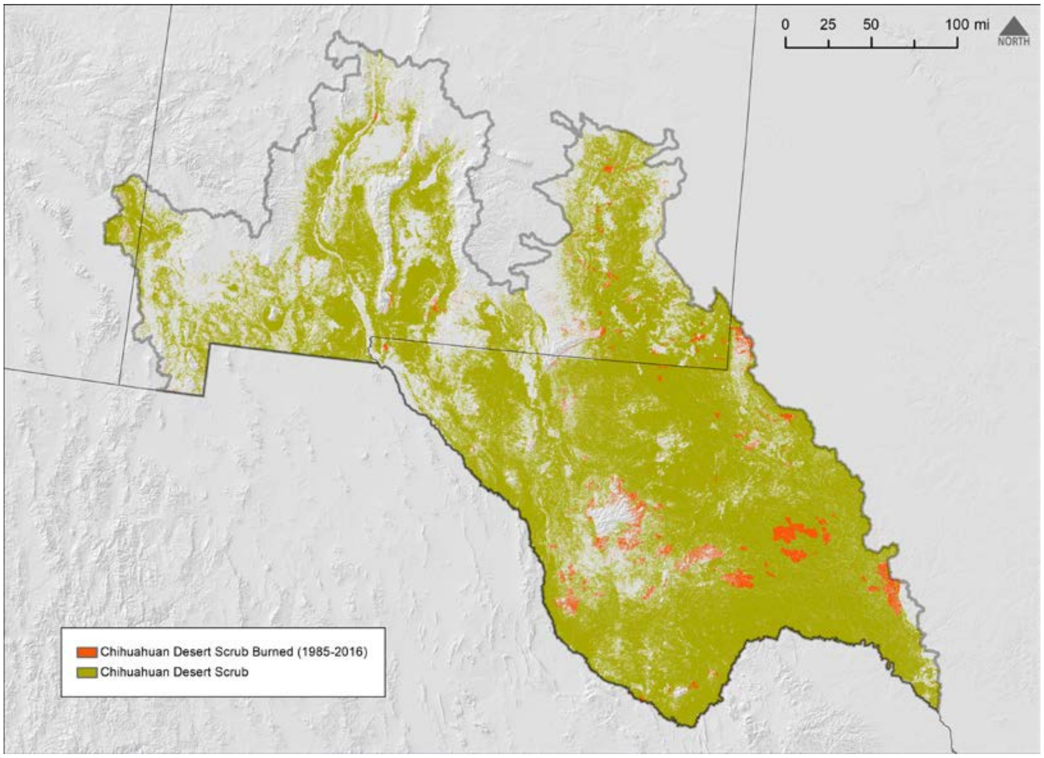


Figure 6-13. Wildfires, 1985-2016, in relation to the Chihuahuan Desert Scrub (top) and Pinyon-Juniper Woodlands (bottom) CEs.



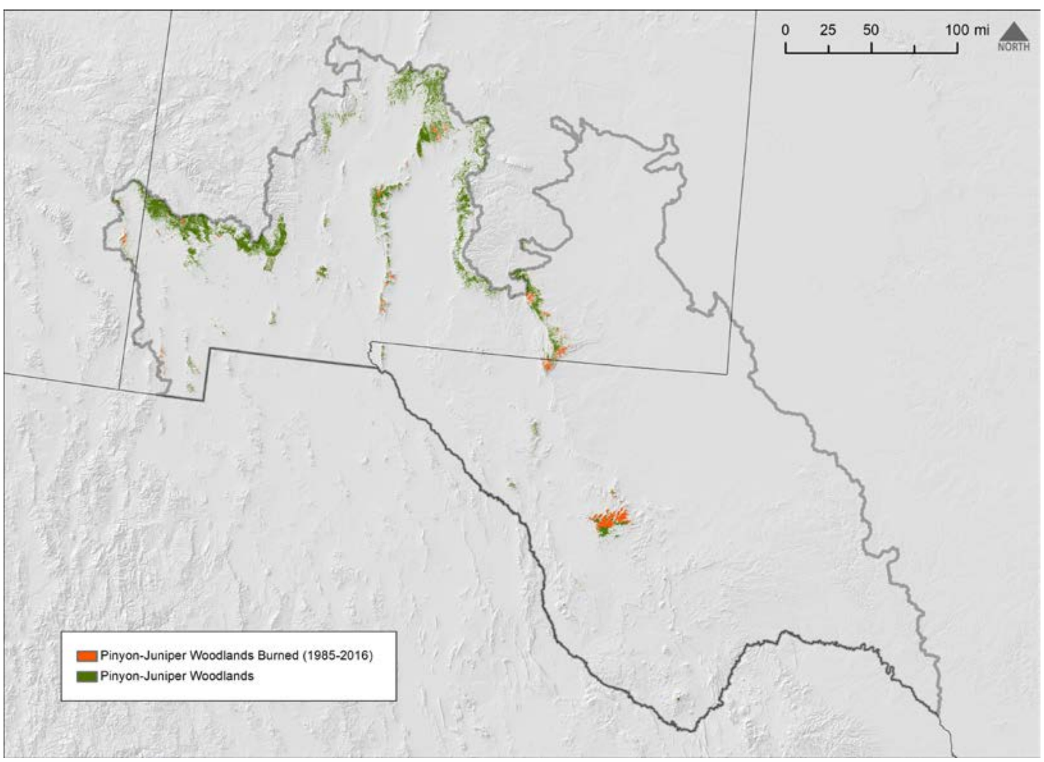
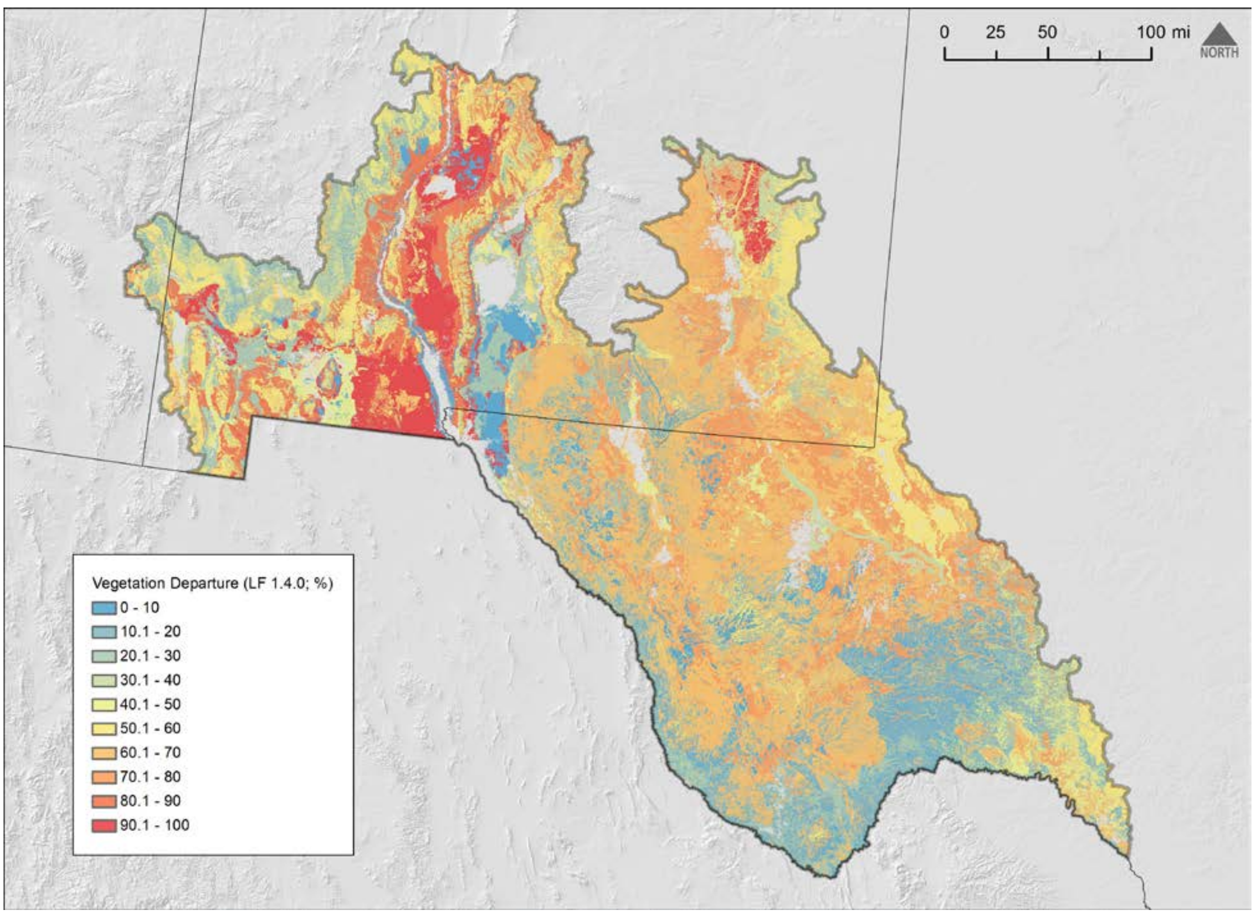


Figure 6-14 shows the degree to which land cover vegetation within the analysis extent differs from estimated historic conditions prior to Euro-American settlement based on LANDFIRE Vegetation Departure (VDEP) data (LANDFIRE 2016). VDEP values take into account not only species composition but also seral stage and vegetation structure and canopy closure, as represented in state-transition models for the individual ecological system cover types in a region. VDEP values therefore are intentionally particularly sensitive to changes in fire regimes. The VDEP dataset also explicitly excludes areas with development cover types, making it relatively unaffected by other stressors that can drastically alter vegetation. The VDEP dataset also excludes areas classified as natural barrens. VDEP values range from 0 - 100, indicating a range from unaltered vegetation to a complete departure from expected landscape mosaic composition.

Figure 6-14 shows high to extremely high values for vegetation departure along the lower elevations of the Rio Grande valley in New Mexico and the adjacent Jornada del Muerto and Jornada Draw closed valleys immediately to the east, and along the lower elevations of the Pecos River valley roughly from the vicinity of Roswell, New Mexico, northward. Another, more scattered area of high to extremely high VDEP values roughly parallels the Interstate-10 corridor westward from the Rio Grande valley to the Arizona border.

Figure 6-14. Vegetation departure across all terrestrial ecological system CEs.



Conversely, Figure 6-14 shows low to extremely low VDEP values across the Tularosa and Salt Basin closed valleys, roughly within the large military reservations that encompass these areas; across the Rio Grande valley through the Big Bend region, and across much of the southernmost Pecos River valley; and across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range that comprise the northwestern boundary of the analysis extent.

Figure 6-15 and Figure 6-16 show the same VDEP data as in Figure 6-14, but only for pixels classified as parts of the Chihuahuan Desert Grassland and Chihuahuan Desert Scrub CEs, respectively. These latter two figures show that the area of high to extremely high VDEP values along the Rio Grande valley in New Mexico and the adjacent Jornada del Muerto and Jornada Draw closed valleys, and the area of similarly high to extremely high VDEP values along the Pecos River valley extending northward from Roswell, New Mexico, mostly encompass areas of Chihuahuan Desert Scrub. However, the area of high to extremely high VDEP values extending westward from the Rio Grande valley to the Arizona border, and portions of the area of high to extremely high VDEP values in the northern Jornada del Muerto valley, mostly encompass areas of Chihuahuan Desert Grassland.

Figure 6-15. Vegetation departure across the Chihuahuan Desert Grassland CE.

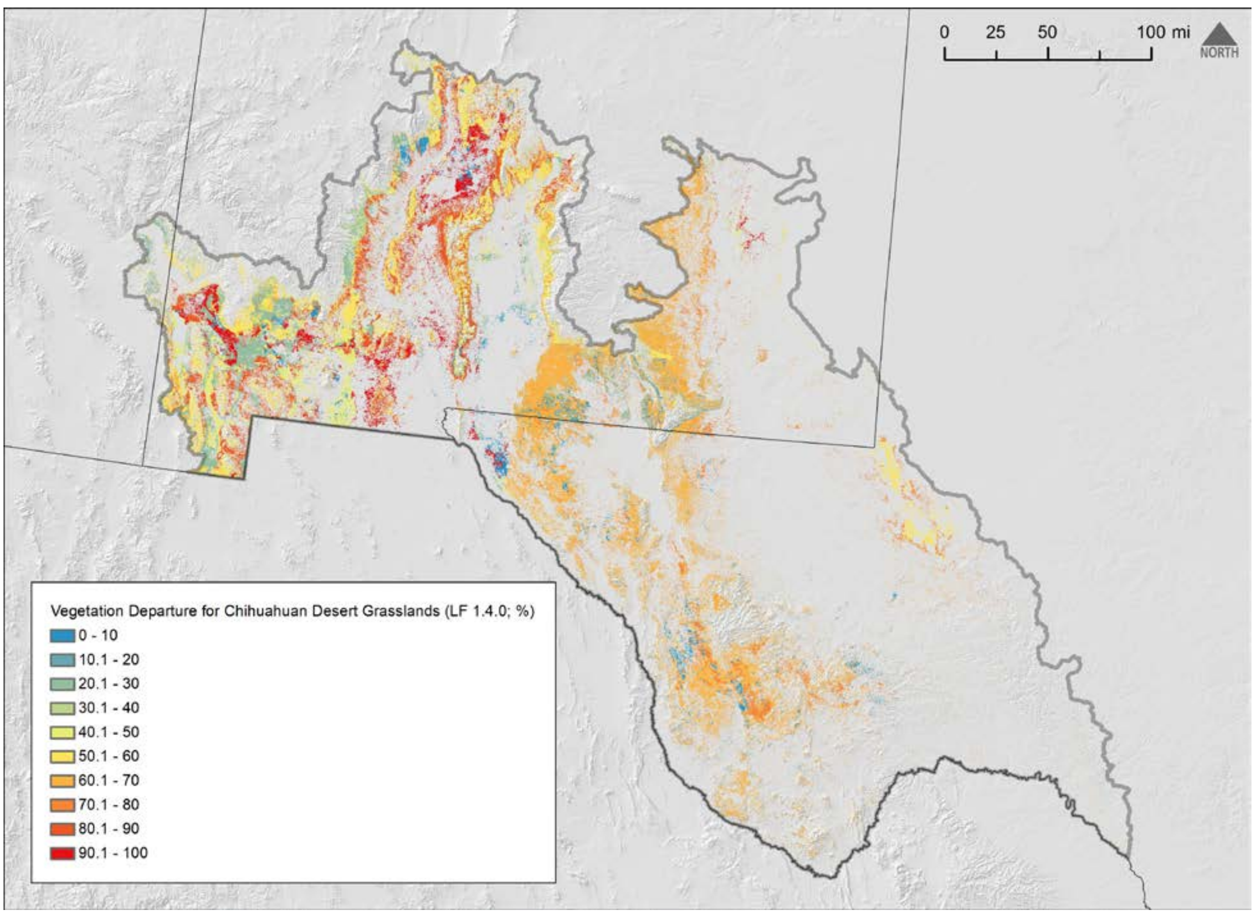
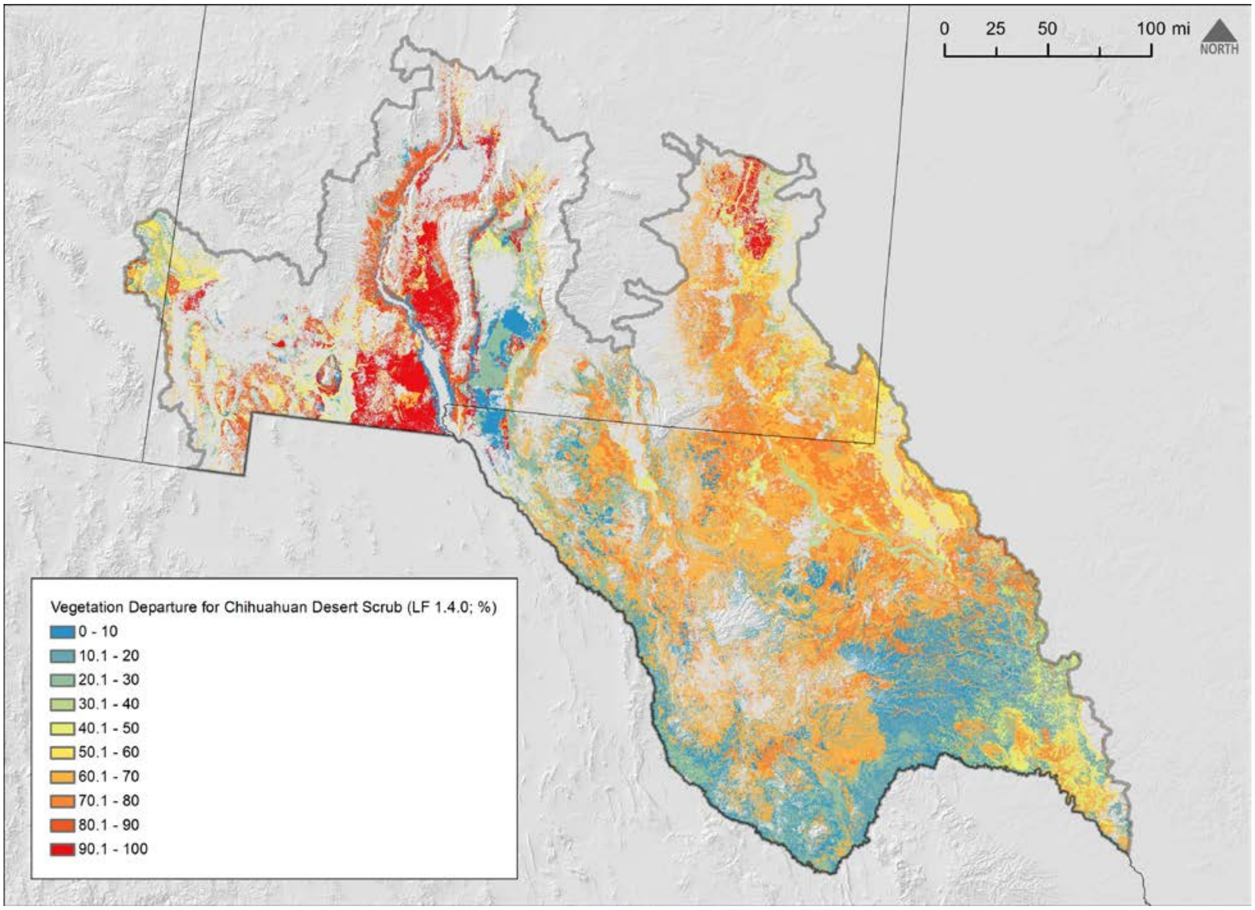


Figure 6-16. Vegetation departure across the Chihuahuan Desert Scrub CE.



Finally, Figure 6-17 shows the estimated “Wildfire Hazard Potential” (WHP) values for 2014 across the analysis extent, as calculated by the U.S. Department of Agriculture, Forest Service, Fire Modeling Institute (Dillon 2015, Dillon et al. 2015, USDA FS 2015). The WHP data depict “the relative potential for wildfire that would be difficult for suppression resources to contain. To create the 2014 version we built upon spatial estimates of wildfire likelihood and intensity generated in 2014 with the Large Fire Simulator (FSim) for the Fire Program Analysis system (FPA), as well as spatial fuels and vegetation data from LANDFIRE 2010 and point locations of fire occurrence from FPA (ca. 1992 - 2012)… Areas mapped with higher WHP values represent fuels with a higher probability of experiencing torching, crowning, and other forms of extreme fire behavior under conducive weather conditions, based primarily on 2010 landscape conditions… On its own, WHP is not an explicit map of wildfire threat or risk, but when paired with spatial data depicting highly valued resources and assets such as communities, structures, or powerlines, it can approximate relative wildfire risk to those resources and assets. WHP is also not a forecast or wildfire outlook for any particular season, as it does not include any information on current or forecasted weather or fuel moisture conditions. It is instead intended for long-term strategic planning and fuels management” (USDA FS 2015).

Figure 6-17. Wildfire hazard potential.

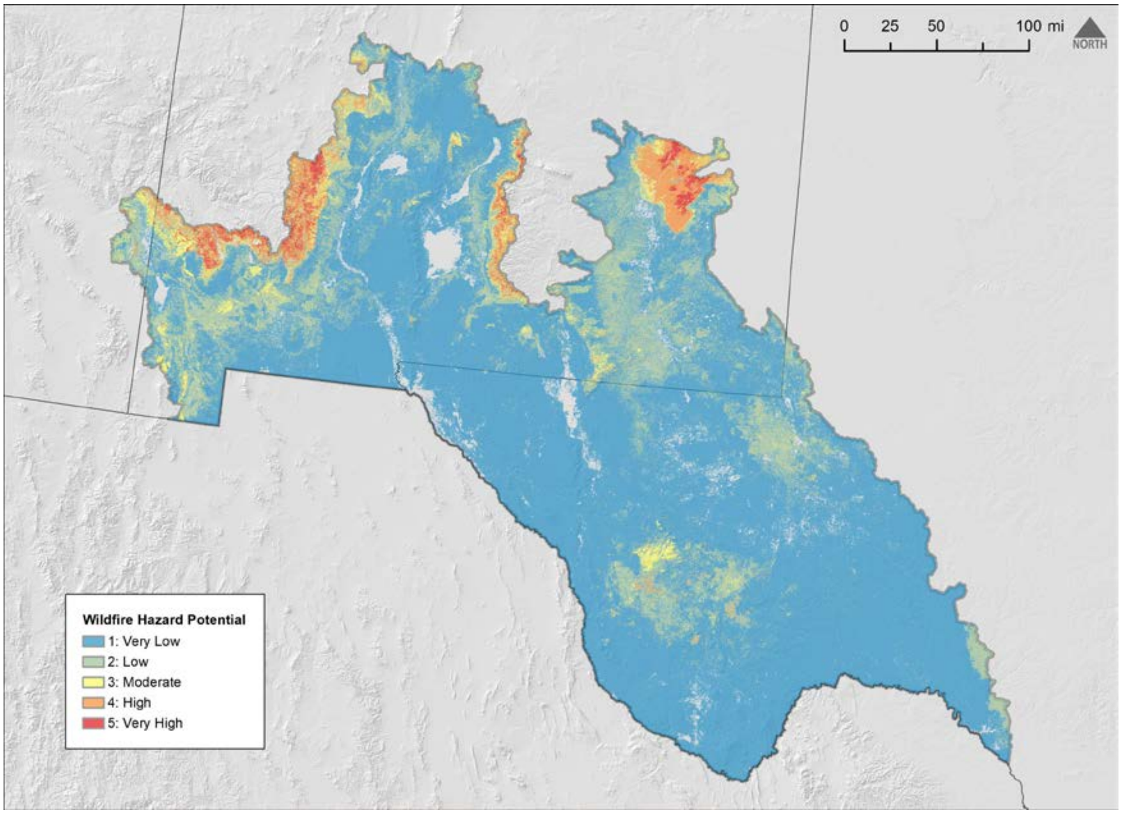


Figure 6-17 shows three areas within the analysis extent with high to very high WHP values: across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range that comprise the northwestern boundary of the analysis extent; across a large fraction of the upper Pecos River valley extending roughly from the vicinity of Roswell, New Mexico, northward; and along the western slopes of the Sacramento Mountains along the east side of the entire Tularosa Basin. Areas with moderate WHP values occur on the northwest flanks of the Davis Mountains in Texas, along the crest of the Guadalupe Mountains in Texas and New Mexico, and on scattered low mountain ranges in far southwestern New Mexico. As with the VDEP maps above, Figure 6-17 excludes developed lands and areas of natural barrens. It is perhaps noteworthy that, among the areas with high to very high WHP values, only the area extending northward from Roswell, New Mexico, exhibits high values for both VDEP (see above) and WHP. This overlap suggests that this area not only has experienced significant vegetation and fire regime alteration in the past, but remains highly vulnerable to wildfire today. As shown further above, the area did not experience a significant number of wildfires between 1985 and 2016, and none with large perimeters.

Figure 6-17 offers the possibility of examining how two CAs interact – invasive species and uncharacteristic wildfire. The potential effects of invasive plants on fire patterns across a landscape are common management concerns across the western U.S. However, the invasive plant data available to this REA are spatially too coarse for such a comparison, and a quick visual examination suggests there is little to be gained from a GIS analysis. For example, Lehmann lovegrass is suspected of supporting more intense fires than can native grassland vegetation in the region, as discussed in the Pre-Assessment report (see Unnasch et al. 2017, Chapter 5). A quick visual comparison of the distribution of Lehmann lovegrass shown in Figure 6-5, top, with the distribution of high WHP values in Figure 6-17 indicates that the two distributions have nothing in common. The distribution of cheatgrass shown in Figure 6-3, top, bears a closer resemblance to the distribution of high WHP values in Figure 6-17, but the county data on plant distribution are spatially far too coarse to support any quantitative analysis.

6.4 Landscape Restoration

As noted at the beginning of this chapter, and also in Chapter 3, above, and in the Pre-Assessment report (Unnasch et al. 2017), landscape restoration is a change agent in the U.S. portion of the ecoregion but it is not a stressor. Rather, it is an intentional counter-measure against some stressors. Landscape restoration can bring about significant changes in an ecoregion that are of interest to the BLM and other land management agencies. As also noted at the beginning of this chapter, the assessment of landscape restoration for this REA specifically sought examine the relative success rate of restoration efforts. Unfortunately, the available geospatial datasets do not provide systematic information on the effectiveness of these restoration efforts. On the other hand, data are available at least on the spatial distribution of landscape restoration activities, as shown in Figure 6-18 – Figure 6-20.

Figure 6-18. Vegetation treatments, BLM data.

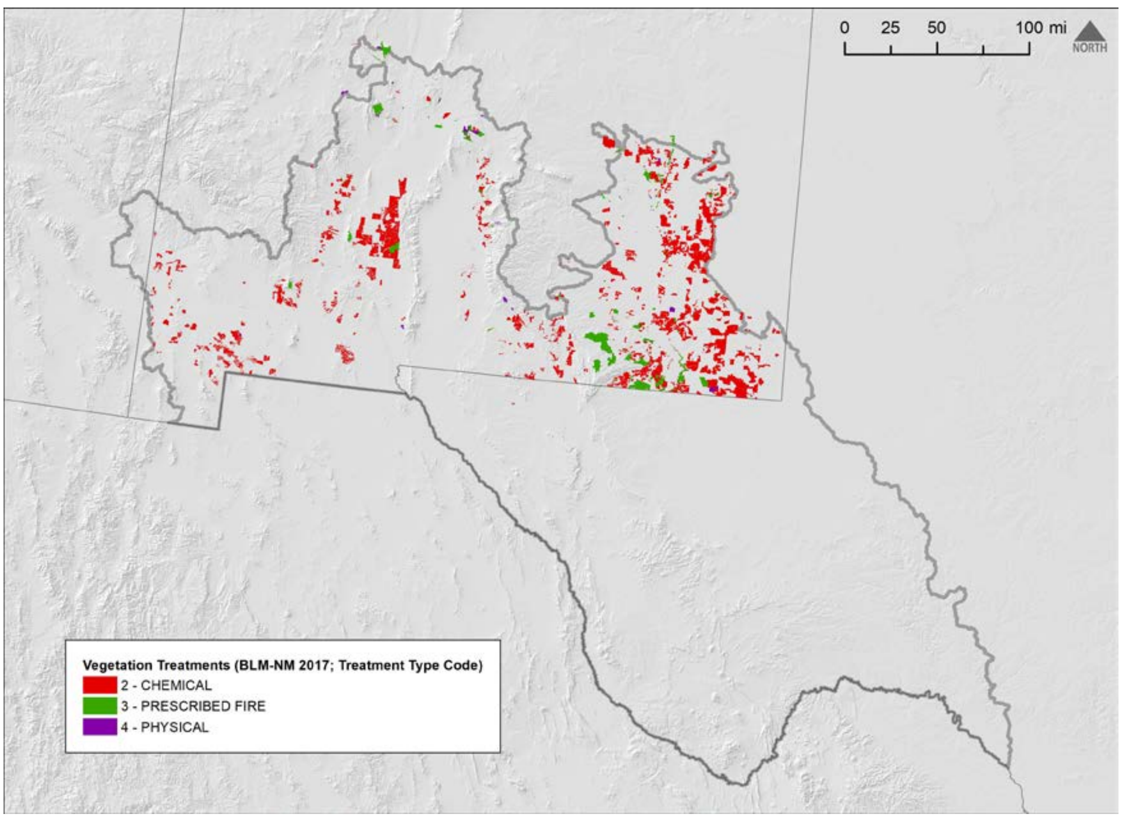
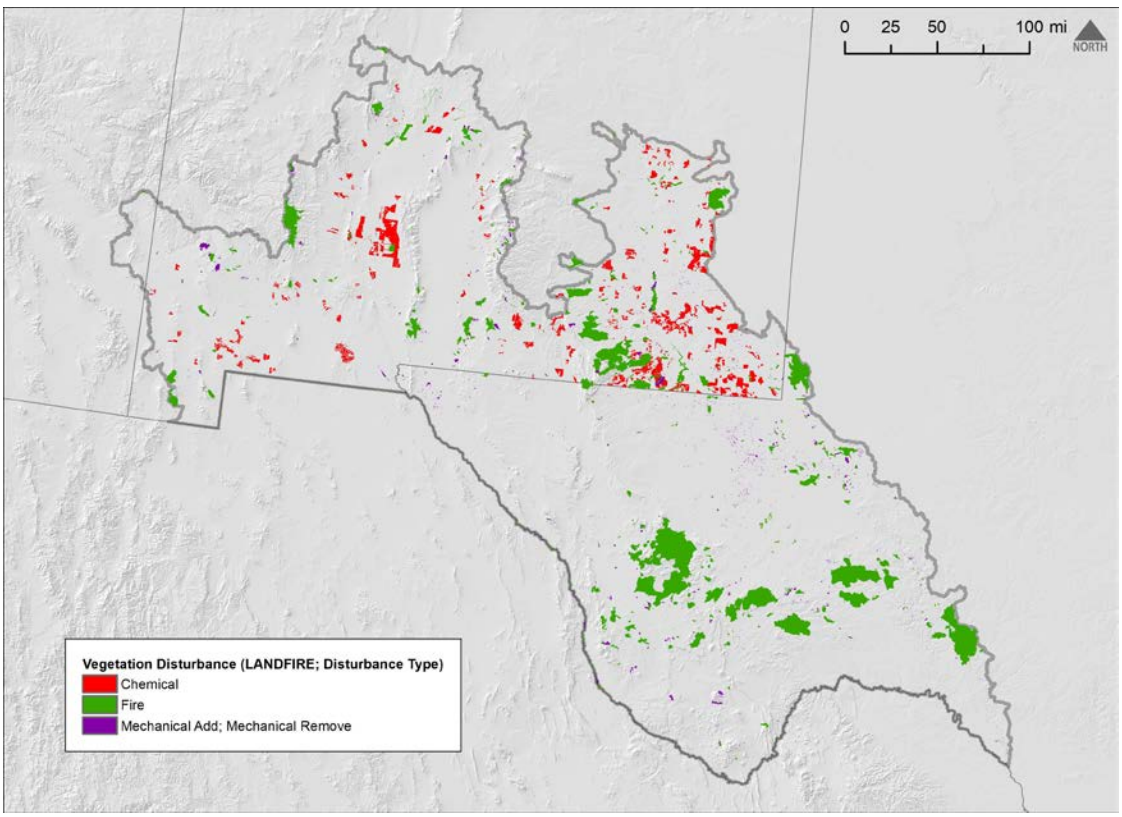


Figure 6-18 presents data from the BLM New Mexico program, showing the cumulative distribution of vegetation treatments through June 1, 2017. The BLM dataset contains several data fields concerning the types of vegetation treatments applied. Figure 6-18 summarizes these data by three categories: chemical, prescribed fire, and physical (e.g., mechanical) treatment. The BLM dataset does not include several of the burns recorded in the wildfire datasets examined earlier in this chapter, indicating that the burns missing from the BLM vegetation treatments map were not prescribed fire treatments.

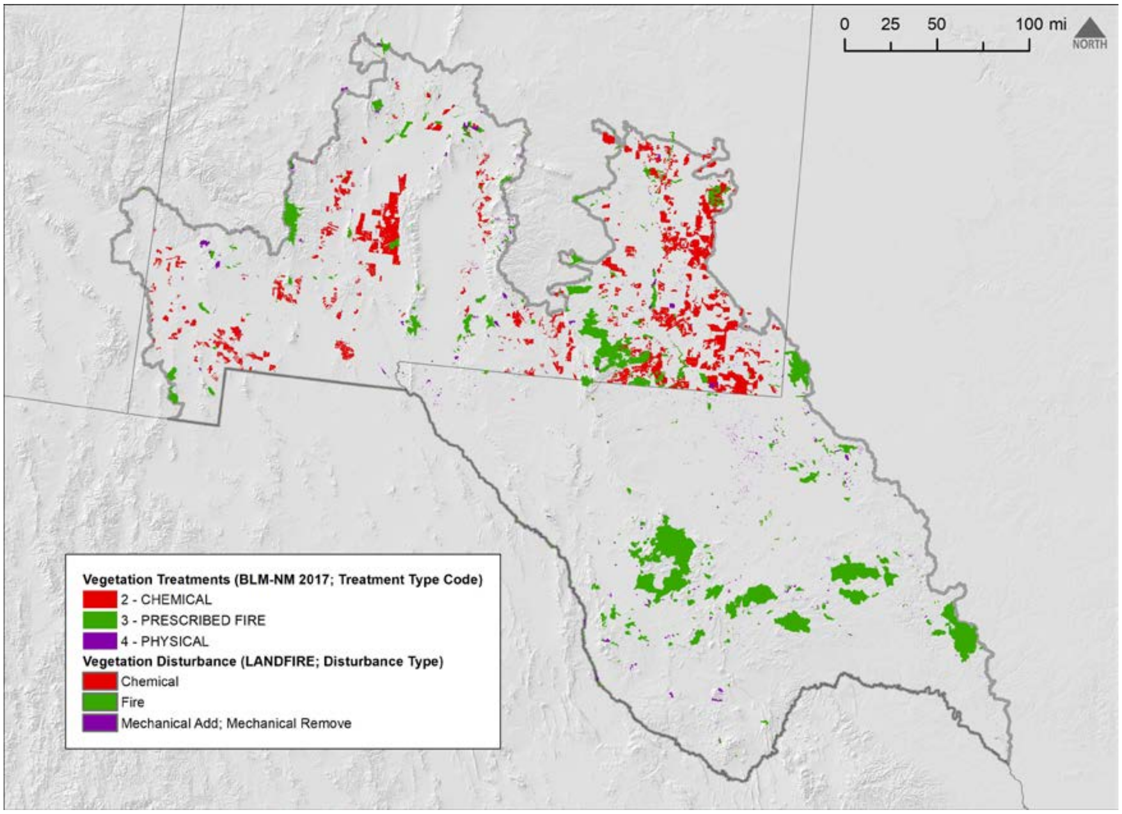
Figure 6-19 presents data from the LANDFIRE program, showing the distribution of vegetation disturbance (VDIST) events, 1999-2014 (LANDFIRE 2016). The LANDFIRE dataset also contains several data fields on the types of vegetation treatments applied. As with Figure 6-18, to simplify comparisons, Figure 6-19 summarizes the LANDFIRE VDIST data by three categories: chemical, prescribed fire, and physical (e.g., mechanical) treatment. The LANDFIRE VDIST dataset includes many of the same events as the BLM vegetation treatments dataset, but differs in including Texas and including both wildfires and prescribed burns.

Figure 6-19. Vegetation disturbances based on LANDFIRE Vegetation Disturbance (VDIST) data.



Finally, Figure 6-20 combines the BLM vegetation treatment data with the LANDFIRE VDIST data to provide a snapshot of the entire analysis extent. The distribution of fire treatment types closely matches the distribution of burns indicated in the maps of wildfire earlier in the present chapter. The earlier maps covered a longer sweep of time, however, 1985-2016 versus 1999-2016 in the LANDFIRE VDIST data. Chapters 7-10 discuss the distribution of landscape restoration treatment types in relation to the distributions of all CEs.

Figure 6-20. Vegetation treatments and disturbances, BLM and LANDFIRE VDIST data combined.



7 Terrestrial Ecological System Conservation Elements

7.1 Introduction

This chapter presents the assessments focused on the three dryland ecological system Conservation Elements (CEs), Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands. Nine Management Questions (MQs) concern or include these three CEs, as follows:

MQ A: What is the geographic distribution of each CE?

MQ B: What is the current condition of each CE across its geographic distribution?

MQ C: What is the current geographic distribution of the impacts of each Change Agent (CA) in relation to each CE?

MQ D: What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?

MQ 1: Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?

MQ 2: What is the geographic distribution of the Chihuahuan desert amphibian assemblage?

MQ 6: Where will urban and industrial growth impact intact grasslands or impede their recovery?

MQ 7: How do the current and historic geographic distributions of the dry-system CEs differ?

MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Chapter 4, above, addresses the forecasted impacts of climate change on the three dryland ecological system Conservation Elements, part of the subject of MQ D. Chapters 5 and 6, above, address the current impacts of the other CAs, the subject of MQ C. Chapter 6 also addresses MQ 1, concerning the distribution and effectiveness of restoration treatments. The assessment of the Chihuahuan desert amphibian assemblage, the subject of MQ 2, addresses four species, the Arizona toad (*Anaxyrus microscaphus*), Chiricahua leopard frog (*Lithobates (*aka *Rana) chircahuaensis*), northern leopard frog *(L. pipiens*), and Yavapai leopard frog (*L. yavapaiensis*). Only one of these four amphibians, the Arizona toad, uses upland habitat, while all four use aquatic or wetland habitats during some part(s) of their life cycles. Consequently, this report addresses MQ 2 in Chapter 8, Aquatic and Wetland Systems, rather than here in Chapter 7. Chapter 5 addresses MQ 6, concerning where urban and industrial growth may impact intact grasslands or impede their recovery, a topic that overlaps with that of MQ C. Section 7.3 in the present chapter addresses MQ 7, concerning differences between the current and historic geographic distributions of the three dryland ecological system CEs, as part of an overall consideration of the current condition of these three CEs. Finally, Section 7.4 in the present chapter addresses MQ 13. This MQ concerns the geographic distribution of the impacts of gypsic soil and water on ecological conditions, both in general and in relation to each of the three dryland ecological system CEs.

7.2 Conservation Element Distributions

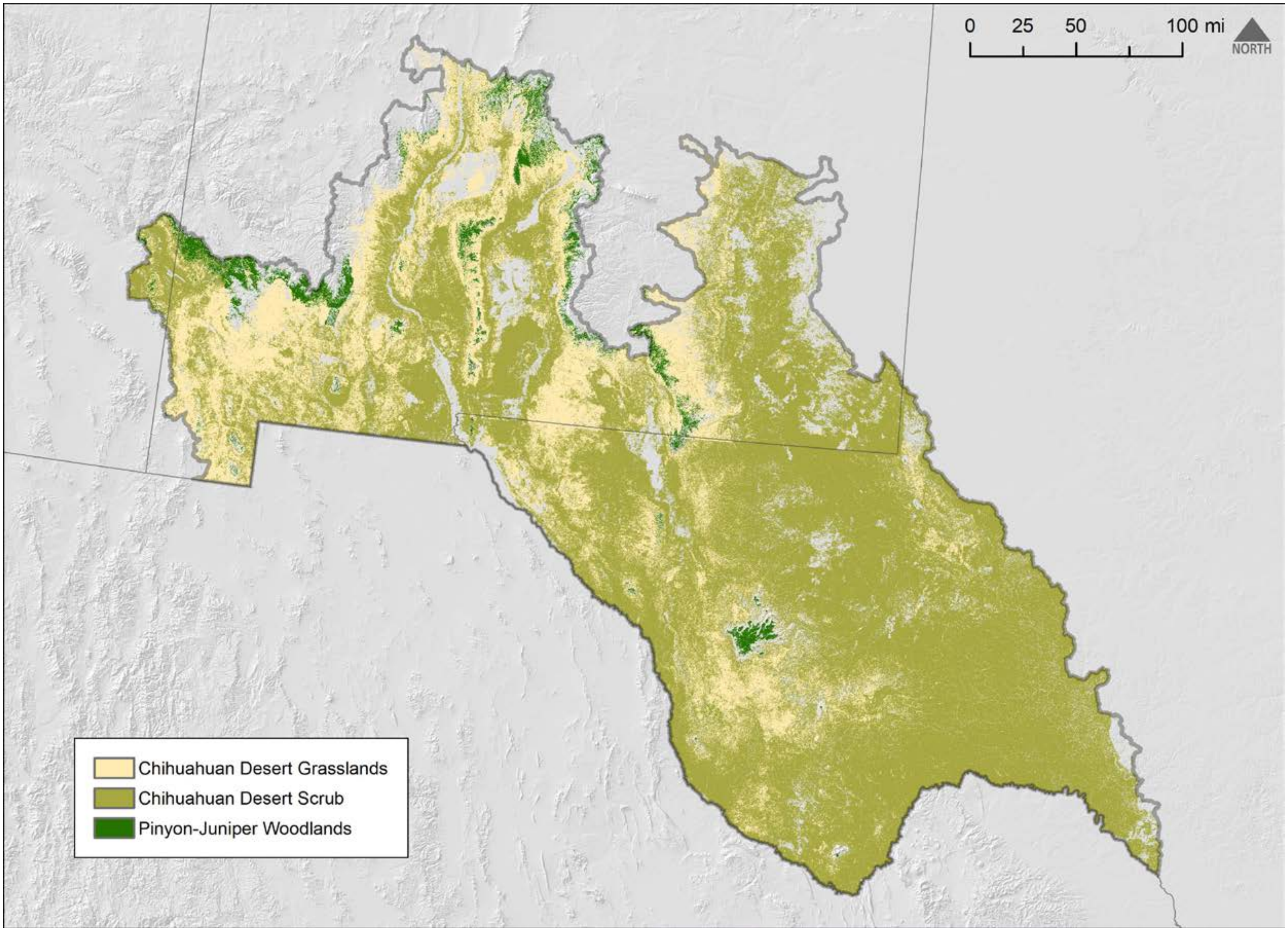
Figure 7-1 shows the current distributions of the three terrestrial ecological system CEs, based on the following data (see also Pre-Assessment Report, Chapters 5-7, Unnasch et al. 2017):

- Chihuahuan Desert Grasslands: National GAP Land Cover Data (USGS 2011, Gergely and McKerrow 2016) for the following ecological systems: Apacherian-Chihuahuan Semi-Desert Grassland and Steppe; Chihuahuan Loamy Plains Desert Grassland; Chihuahuan-Sonoran Desert Bottomland and Swale Grassland; Chihuahuan Sandy Plains Semi-Desert Grassland; and Madrean Juniper Savanna.
- Chihuahuan Desert Scrub: National GAP Land Cover Data (USGS 2011, Gergely and McKerrow 2016) for the following ecological systems: Apacherian-Chihuahuan Mesquite Upland Scrub; Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub; Chihuahuan Mixed Desert and Thorn Scrub; Chihuahuan Mixed Salt Desert Scrub; Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub; Chihuahuan Succulent Desert Scrub; Tamaulipan Calcareous Thornscrub; Tamaulipan Mesquite Upland Scrub; and Tamaulipan Mixed Deciduous Thornscrub.
- Pinyon-Juniper Woodlands: National GAP Land Cover Data (USGS 2011, Gergely and McKerrow 2016) for the following ecological systems: Madrean Pinyon-Juniper Woodland; and Southern Rocky Mountain Pinyon-Juniper Woodland.

The National GAP Land Cover data are based on Landsat Thematic Mapper (TM) satellite imagery (1999-2001) and a variety of other datasets (USGS 2011). Areas in Figure 7-1 not covered by one of the three terrestrial ecological system CEs (colorless areas in Figure 7-1) are covered by other spatially extensive CE types, such as Playas and Playa Lakes, by spatially limited ecological system types, and by various types of development (see above, Chapter 5).

The distributions of the three terrestrial ecological system CEs across the U.S. portion of the ecoregion largely reflect the interactions of climate and topography, as discussed in the Pre-Assessment Report (Unnasch et al. 2017) and earlier in the present report (see above, Chapters 2 and 4). The Chihuahuan Desert Grasslands CE occurs on piedmonts, foothills, and lowlands mainly between 1,100 and 1,700 m in elevation. These topographic zones tend to experience slightly less precipitation and slightly cooler temperatures than do areas at lower elevations, which in turn are dominated by the Chihuahuan Desert Scrub CE. In turn, the Pinyon-Juniper Woodlands CE occurs generally at elevations between 1,400 and 2,200 m in elevation. These elevations experience slightly greater precipitation and slightly cooler temperatures compared to areas dominated by Chihuahuan Desert Grasslands. Pinyon-juniper woodlands in fact are often bordered by grasslands at their lower elevations. The separation of grasslands from woodlands in the U.S. portion of the ecoregion reflects the impacts of precipitation patterns and long-term climate variations on fundamental aspects of plant physiology: The success of C_4 perennial grasses at low elevations depends on summer precipitation (Havstad and Schlesinger 2006), while C_3 shrubs in grasslands and woody species at higher elevation rely more on winter precipitation.

Figure 7-1. Distribution of terrestrial ecological system CEs.



7.3 Conservation Element Current Conditions

The REA assessed the current conditions of the three terrestrial ecological system CEs using three types of information, on: (1) the distribution of impacts from the change agents assessed in Chapters 4-6; (2) current conditions for which no reference values are available; and (3) current conditions for which information on estimated reference conditions is available for comparison.

7.3.1 Impacts of Change Agents

Chapter 4, above, addresses in detail the ways in which climate change potentially will affect the present locations of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs, and potentially affect their future distributions. The results forecast that the area currently occupied by the Chihuahuan Desert Grasslands CE will shrink, replaced by the Chihuahuan Desert Scrub CE. The results also forecast that the area currently occupied by the Pinyon-Juniper Woodlands CE will recede upward in elevation or disappear, depending on local topographic relief, replaced by grasslands and/or scrub.

Chapter 5, above, discusses the present and forecasted future distributions of development within the analysis extent. Most residential, commercial, industrial, and irrigated agricultural development within the analysis extent occurs within areas formerly dominated by scrub or on lands formerly dominated by cover types other than the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs. Alamogorda, Deming, and Silver City, New Mexico, may be exceptions to this overall pattern: their residential, commercial, and industrial development occupies areas formerly dominated by grasslands. In turn, most future residential, commercial, and industrial development across the analysis extent similarly is forecasted to largely affect areas of scrub vegetation. However, lands in far western New Mexico around Deming and Silver City, and along the U.S.-54 corridor from Alamogorda north to Carrizozo along the east side of the Tularosa Basin, also in New Mexico, again are exceptions. Around these latter communities, residential, commercial, and industrial development may substantially encroach on existing grassland vegetation instead.

Oil and gas development is concentrated in a part of the ecoregion largely dominated by scrub vegetation and cover types other than the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs. The only substantial exception to this relationship is a zone of greater grassland cover in Texas immediately adjacent to and extending roughly south-southeast from the southeastern corner of New Mexico. This latter zone lies in an area of already intense oil and gas development.

Chapter 5, above, also discusses the distribution of grazing allotments on U.S. Forest Service and BLM lands within the REA analysis extent in Arizona and New Mexico. These allotments include nearly every area of occurrence of the Chihuahuan Desert Grasslands CE within the REA analysis extent in these two states. As noted in Chapter 5, however, the REA was not able to acquire any data on grazing intensity or impacts within the allotments or on the large expanses of private land used for livestock grazing in New Mexico and Texas.

Chapter 6, above, discusses the distribution of invasive plants across the REA analysis extent, based on County-scale data. The data presented in Chapter 6 indicate that non-native grasses, such as cheatgrass, Lehmann lovegrass, and buffelgrass, occur widely throughout the REA analysis extent. The overlapped distributions of the several invasive plant species assessed cover every county within and overlapping the analysis extent many times over. However, as also discussed in Chapter 6, the data are too spatially coarse to be helpful in assessing the extent to which these numerous non-native species have altered the composition, structure, or function of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs in different parts of the analysis extent. Even without such regional-scale data, however, invasive plants are widely documented as ubiquitous – and often as ecologically disruptive – in all three terrestrial ecological system CEs, as discussed in detail in the Pre-Assessment report (Unnasch et al. 2017, Chapters 5-7).

Chapter 6 also discusses the potential impacts of uncharacteristic wildfire on the three terrestrial ecological system CEs. Wildfires between 1985 and 2016 occurred relatively frequently across areas of the Pinyon-Juniper Woodlands CE (12% burned), only slightly less frequently across areas of the Chihuahuan Desert Grasslands CE (7% burned), and substantially less frequently across areas of the Chihuahuan Desert Scrub CE (3% burned). Table 7-1 shows the distribution of LANDFIRE vegetation departure (VDEP) values (LANDFIRE 2016) by percentile for each of the three terrestrial ecological system CEs, based on the data displayed in Chapter 6, Figures 6-14 – 6-16. VDEP values, largely but not exclusively a consequence of altered fire patterns, are high across the current distribution of the Chihuahuan Desert Grasslands CE, with over half of its total area exhibiting VDEP values between 51 and 70% and more than 76% exhibiting VDEP values >50%. The current distribution of Chihuahuan Desert Scrub CE includes several very large areas with VDEP values < 50%, although the distribution also includes several very large areas with VDEP values between 61 and 80% as well. As a result, more than 61% of all Chihuahuan Desert Scrub pixels have VDEP values >50%. VDEP values are mostly below 40% across the distribution of Pinyon-Juniper Woodlands, with a secondary concentration of VDEP values between 51 and 60%. Barely half of all Pinyon-Juniper Woodlands pixels have VDEP values >50%.

Table 7-1. Vegetation Departure (VDEP) percentile distributions by terrestrial ecological system CE.

CE➔ VDEP Percentile🡻	Chihuahuan Desert Grasslands CE	Chihuahuan Desert Scrub CE	Pinyon-Juniper Woodlands CE
0-10%	5.64%	10.72%	8.86%
11-20%	1.89%	8.70%	13.56%
21-30%	8.96%	11.11%	3.37%
31-40%	2.80%	2.90%	23.42%
41-50%	4.33%	5.48%	0.54%
51-60%	18.04%	6.55%	29.92%
61-70%	33.21%	28.20%	5.83%
71-80%	7.89%	16.30%	8.26%
81-90%	10.91%	4.40%	5.54%

Table 7-2 shows the distribution of Wildfire Hazard Potential (WHP) for each of the three terrestrial ecological system CEs, based on the data displayed in Chapter 6, Figure 6-17. In contrast to the VDEP results, High to Very High WHP values occur almost exclusively across the higher-elevations currently dominated by the Pinyon-Juniper Woodlands CE, including the east-facing slopes of the mountains the border the west side of the Rio Grande valley, and the west-facing slopes of the mountains that border the east side of the Tularosa Basin. The only exception to this pattern of distribution of WHP values occurs in the Pecos River valley, where an area of primarily scrub vegetation from Roswell northward also has WHP values in the High to Very High range.

Table 7-2. Wildfire Hazard Potential (WHP) severity distribution by terrestrial ecological system CE.

CE➔ WHP severity🡻	Chihuahuan Desert Grasslands CE	Chihuahuan Desert Scrub CE	Pinyon-Juniper Woodlands CE
1: Very Low	72.31%	83.03%	33.58%
2: Low	22.00%	13.93%	20.71%
3: Moderate	4.07%	1.29%	21.66%
4: High	1.37%	1.43%	17.28%
5: Very High	0.25%	0.31%	6.77%

Finally, Chapter 6 also discusses the distribution of landscape restoration treatments across the analysis extent. The data presented in Chapter 6 do not indicate the vegetation type(s) that each restoration treatment sought to restore. Table 7-3 shows the percentage of each treatment type (by area) that took place within areas dominated by each of the three terrestrial ecological system CEs, using the BLM vegetation treatment data presented in Chapter 6, Figure 6-18. The LANDFIRE Vegetation Disturbance (VDIST) data shown in Chapter 6, Figure 6-19, include both prescribed fires and wildfires, and therefore are not included in Table 7-3. Both chemical and physical (mechanical) treatments have been applied more often to the Chihuahuan Desert Scrub CE than to the other two terrestrial ecological systems. Prescribed fire treatments have been applied roughly equally the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs. Areas dominated by the Pinyon-Juniper Woodlands CE receive the least attention, across all three treatment types.

Table 7-3. Distribution of landscape restoration treatment types by terrestrial ecological system CE.

Treatment type➔ CE🡻	Chemical Treatments	Prescribed Fire Treatments	Physical Treatments
Chihuahuan Desert Grasslands	23.72%	45.08%	18.75%
Chihuahuan Desert Scrub	75.65%	44.92%	60.99%
Pinyon-Juniper Woodlands	0.62%	10.00%	20.26%

7.3.2 Non-Referenced Condition Indicators

Figure 7-2 shows LANDFIRE Existing Vegetation Cover (EVC) data for the REA analysis extent (LANDFIRE 2016). The EVC data provide estimates of the vertically projected percent of live tree, shrub and herbaceous canopy cover on a 30-m grid cell. The estimates are based on relationships calculated between ground-level training data and a combination of Landsat, elevation, and ancillary data. The training data for the canopy estimates consist of plot data from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (USDA FS 2017, http://fia.fs.fed.us/; Toney et al. 2009) and other ground-based monitoring programs (LANDFIRE 2016).

The LANDFIRE EVC estimates shown in Figure 7-2 indicate that vegetation cover varies widely within the areas currently occupied by the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs. Both tree and herbaceous cover percentages generally increase with elevation within their overall geographic distributions (see Figure 2-3 in Chapter 2, above). However, two areas distinctly do not follow this broad pattern: (1) An area of very low herbaceous cover extending south from the Sacramento Mountains in New Mexico well into Texas, along an arc of generally higher terrain currently occupied by the Chihuahuan Desert Grasslands CE; and (2) an area of moderately high shrub cover and high herbaceous cover across the northern Pecos River valley roughly from the vicinity of Roswell, New Mexico northward. As noted in Chapter 6, above, the latter area also has very high values for both vegetation departure (LANDFIRE VDEP) and Wildfire Hazard Potential.

Figure 7-2. Percent herb, shrub, tree cover based on LANDFIRE Existing Vegetation Cover (EVC) data.

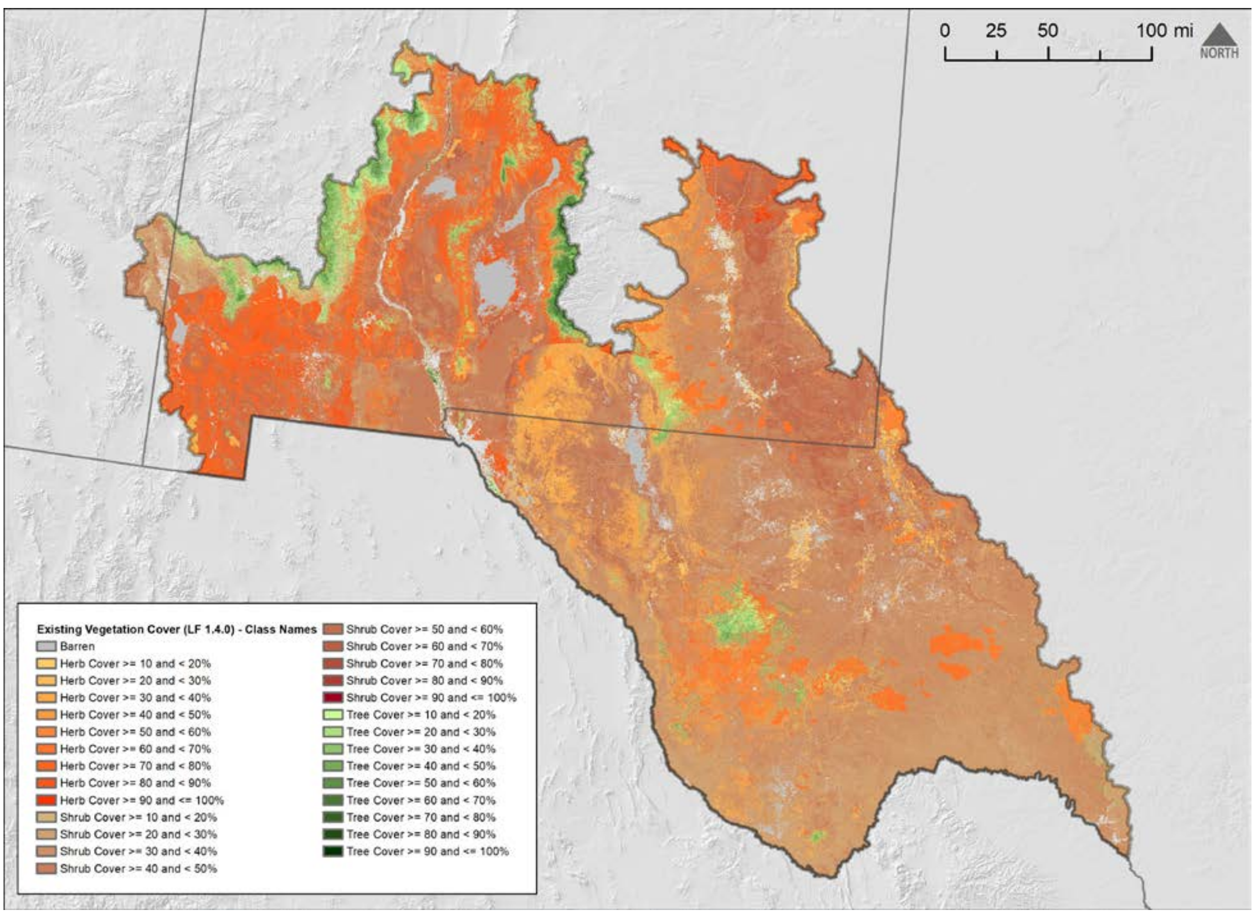
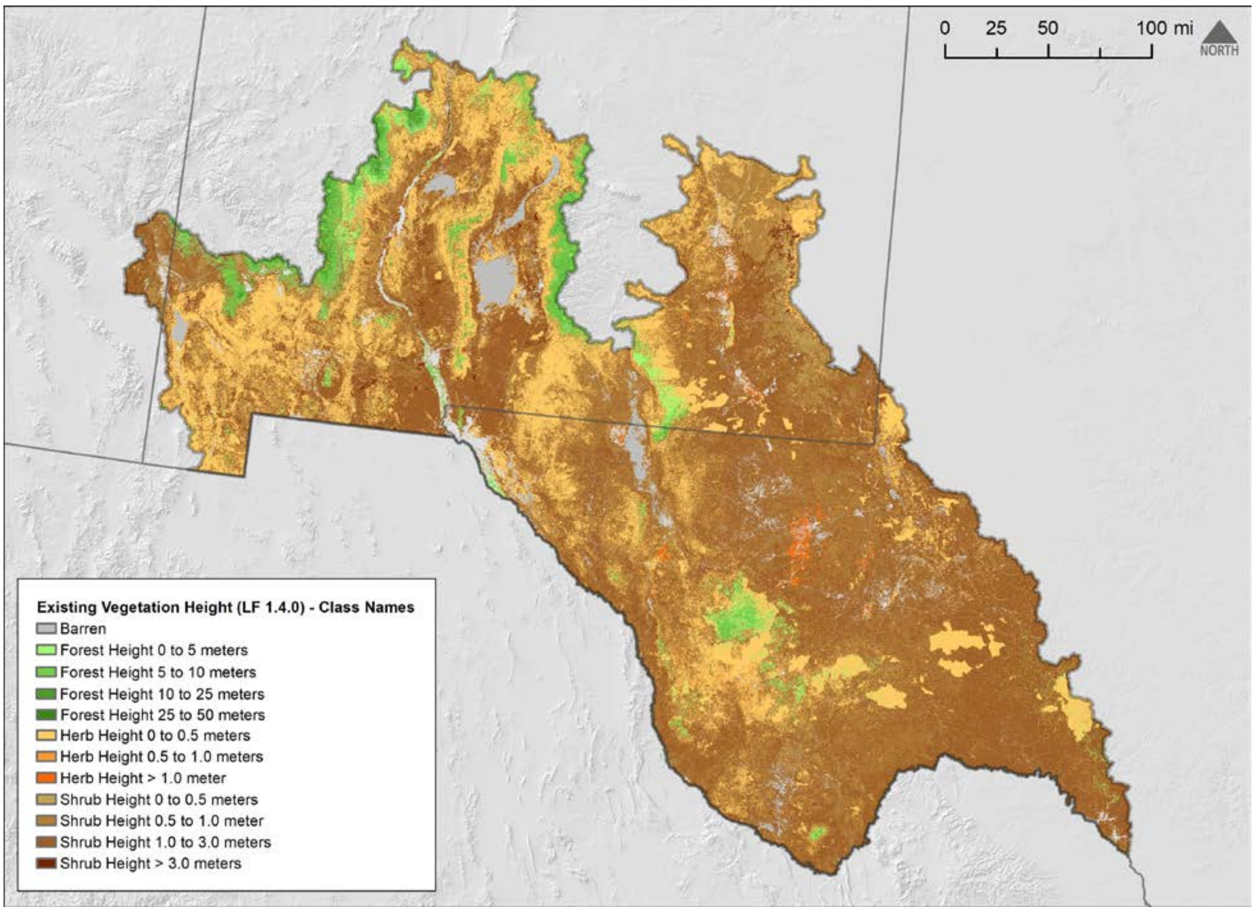


Figure 7-3 shows LANDFIRE Existing Vegetation Height (EVH) data for the REA analysis extent (LANDFIRE 2016). These data provide estimates of the average height of the dominant vegetation on a 30-m grid, calculated separately for tree, shrub and herbaceous lifeforms using training data and other layers. The estimates are based on relationships calculated between ground-level training data and a combination of Landsat, elevation, and other data. As with the LANDFIRE EVC data discussed above, the training data for the canopy height estimates consist of plot data from the USDA Forest Service, Forest Inventory and Analysis (FIA) program (USDA FS 2017, http://fia.fs.fed.us/; Toney et al. 2009) and other ground-based monitoring programs (LANDFIRE 2016).

Figure 7-3. Vegetation height based on LANDFIRE Existing Vegetation Height (EVH) data.



The LANDFIRE EVH estimates shown in Figure 7-3 indicate that herbaceous vegetation height is generally less than 0.5 m, except in scattered locations mostly along the Pecos River in New Mexico and in the vicinity of the town of Pecos, Texas. Shrub height also is generally less than 3.0 m, but large areas across the northern third of the analysis extent are estimated to have shrub heights less than 1.0 m. A few small patches with estimated shrub heights greater than 3.0 m also occur scattered across the northern third of the analysis extent. Forest canopy height varies fairly consistently with elevation. The area indicated in Figure 7-2 with moderately high shrub cover and high herbaceous cover across the northern

Pecos River valley roughly from the vicinity of Roswell, New Mexico northward, shows in Figure 7-3 as having relatively low shrub height, generally below 0.5 m.

7.3.3 Referenced Condition Indicators

Chapter 6, above, presents and discusses data on the degree to which current land cover vegetation within the REA analysis extent differs from estimated historic conditions based on LANDFIRE Vegetation Departure (VDEP) data (LANDFIRE 2016). The VDEP dataset excludes areas with development cover types and natural barrens. VDEP values range from 0 - 100, indicating a range from unaltered vegetation to a complete departure from expected vegetation composition, structural stage, and canopy closure.

The VDEP results discussed in Chapter 6 (see Figures Figure 6-14 – Figure 6-16) show areas of high to extremely high VEDP values in three zones: (1) along the lower elevations of the Rio Grande valley in New Mexico and the adjacent Jornada del Muerto and Jornada Draw closed valleys immediately to the east that mostly encompass areas of Chihuahuan Desert Grassland; (2) along the lower elevations of the Pecos River valley roughly from the vicinity of Roswell, New Mexico, northward, that mostly encompass areas of Chihuahuan Desert Scrub; and (3) along a band extending westward from the Rio Grande valley to the Arizona border. Conversely, the VDEP results discussed in Chapter 6 (see Figures 6-14 – 6-16) show three large areas of low to extremely low VDEP values: (1) across the Tularosa and Salt Basin closed valleys, roughly within the large military reservations that encompass these areas; (2) across the Rio Grande valley through the Big Bend region, and across much of the southernmost Pecos River valley; and (3) across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range that comprise the northwestern boundary of the analysis extent. The first two of these three zones with low VDEP values encompass areas dominated by the Chihuahuan Desert Scrub CE; the last of the three zones with low VDEP values encompasses areas dominated by the Pinyon-Juniper Woodlands CE.

Figure 7-4 and Figure 7-5 provide additional information for comparing current to reference conditions for the three terrestrial ecosystem CEs. Figure 7-4 shows LANDFIRE Existing Vegetation Type (EVT) data (LANDFIRE 2016) for three generalized vegetation cover types – conifer woodland, grassland, and shrubland – that correspond closely to the Pinyon-Juniper Woodlands, Chihuahuan Desert Grasslands, and Chihuahuan Desert Scrub CEs (compare Figure 7-1 with Figure 7-4). Figure 7-5, in turn, shows LANDFIRE Biophysical Setting (BpS) data (LANDFIRE 2016) for these same three generalized vegetation cover types. BpS models estimate the likely spatial distributions of historic ecosystems prior to Euro-American settlement on a 30-m grid based on their geophysical requirements, using the same cover types addressed in the EVT dataset. It "… represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement … based on both the current biophysical environment and an approximation of the historical disturbance regime [based on] current scientific knowledge regarding the functioning of ecological processes - such as fire - in the centuries preceding non-indigenous human influence… The BpS data layer is used in LANDFIRE to depict reference conditions of vegetation across landscapes. The actual time period for this data set is a composite of both the historical context provided by the fire regime and vegetation dynamics models and the more recent field and geospatial data used to create it" (LANDFIRE 2016, biophysical setting metadata at https://www.landfire.gov/NationalProductDescriptions20.php).

Figure 7-4. Current distributions of conifer woodland, grassland, and shrubland cover based on LANDFIRE Existing Vegetation Type (EVT) data.

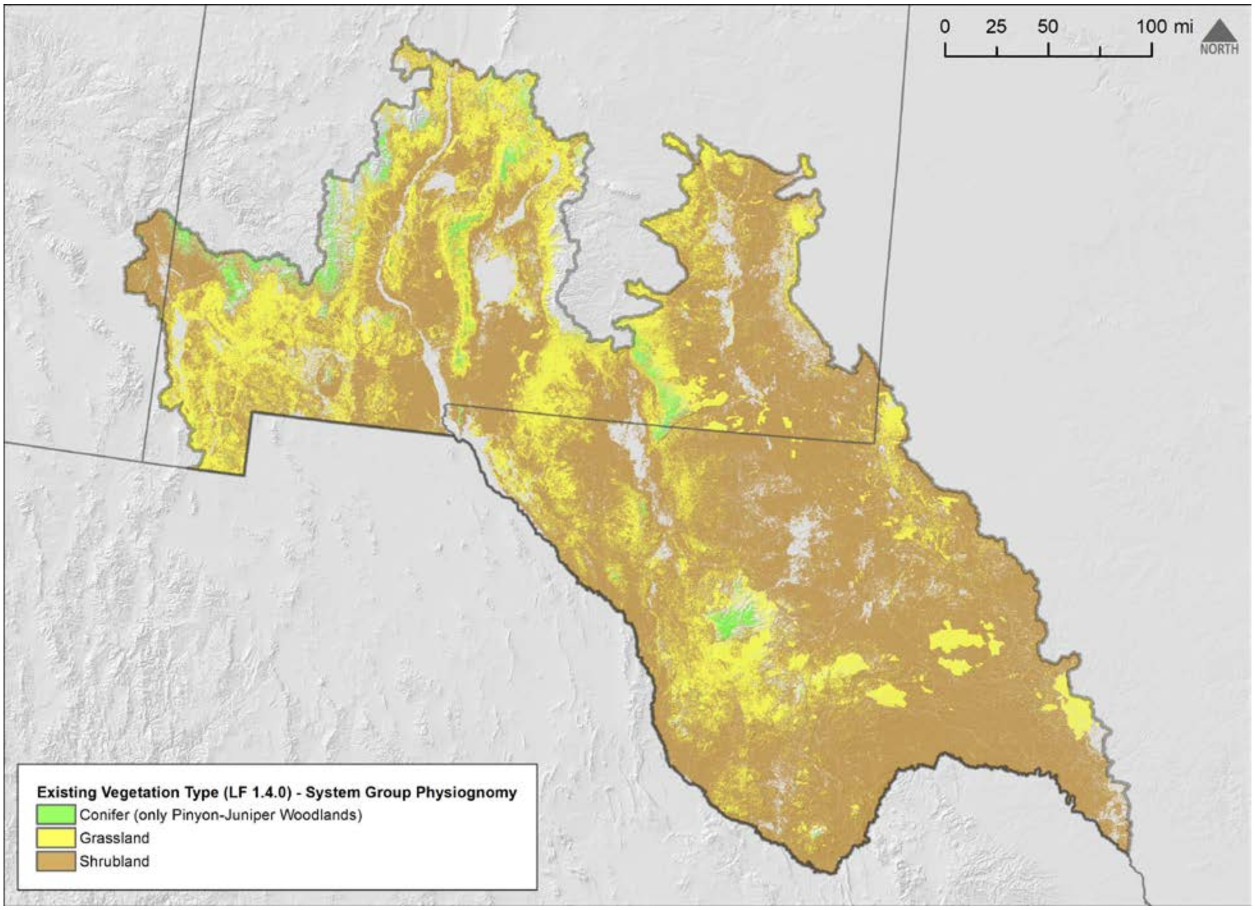


Table 7-4 compares the distributions of the conifer woodland, grassland, and shrubland general cover types, between current conditions and estimated historic, reference conditions, based on the LANDFIRE EVT and BpS datasets, respectively. Table 7-4 compares Figure 7-4 with Figure 7-5, quantifying the extent of change (difference) between the estimated historic and current distributions of these general land cover types. Table 7-4 shows that only 29% of the area estimated to have had predominantly grassland cover under historic conditions prior to Euro-American settlement remains grassland today, while nearly 65% of the area of historic grassland cover has transitioned to shrubland today. In contrast, nearly 72% of the area estimated to have had predominantly shrubland cover under historic conditions remains shrubland today, while only 21% of the area of historic shrubland cover has transitioned to grassland. Nearly 47% of the area estimated to have had predominantly conifer woodland cover under historic conditions remains conifer woodland today. Roughly 19% of the estimated area of historic conifer woodland cover has transitioned to grassland, and nearly 13% has transitioned to shrubland. Almost no area of either historic grassland or shrubland has transitioned to conifer woodland cover.

Nearly 6% of the estimated historic area of grassland cover, nearly 7% of the estimated historic area of shrubland cover, and nearly 22% of the estimated historic area of conifer woodland cover have transitioned to other cover types (i.e., other than shrubland or conifer woodland).

Figure 7-5. Historic distributions of conifer woodland, grassland, and shrubland cover based on LANDFIRE Biophysical Setting (BpS) estimates.

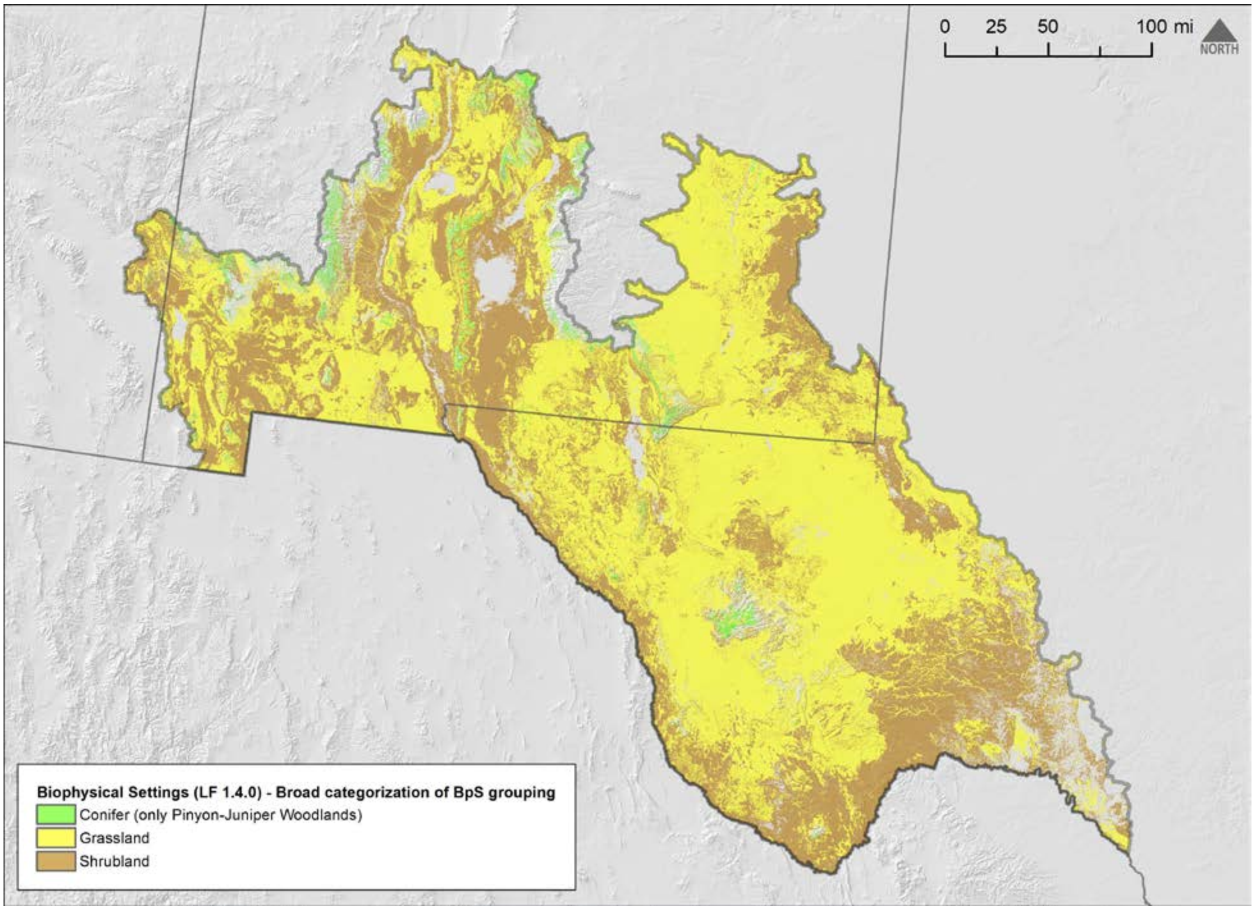


Table 7-4. Change from estimated historic to current distributions of grassland, shrubland, and conifer woodland cover based on LANDFIRE BpS and EVT datasets.

Changed to (EVT)➔ From (BpS)🡇	Current Grassland Cover	Current Shrubland Cover	Current Conifer Woodland Cover	Other Cover	Total
Historic Grassland Cover	29.09%	64.77%	0.39%	5.74%	100%
Historic Shrubland Cover	21.04%	71.55%	0.46%	6.94%	100%
Historic Conifer Woodland Cover	19.03%	12.76%	46.61%	21.60%	100%

Table 7-5 summarizes the changes from the estimated historic distributions of grassland, shrubland, and conifer woodland cover addressed in Figure 7-4, Figure 7-5, and Table 7-4. Among all pixels within the analysis extent classified in the BpS dataset as dominated by either grassland, shrubland, or conifer woodland, more than 61% were classified as dominated by grassland, with shrubland cover occurring on nearly 37%. In contrast, among all pixels within the analysis extent currently dominated by either grassland, shrubland, or conifer woodland, more than 66% were classified as dominated by shrubland, with grassland cover occurring on only approximately 26%.

Table 7-5. Overall proportions of estimated historic and current grassland, shrubland, and conifer woodland cover based on LANDFIRE BpS and EVT datasets, respectively.

Cover Type	Historic	Current
Grassland	61.14%	25.93%
Shrubland	36.97%	66.30%
Conifer	1.89%	1.29%
Total	100%	93.52%

7.4 Distribution and Impacts of Gypsum in Soil and Water

MQ 13 asks, what is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA? This MQ arose out of concerns that gypsic soil and water in the U.S. portion of the ecoregion potentially have created unique ecological conditions warranting special management attention.

As discussed in the Pre-Assessment Report, Chapters 2-3 (Unnasch et al. 2017), the geological history of the U.S. portion of the ecoregion has resulted in the widespread presence of sedimentary bedrock formations with high concentrations of evaporites, both halites and sulfates including anhydrite, the latter of which transforms into gypsum when exposed to water. Erosion and leaching of water through these formations has resulted in the widespread presence of gypsum-enriched soils, surface water, and groundwater. Heavy precipitation during the Pleistocene created several large, salty lakes, the post-Pleistocene evaporation of which concentrated their salts in playas and playa lakes, for example in the Tularosa Basin and in the Salt Basin near Dell, Texas (Bachman 1981, 1987, Hussain and Warren 1989, Hawley 1993, Angle 2001, Monger et al. 2006, NPS-CDIMN 2010). Evaporation from these gypsum-rich playas and playa lakes, and wind erosion of the resulting exposed evaporites, also sometimes has given rise to dune fields of gypsum crystals, such as at White Sands in the Tularosa Basin (NPS-CDIMN 2010, Szynkiewicz et al. 2010).

Even outside the areas formerly covered by Pleistocene lakes, exposures of evaporite-rich sedimentary formations contribute salt and gypsum to the overlying soils (El Hage and Moulton 1998, Monger et al. 2006, McCraw et al. 2007, Moore and Jansen 2007, McCraw 2008, Hudnall and Boxell 2010). Watershed runoff from these areas results in elevated salt and gypsum concentrations in the receiving streams, including the Pecos River. Further, evaporation in areas with gypsum-enriched groundwater has drawn gypsum toward the ground surface (El Hage and Moulton 1998, Cowley et al. 2003, Miyamoto et al. 2005, Hoagstrom 2009, Stafford et al. 2009, Hogan 2013, Szynkiewicz et al. 2015a, 2015b). Subsurface leaching of evaporite-rich sedimentary formations also results in the formation of karst landscapes in some areas, through the collapse of caves created by the dissolution of mineral salts. This subsurface leaching produces elevated concentrations of halites and gypsum in the groundwater that passes through these deposits – groundwater that in turn may emerge in sinkholes, at springs, or along seepage faces beneath streams (e.g., recently, Stafford et al. 2008a, 2008b, 2008c, 2009, Land and Huff 2010, Partey et al. 2011, Land and Veni 2012, Szynkiewicz et al. 2012, Stafford 2013, Sigstedt et al. 2016).

Salts in soils and water, in general, and gypsum in soils and water, in particular, place severe physiological demands on any plants or animals that may live there, including microbes and macroinvertebrates. These demands in turn select for biota with unique adaptations (e.g., Moore and Jansen 2007, Moore et al. 2015). The geologic history of the U.S. portion of the Chihuahuan desert ecoregion therefore has selected for an array of plant and animal species with unique physiological adaptations to the saline and/or gypsic soils, playas and playa lakes, springs, and streams of much of the area (e.g., Waterfall 1946, Miller 1977, Blinn 1993, Edwards 1997, Hoagstrom and Brooks 1999, Propst 1999, MacRae et al. 2001, Lang and Rogers 2002, Cowley et al. 2003, Howells 2003, Lang et al. 2003, White et al. 2006, Grunstra and Van Auken 2007, Moore and Jansen 2007, Hoagstrom 2009, Turner et al. 2010, USFWS 2010, Turner and Edwards 2012, USBR 2012, USFWS 2013). Land managers across the U.S. portion of the ecoregion therefore may need to take into account the distribution of gypsic soil and water conditions, and native species uniquely adapted to these conditions, in making land-management decisions.

A review of the land-cover data on ecological system types across the U.S. portion of the ecoregion, carried out as part of this REA, revealed that these types do not consistently capture all areas where gypsic geology, geochemistry, and soils affect terrestrial or wetland or aquatic ecological conditions (see the Pre-Assessment Report, Chapters 2-3, Unnasch et al. 2017). On the other hand, as also discussed in the Pre-Assessment Report, Chapters 2-3 (Unnasch et al. 2017), numerous studies and reports exist on the gypsic bedrock geology, soils, playas, dunes, aquifers, karst regions, saline waters, and biota of the ecoregion. This literature documents a strong relationship between the bedrock geology of the ecoregion and the distribution of gypsic geochemical, soil, and watershed conditions across the U.S. portion of the ecoregion. This relationship, together with the availability of data on the distribution of gypsum- and anhydrite-bearing geologic formations and gypsic soils across the U.S. portion of the ecoregion, makes it possible to assess the geographic distribution of localities where gypsic geochemical, soil, and watershed conditions may affect ecological conditions and resources.

Table 7-6 lists the sedimentary geologic formations in the U.S. portion of the ecoregion, the descriptions of which in the State geologic atlases for New Mexico and Texas (New Mexico Bureau of Geology and Mineral Resources 2003, USGS and TNRIS 2016) indicate that the formations contain gypsum and/or anhydrite. The geologic atlases show the distribution of surface exposures. The overall, combined surface and subsurface distributions of these formations – and their ability to contribute to groundwater chemistry – are necessarily larger.

Table 7-6. Sedimentary geologic formations within the analysis extent containing gypsum and/or anhydrite, by state.

State	Map ID[1]	Formation	Sulfate Minerals Reported
NM	Pc	Castile (Upper Permian-Ochoa Series)	Anhydrite
NM	Pgq	Queen and Grayburg (Guadalupian)	Gypsum and anhydrite
NM	Pr	Rustler (Upper Permian)	Gypsum
NM	Psr	Seven Rivers (Guadalupian)	Gypsum and anhydrite
NM	Pty	Tansill and Yates (Guadalupian)	Anhydrite
NM	Py	Yeso (Leonardian)	Gypsum and anhydrite[2]
NM	Qeg	Gypsic eolian deposits	Gypsum
TX	Psc	Salado and Castile	Gypsum and anhydrite
TX	Prc	Rustler, Salado, and Castile	Gypsum
TX	Pru	Rustler (Upper Permian-Ochoa Series)	Gypsum
TX	Pts	Tessey (Permian, Ochoa Series)	Anhydrite[3]
TX	Qao	Old Quaternary	Gypsum[4]
TX	Qb	Young Quaternary	Gypsum[5]
TX	Qg	Gatuna	Gypsum[6]

Notes:

1. The two states use different identification codes for the same formations or different combinations of these (New Mexico Bureau of Geology and Mineral Resources 2003, USGS and TNRIS 2016).
2. The New Mexico Bureau of Geology and Mineral Resources (2003) legend for its Geologic Map of New Mexico identifies the Yeso Formation as the gypsum- and anhydrite-bearing formation present in the Sacramento and San Andres Mountains. The National Park Service identifies these mountains as the sources of the gypsum within White Sands National Monument (NPS 2005). The Yeso formation is likely the source of the gypsum in the soils of the Jornada Experimental Range as well (Monger et al. 2006).
3. The USGS and TNRIS (2016) legend for the Geologic Atlas of Texas characterizes this formation as limestone, but King (1937) states that anhydrite is abundant in the lower 75% of the formation and equates the formation with the gypsum-rich Rustler and Castile formations to the north.
4. The USGS and TNRIS (2016) legend for the Geologic Atlas of Texas characterizes this formation as "[a]lluvium, colluvium, caliche, and gypsite on surfaces dissected by modern drainage."
5. The USGS and TNRIS (2016) legend for the Geologic Atlas of Texas characterizes this formation as "[l]acustrine and fluviatile deposits of clay, silt, sand, and gypsum in bolsons."
6. The USGS and TNRIS (2016) legend for the Geologic Atlas of Texas characterizes this formation as "[m]ostly sand, fine, friable, yellowish to reddish orange, red; some conglomerate, gypsum, limestone, and siltstone, gray, purplish, red, and shale, greenish; upper few feet calichified; ... [c]onfined to New Mexico."

Table 7-7 in turn lists the gypsic soils in the U.S. portion of the ecoregion, based on mineralogy data in the U.S. Department of Agriculture, Natural Resources Conservation Service, STATSGO2 soils database (USDA NRCS 2016, USDA NRCS 2017b). The database classifies soils based on their percent of gypsum by dry weight. The database does not distinguish soils based on the presence or concentration of anhydrite. Table 7-7 lists the Soil Map Units for which the weighted average of the representative value of % gypsum for all layers for the dominant component is >1%, for reasons explained below.

Table 7-7. Soil Map Units by State with >1% Gypsum in the analysis extent.

State	Map Unit (Map Unit Symbol)
NM	Montoya-La Lande-Ima (s5380)
NM	Pecos-Glendale-Bigetty (s5284)
NM	Pima-Harkey-Arno-Anthony (s5264)
NM	Reeves-Holloman-Gypsum land (s5268)
NM	Reeves-Holloman-Gypsum land (s7375)
NM	Reeves-Milner-Hollomex (s5283)
TX	Monahans-Ima-Hodgins (s7483)
TX	Pecos-Patrole-Gila-Arno (s7542)
TX	Reakor-Ratliff-Holloman (s7588)
TX	Reeves-Holloman-Gypsum land (s5268)
TX	Reeves-Holloman-Gypsum land (s7375)
TX	Reeves-Reagan-Orla-Monahans-Hoban (s7373)
TX	Saragosa-Orla (s7519)
TX	Upton-Reeves-Reakor-Iraan-Balmorhea (s7596)
TX	Verhalen-Redona-Reagan-Musquiz (s7598)
TX	Verhalen-Toyah-Reakor-Delnorte-Dalby (s7706)

Figure 7-6 shows the distribution of surface exposures of the sedimentary geologic formations containing gypsum and/or anhydrite across the U.S. portion of the ecoregion, listed in Table 7-6. Figure 7-7 shows the distribution of the Soil Map Units with percent gypsum > 1%, listed in Table 7-7.

Figure 7-6. Distribution of geologic formations containing gypsum and/or anhydrite.

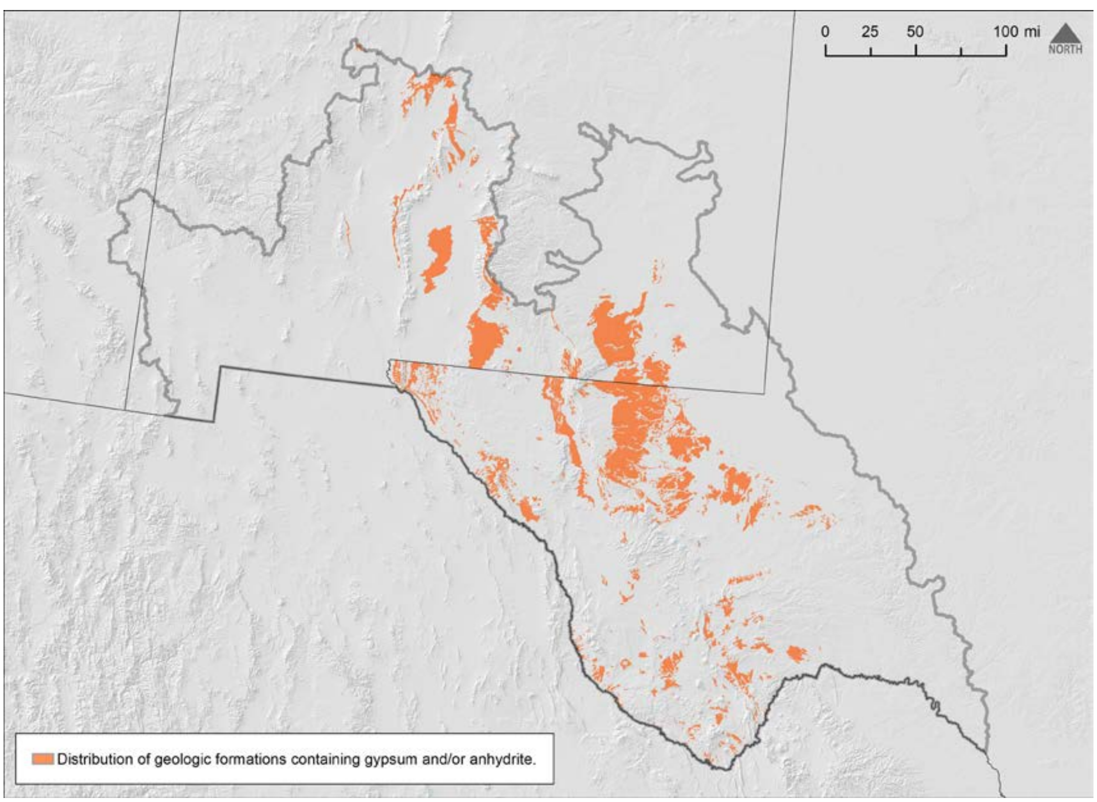


Figure 7-7. Distribution of soils with gypsum > 1%.

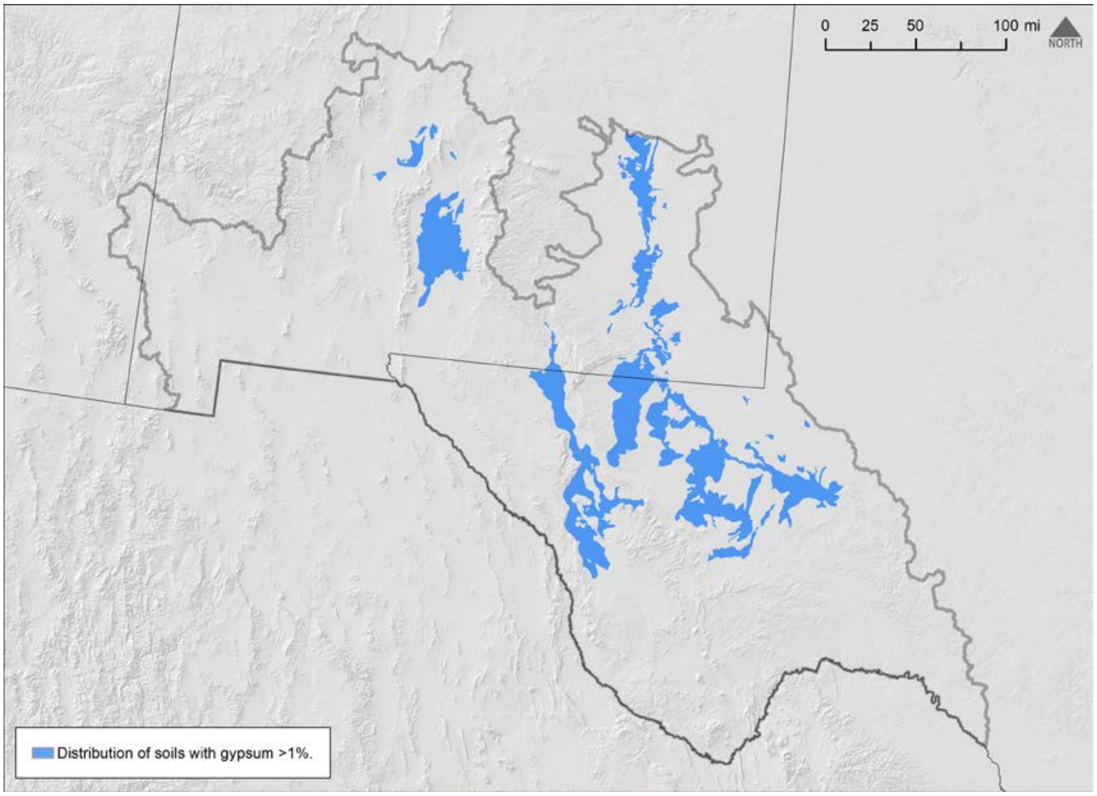


Figure 7-8 in turn shows the combined distributions of gypsic soils (percent gypsum > 1%) and surface exposures of sedimentary geologic formations containing gypsum and/or anhydrite. However, Figure 7-8 differs from the preceding two figures, by representing the presence/absence of these soils and surface geologic exposures by 5th-Level watershed rather than by 30-m pixel. Mapping by watersheds recognizes that the subsurface distributions of geologic formations may extend far beyond the limits of their surface exposures. Further, mapping by watersheds recognizes that the ecological influence of surface and subsurface gypsic and/or anhydric geologic formations and of gypsic soils may extend over large areas through downslope erosion and effects on surface, soil water, and groundwater chemistry. Mapping by watersheds provides a provisional means for representing these larger spatial effects in the absence of systematic geospatial data on surface, soil water, and groundwater chemistry.

Figure 7-8. Watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations.

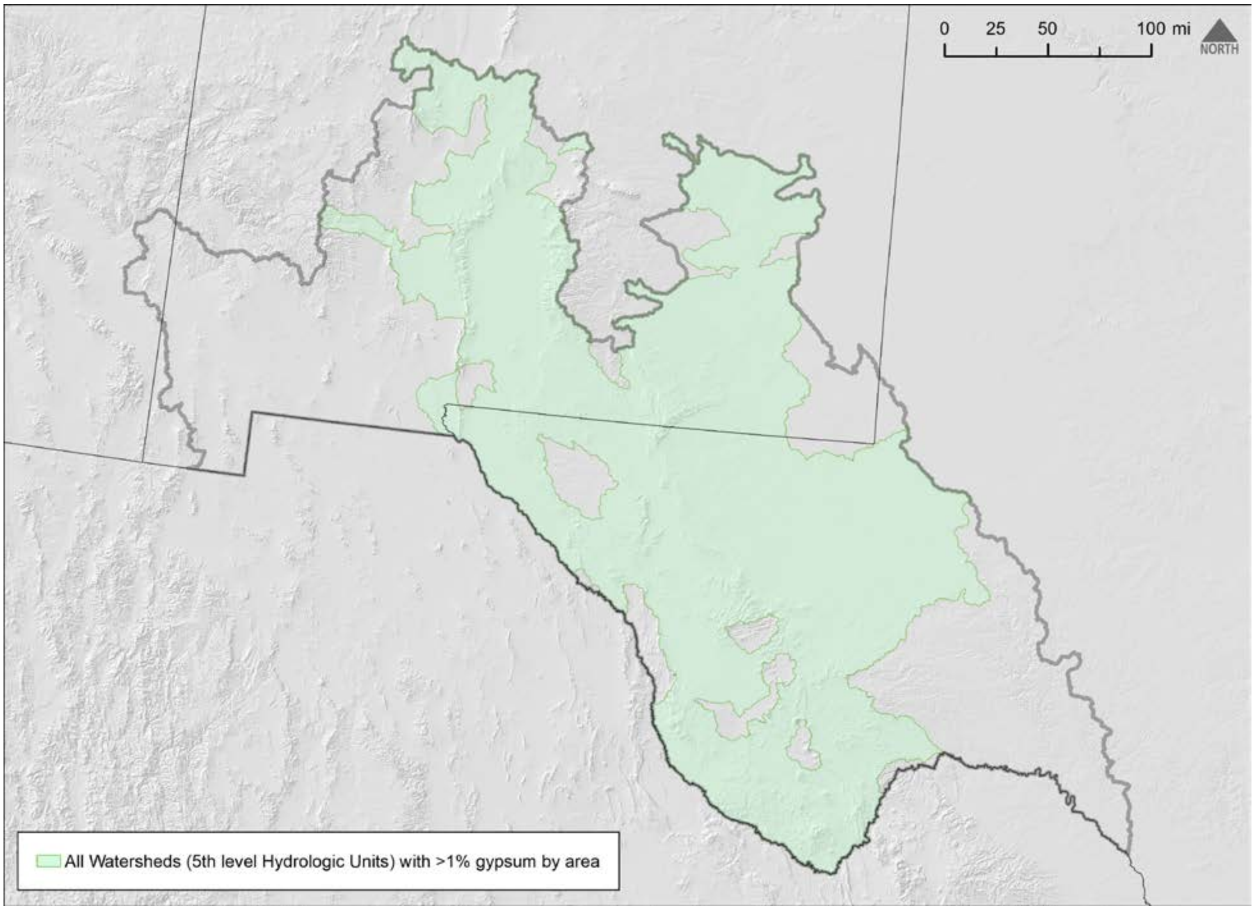
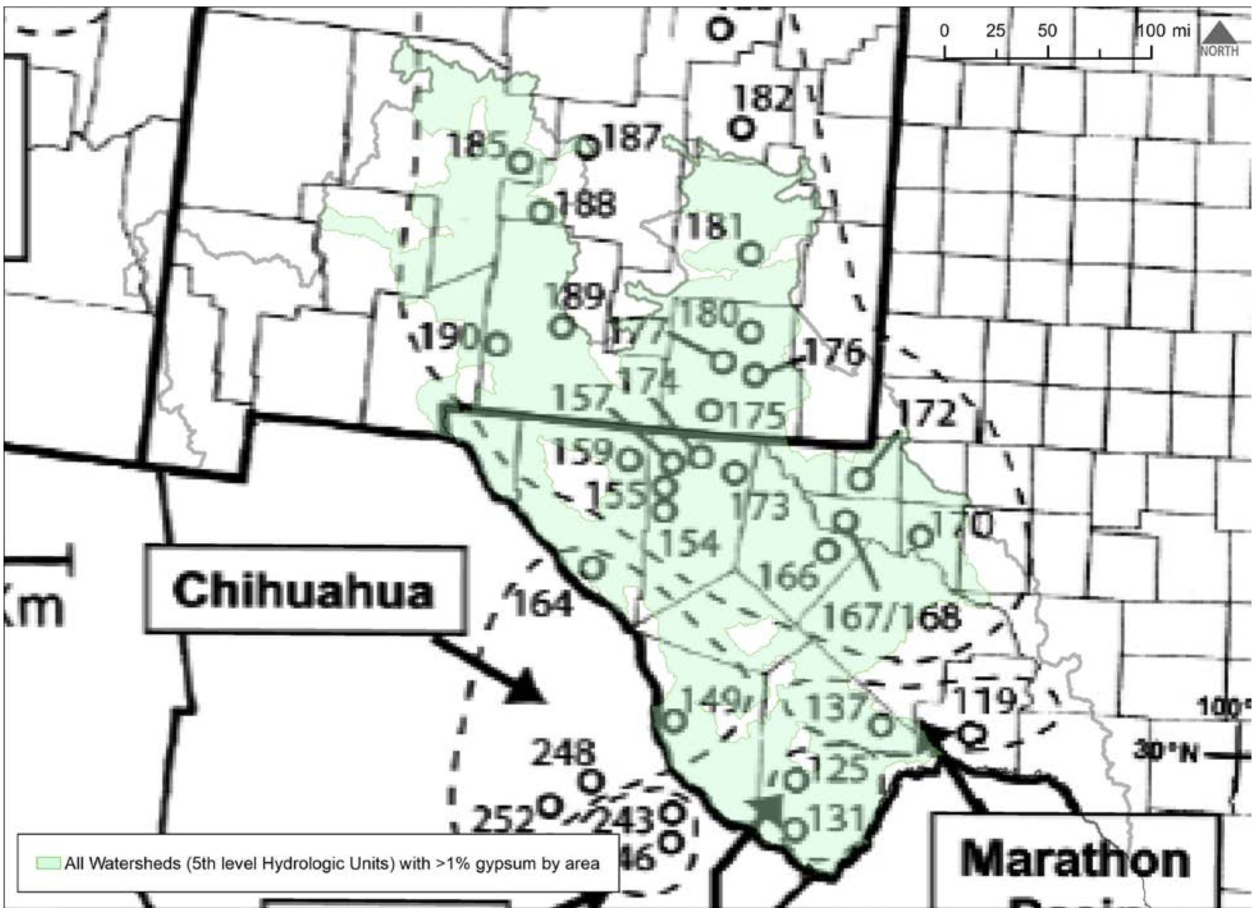


Figure 7-9 compares the distribution of watersheds with gypsic soils (percent gypsum > 1%) and/or surface exposures of gypsic and/or anhydric geologic formations (see Figure 7-8) in the U.S. portion of the ecoregion with the distribution of gypsophilous plants documented by Moore and Jansen (2007, Figure 2) in a study of the origins and biogeography of gypsophily in the Chihuahuan Desert ecoregion. Moore and Jansen (2007) specifically studied Chihuahuan Desert plants of the Genus Tiquilia, Subgenus Eddya, recognized as “arid-adapted annual to perennial prostrate herbs and subshrubs” classifiable as either gypsophiles (plants able to grow only on gypsic soils) or gypsovags (plants able to grow on or off gypsic soils). The overlay in Figure 7-9 shows the distribution of the *Tiquilia hispidissima* clade, the most common group of gypsophiles found in the U.S. portion of the ecoregion, as mapped by Moore and Jansen (2007), in Figure 2 of their publication. The blurred quality of the overlay in Figure 7-9 is a consequence of matching the scale and projection of the published map to the scale and projection of the REA map.

The selection of a 1% threshold for the percent gypsum in soils in Figure 7-7 – Figure 7-9 is the result of a trial-and-error process of examining different threshold concentrations of gypsum in the STATSGO2 soils data, to find a threshold that most closely matched the distribution of gypsophilous plants documented by Moore and Jansen (2007). Soils with percent gypsum ≤ 1% are widely but unevenly distributed in the U.S. portion of the ecoregion outside the watersheds shown in Figure 7-8. However, none of the collection locations for *Tiquilia hispidissima* studied by Moore and Jansen (2007) occurred in areas with percent soil gypsum ≤ 1%. Further, only one collection location – No. 119, located in the center of the southeastern quadrant of Figure 7-9 – falls within a watershed with neither gypsic soils (percent gypsum > 1%) nor surface exposures of gypsic and/or anhydric geologic formations. This single outlier is located in the eastern half of the Marathon Basin, the western half of which contains surface exposures of gypsic and/or anhydric geologic formations.

Figure 7-9. Distribution of gypsophilous plants per Moore and Jansen (2007) across watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations within the REA analysis extent.



Watersheds with percent soil gypsum > 1% and/or with surface exposures of gypsic and/or anhydric geologic formations therefore are provisionally identified here as lands within which gypsic and/or anhydric minerals and soils are most likely to affect ecological conditions. These watersheds span most of the New Mexico portion of the Pecos River basin and almost all watersheds originating in the Guadalupe, San Andres, Oscura, Davis, Glass, Chinati, and Chisos Mountains – essentially the middle 60-80% of the analysis extent from north to south. The only substantial portions of the U.S. portion of the ecoregion entirely without gypsic and/or anhydric soil conditions are the plains east of the Pecos River in Texas, the plains east of the Pecos River in extreme southeastern New Mexico, and most of the ecoregion west of the Rio Grande.

Figure 7-10 compares the current distribution of the three terrestrial ecological system CEs (Figure 7-1) with the distribution of watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations (see Figure 7-8 and Figure 7-9). Ground cover across these watersheds largely consists of Chihuahuan Desert Scrub and Chihuahuan Desert Grasslands, although some watersheds reach into higher elevations dominated by Pinyon-Juniper Woodlands. Grasslands are more common in affected watersheds to the north, but grasslands are more common across the northern portions of the analysis extent in general. It should be noted that, as Moore and Jansen (2007) discuss, gypsophiles in the ecoregion tend to occur only in discrete patches ("islands" in their terminology) with elevated soil gypsum levels within larger areas of grasslands and shrublands, while gypsovags will occur more widely. In contrast, the geologic and soils data appropriate for a rapid ecoregional assessment are not suitable for identifying locations of individual potential islands of gypsophilous vegetation. Such data provide the basis only for identifying watersheds in which such islands are likely to occur.

Figure 7-10. Current distribution of dryland ecological system Conservation Elements relative to watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations.

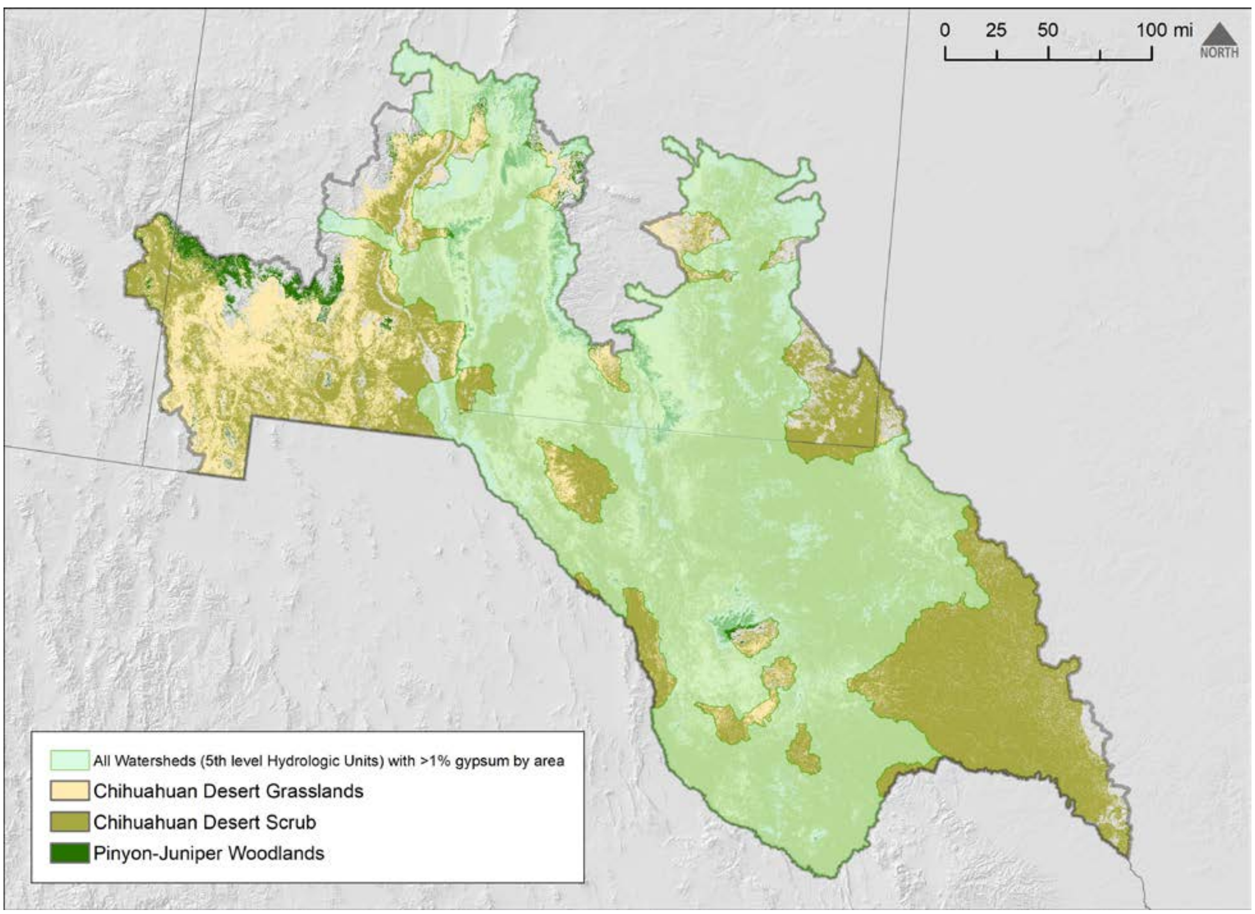


Figure 7-8 also provides a basis for examining the extent to which the distributions of the Change Agents discussed in Chapters 4-6 may overlap with the spatial distributions of potential ecological impacts from gypsic soils, soil water, and groundwater chemistry. The assessment of potential impacts of climate change, in Chapter 4, indicates that, except at higher elevations, scrub vegetation will likely come to dominate most of the watersheds indicated in Figure 7-8. The extent to which the changes in temperature and precipitation patterns potentially could affect the gypsophiles and gypsovags noted by Moore and Jansen (2007, see also Moore et al. 2015) is presently unknown. However, the gypsophilous plant species discussed by Moore and Jansen (2007) occur within larger grassland and scrub ecological systems and they or other members of the same genera have ranges that extend well to the south, into Mexico. It seems reasonable to propose, therefore, that climate change potentially will result in shifts in the geographic distributions of gypsophilous plant species but not in the extirpation of such species within the U.S. portion of the ecoregion.

Development in the U.S. portion of the ecoregion (Chapter 5, above) is forecasted to occur in several of the watersheds with gypsic soils and water identified in Figure 7-8, particularly along the Pecos River valley and across the eastern side of the Tularosa Basin. However, forecasted development west of the Rio Grande valley will not fall within any of the watersheds identified in Figure 7-8. On the other hand, grazing (Chapter 5, above) is widespread across these same watersheds, as are numerous invasive terrestrial plant species (Chapter 6, above). The ways in which these invasive plant species interact with gypsophilous plant species may warrant investigation. The effects of altered wildfire regimes (Chapter 6) on gypsophilous plant species also may warrant investigation. However, the gypsophilous plant species discussed by Moore and Jansen (2007) clearly successfully evolved and persist in an ecoregion in which wildfire was a natural ecological feature of the landscape.

8 Aquatic-Wetland Ecological System Conservation Elements

8.1 Introduction

This chapter presents the assessments focused on the five aquatic-wetland ecological system Conservation Elements (CEs), Large River-Floodplain Systems, Montane-Headwater Perennial Streams, Lowland-Headwater Perennial Streams, Springs-Emergent Wetlands, and Playas and Playa Lakes. Ten Management Questions (MQs) concern or include these five CEs, as follows:

MQ A: What is the geographic distribution of each CE?
MQ B: What is the current condition of each CE across its geographic distribution?
MQ C: What is the current geographic distribution of the impacts of each Change Agent (CA) in relation to each CE?
MQ D: What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?
MQ 2: What is the geographic distribution of the Chihuahuan desert amphibian assemblage?
MQ 3: Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?
MQ 9: What and where are the aquifers and their recharge zones that support the wet systems?
MQ 10: How do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?
MQ 12: Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?
MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Chapter 4, above, addresses the forecasted impacts of climate change on the five aquatic-wetland ecological system Conservation Elements, part of the subject of MQ D. Chapters 5 and 6, above, address the current impacts of the other CAs, the subject of MQ C. The assessment of the Chihuahuan desert amphibian assemblage, the subject of MQ 2, addresses four species, the Arizona toad (*Anaxyrus microscaphus*), Chiricahua leopard frog (*Lithobates (*aka *Rana) chircahuaensis*), northern leopard frog *(L. pipiens*), and Yavapai leopard frog (*L. yavapaiensis*). While only one of these four amphibians, the Arizona toad, also uses upland habitat, all four species use aquatic or wetland habitats during some part(s) of their life cycles. Consequently, this report addresses MQ 2 in the present chapter (Section 8.3) rather than in Chapter 7.

Section 8.3 of the present chapter addresses MQ 10, concerning differences between the current and historic geographic distributions of the five aquatic-wetland ecological system CEs, as part of an overall consideration of the current condition of these five CEs. Section 8.3 also addresses MQ 2, concerning the distribution of the Chihuahuan desert amphibian assemblage. Section 8.4 addresses MQ 3, concerning where uncharacteristic wildfire potentially could increase sedimentation into and loss of habitat among the five aquatic-wetland ecological system CEs. Section 8.5 addresses MQ 9, concerning the aquifers and their recharge zones that may support the five aquatic-wetland ecological system CE types. Section 8.6 addresses MQ 12, concerning where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers may need to focus on restoration or control succession. Finally, Section 8.7 addresses MQ 13, concerning the distribution of the impacts of gypsic soil and water on ecological conditions. Chapter 7, above, presents the full assessment of the current geographic distribution of potential impacts of gypsum in the soil and water in general, as well as in relation to the three dryland ecological system CEs and their associated Change Agents. The present chapter does not repeat that background information and focuses only on the geographic distribution of the impacts of gypsic soil and water on the five aquatic-wetland ecological system CEs.

8.2 Conservation Element Distributions

Figure 8-1 shows the current distributions of the five aquatic-wetland ecological system CE types. The following paragraphs describe the data used to map these distributions (see also Pre-Assessment Report, Unnasch et al. 2017, Chapters 8-11).

8.2.1 Large River-Floodplain Systems

This CE refers only to the waters and riparian vegetation corridors of the three large rivers of the ecoregion, the Gila River, Rio Grande, and Pecos River (Figure 8-1). All three originate in mountains outside the ecoregion but flow through the U.S. portion of the ecoregion and historically interacted with substantial floodplains along the way. The distributions of these three rivers and their associated riparian corridors are mapped based on the following three types of data:

1. National Hydrography Dataset (NHD) "Flowlines" (USGS-NGP 2017). The NHD identifies "flow lines," consisting of individual stream segments or reaches of the ephemeral, intermittent, and perennial streams and rivers that make up the surface drainage network of a watershed. The dataset also includes flow lines identified as various types of artificial features such as artificially modified segments of natural stream lines, as well as water infrastructure such as canals and drains, and identifies segments that currently lie beneath artificial impoundments. When a stream or other flow feature has a geographic name in the national (U.S. Geological Survey) topographic mapping system, the NHD includes that name, following the conventions of the Geographic Names Information System (GNIS) (https://nhd.usgs.gov/gnis.html). The GNIS database identifies alternative geographic names for features, when known. A single stream or river may consist of multiple stream segments, each with a separate GNIS Identification Number (GNIS_ID), although the GNIS may apply the same geographic name (GNIS_Name) to multiple segments.

Figure 8-1. Distribution of aquatic-wetland ecological system CEs (Green labels = Montane-headwater perennial streams; Red labels = Lowland-headwater perennial streams).

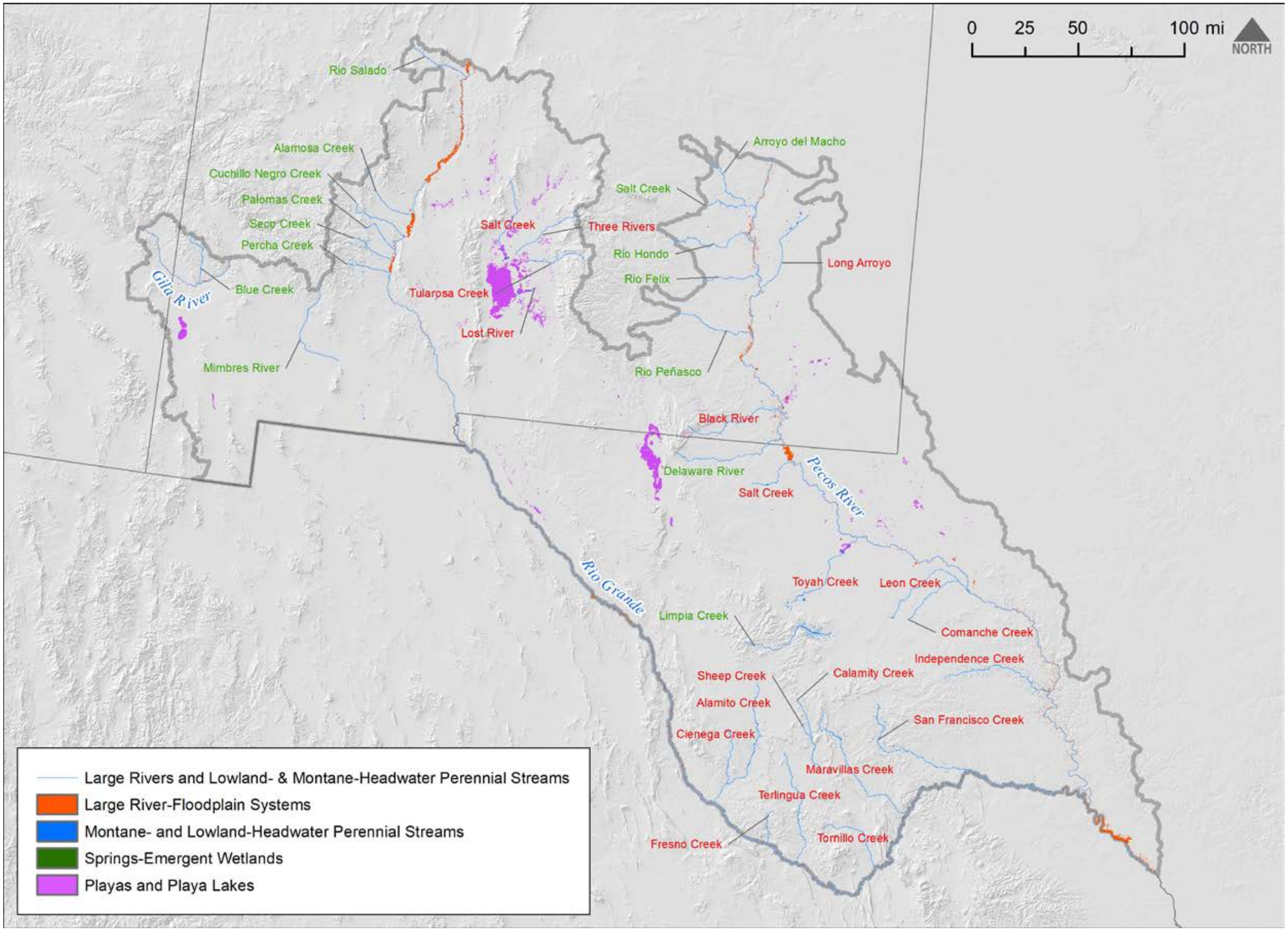
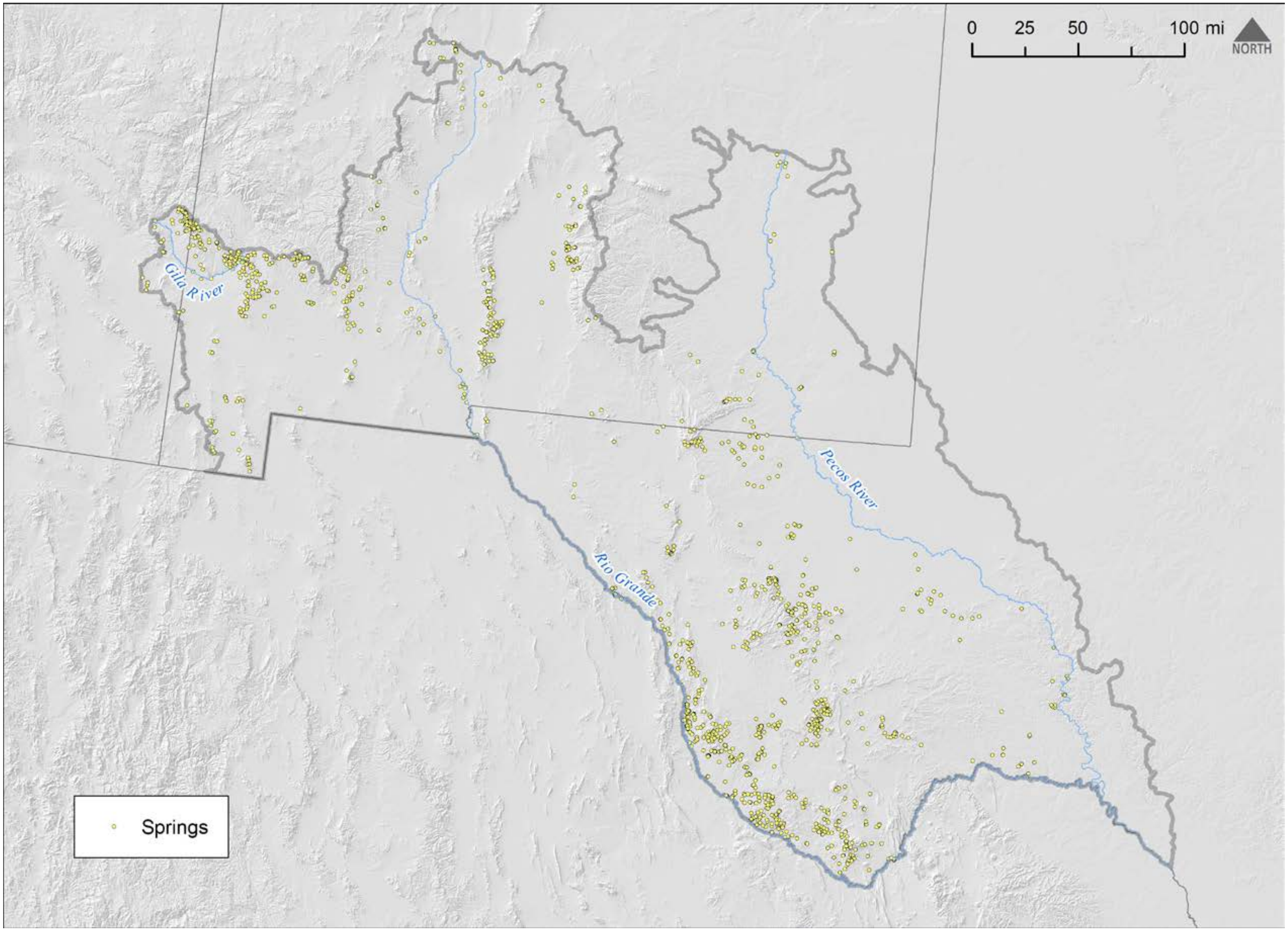


Figure 8-2. Distribution of springs, point locations exaggerated for visibility.



All three large rivers, to varying degrees, are affected by surface diversions, groundwater pumping, channel confinement and stabilization, levee construction, and impoundments. These modifications, to varying degrees, have converted all three large rivers within the U.S. portion of the ecoregion into strings of alternating perennial, intermittent, and artificially modified stream segments. The NHD data used to assess the current distributions of the three large rivers in the U.S. portion of the ecoregion consist of all segments named and/or numbers in the GNIS database as parts of these three rivers, regardless of their type or degree of modification. (The data on artificial modifications are used in the assessment of the impacts of development on the three rivers as discussed below, this chapter). Each flow line assigned to a large river was buffered 16 m per side following methods established for the Madrean Archipelago REA immediately to the west of the Chihuahuan Desert REA (Crist et al. 2014).

2. National Gap Analysis Program (GAP) Land Cover. The riparian corridors of the three large rivers were mapped using National GAP Land Cover data (USGS 2011, Gergely and McKerrow 2016) for the following ecological systems: North American Warm Desert Lower Montane Riparian Woodland and Shrubland, North American Warm Desert Riparian Mesquite Bosque, North American Warm Desert Riparian Systems, North American Warm Desert Riparian Woodland and Shrubland, Western Great Plains Riparian Woodland and Shrubland, North American Arid West Emergent Marsh. Occurrences (30-m pixels) of these ecological systems were included in the mapped distribution of the large river-floodplain systems only when they occur within 5 km of an NHD flow line for one of the three large rivers. The 5 km distance was established through a review of the widths of floodplains historically connected to these rivers in the ecoregion, as represented in the LANDFIRE "Riparian" Biophysical Settings dataset (LANDFIRE 2016; GroupVeg = "Riparian"). (Although included in the definition of this CE type, as discussed in the Pre-Assessment Report, Chapter 9 (Unnasch et al. 2017), the North American Warm Desert Cienega ecological system type does not occur in the National GAP Land Cover database for the analysis extent for the REA). Lands within the 5 km buffer with cover types other than the aforementioned six ecological system types – e.g., lands developed for agriculture or other purposes – were not included in the mapping of the current distribution of the associated large river-floodplain system.

3. National Hydrography Dataset (NHD) "Waterbodies" (USGS-NGP 2017). The riparian corridors of the three large rivers also may include open-water bodies such as natural floodplain lakes and marshes. The assessment included these water bodies by mapping the distribution of the NHD "Lake/Pond" (390), "Reservoir" (436), and "Swamp/Marsh" (466) water features. As with the National GAP land cover data, occurrences (30-m pixels) of these additional NHD feature types were included in the current distribution of the large river-floodplain systems only when they occur within 5 km of an NHD stream line for one of the three large rivers.

8.2.2 Montane- and Lowland-Headwater Perennial Streams

The Montane-Headwater Perennial Stream and Lowland-Headwater Perennial Stream CE types (Figure 8-1.) refer to perennial streams and rivers with headwaters in two different geologic-topographic settings. The distributions of these two types of perennial streams and their associated riparian corridors are mapped based on the following five sources of information:

1. National Hydrography Dataset (NHD) "Flowlines" (USGS-NGP 2017). The assessment of the two perennial stream CEs used same types of NHD data as used in the assessment of the three large rivers, as discussed above. However, the assessment of the two perennial stream types focused on named stream lines of one or more segments, with at least one segment identified in the NHD as perennial, with GNIS segment names and numbers indicating they are parts of a single stream even if some segments are coded as intermittent or artificially modified. The assessment then added all other flow-line segments with variants of the name of each perennial stream (e.g., "East Fork" _____ Creek, "Little" _____ Creek, etc.), including segments identified in the NHD as intermittent and artificial flow lines. (The data on artificial modifications are used in the assessment of the impacts of development on perennial streams, as discussed below, this chapter). After additional filtering (see below), each stream line assigned to a perennial stream was buffered 16 m per side following methods established for the Madrean Archipelago REA immediately to the west of the Chihuahuan Desert REA (Crist et al. 2014).

2. Designations of Stream and Aquatic Species Conservation Priorities. The State Wildlife Action Plans for both New Mexico (NMDGF 2016) and Texas (Connally, ed. 2012) were reviewed to identify all streams recognized as state conservation priorities within the ecoregion. Numerous reports on fishes and amphibians, consulted in developing the conceptual models for the two perennial stream CE types for the Pre-Assessment Report, Chapter 9 (Unnasch et al. 2017) were also reviewed to identify streams that historically provided habitat for species that are now rare, endangered, or otherwise recognizes as Species of Greatest Conservation Need in the two State Wildlife Action Plans. The results of the tabulation of fish species in this literature was then cross-checked with a geospatial database of fish species records for the two states for the same rare, endangered, or otherwise recognizes as Species of Greatest Conservation Need in the two State Wildlife Action Plans. Further information on the latter fish database is presented later in this chapter (see below, Conservation Element Current Condition). The results of these efforts were compared with the results of the NHD compilation (see above) to identify 35 streams for inclusion in the assessment as occurrences of a perennial stream CE type.

3. Topography and Meteorology. Topographic and meteorological data, together with published descriptions of individual streams, were used to distinguish between perennial streams with headwaters that lie in mountains (steeper stream gradient, higher-elevation headwaters, greater rain- and snowfall) versus at/near valley floors (shallower stream gradient, lower-elevation headwaters, less rain- and snowfall, known spring sources). This resulted in a differentiation of the 35 perennial streams into the montane- versus lowland-headwater types. It was not always clear which type to assign to some streams, because they may receive at least seasonally significant inputs from runoff, shallow groundwater, and deeper groundwater sources at both montane and lowland elevations. For simplicity, streams with perennial flow originating in montane settings were classified as montane-headwater streams, even if they also

received significant lowland inputs as well. All other perennial streams were classified as lowland-headwater streams.

4. National Gap Analysis Program (GAP) Land Cover. The riparian corridors of the 35 recognized perennial streams were mapped based on National GAP Land Cover data (USGS 2011, Gergely and McKerrow 2016) for the following ecological systems: North American Warm Desert Lower Montane Riparian Woodland and Shrubland, North American Warm Desert Riparian Mesquite Bosque, North American Warm Desert Riparian Systems, North American Warm Desert Riparian Woodland and Shrubland, Western Great Plains Riparian Woodland and Shrubland, North American Arid West Emergent Marsh. Occurrences (30-m pixels) of these ecological systems were included in the mapped distribution of perennial streams only when they occur within 5 km of an NHD flow line for one of the 35 recognized perennial streams identified earlier in the assessment (see large rivers, above, for description and explanation of methods). (Again, although included in the definition of the perennial stream types, as discussed in the Pre-Assessment Report, Chapter 8 (Unnasch et al. 2017), the North American Warm Desert Cienega ecological system type does not occur in the National GAP database for the analysis extent). Lands within the 5km buffer with cover types other than the aforementioned six ecological system types – e.g., lands developed for agriculture or other purposes – were not included in the mapping of the current distribution of the associated large river-floodplain system.

5. National Hydrography Dataset (NHD) "Waterbodies" (USGS-NGP 2017). The assessment recognized that the riparian corridors of the 35 recognized perennial streams might also include open-water bodies such as natural floodplain lakes and marshes. The assessment included these water bodies by mapping the distribution of NHD "Lake/Pond" (390), "Reservoir" (436), and "Swamp/Marsh" (466) water features. As with the GAP Land Cover data, occurrences (30-m pixels) of these additional NHD feature types were included in the mapped distribution of the perennial streams only when they occur within 5 km of an NHD flow line for one of the 35 recognized perennial streams.

8.2.3 Springs-Emergent Wetlands

The distribution of Springs-Emergent Wetlands (Figure 8-1. and Figure 8-2) is mapped based on the following two types of data:

1. Springs and Springs-Dependent Species Online Database. The Springs Stewardship Institute (SSI) has compiled a database of springs (SSI 2017) for the Desert Landscape Conservation Cooperative (Desert LCC; https://desertlcc.org/). The SSI database incorporates data from the NHD, state heritage records, State Wildlife Conservation Plans, the GNIS database of mapped water features with names indicating the feature is or is associated with a spring, and the published literature. The data include names and point locational coordinates. Figure 8-1. shows the distribution of springs by the 30-m pixel in which the point location of each spring falls. Because the point locations are very difficult to discern as 30-m pixels, Figure 8-2 shows the distribution of springs using a larger symbol to indicate each point location.

2. National Gap Analysis Program (GAP) Land Cover (USGS 2011). Marsh habitat for springs-emergent wetlands was mapped based on National GAP Land Cover distribution data for the North American Arid West Emergent Marsh ecological system. However, this ecological system may occur in many settings in the ecoregion other than in association with spatially distinct springs, as noted above in the discussion of the stream and river CE types, and below in the discussion of playas and playa lakes. Occurrences (30-m pixels) of the North American Arid West Emergent Marsh ecological system were included in the mapped distribution of the Springs-Emergent Wetlands CE only when they occur outside of the riparian corridor for a large river or perennial stream (see above) or outside the defined area of a playa or playa lake (see below). This last criterion for the inclusion of occurrences of the North American Arid West Emergent Marsh ecological system may have resulted in the tabulation of some spring-associated wetlands as parts of the riparian zones of perennial stream or large river CEs, because they occur along and are also sources for these flowing waters. Note also that, although also included in the definition of this CE type, the North American Warm Desert Cienega ecological system type does not occur in the National GAP Land Cover dataset for the analysis extent.

3. National Hydrography Dataset (NHD) "Waterbodies" (USGS-NGP 2017). Marsh habitat also was mapped based on NHD distribution data for the "Swamp/Marsh" (466) feature type with a 16-m buffer. However, as with the North American Arid West Emergent Marsh ecological system, this NHD feature type may occur in many settings in the ecoregion other than in association with spatially distinct springs, as noted above in the discussion of the stream and river CE types, and below in the discussion of playas and playa lakes. Occurrences (30-m pixels) of the NHD "Swamp/Marsh" feature type were included in the mapped distribution of the Springs-Emergent Wetlands CE only when they occur outside of the riparian corridor for a large river or perennial stream (see above) or outside the defined area of a playa or playa lake (see below). This last criterion for the inclusion of the NHD "Swamp/Marsh" feature type may have resulted in the tabulation of some spring-associated wetlands as parts of the riparian zones of perennial stream or large river CEs, because they occur along and are also sources for these flowing waters.

8.2.4 Playas and Playa Lakes

The distribution of the Playas and Playa Lakes CE in Figure 8-1 is mapped based on five types of data, some of which have at least partially overlapping distributions. The use of multiple, partially overlapping datasets was necessary to ensure the accurate representation of this CE type:

1. National Hydrography Dataset (NHD) "Waterbodies" (USGS-NGP 2017). The NHD includes the feature type "Playa" (361). All NHD playas were included in the mapping of this Conservation Element, with a 16-m buffer around the periphery of each playa feature. The NHD also includes the feature type "Lake/Pond" (390). A review of the NHD list of "Lake/Pond" features in the U.S. portion of the ecoregion identified several known playas and playa lakes with this feature code, including Lake Lucero in the Tularosa Basin and Playas Lake in the southeastern corner of New

Mexico. The NHD list of “Lake/Pond” features in the ecoregion therefore was searched to identify all that might qualify as playa or playa lakes based on the definition established in the Playas and Playa Lakes conceptual ecological model (see Pre-Assessment Report, Unnasch et al. 2017). This review excluded all features with a name that included the terms “reservoir,” “tank,” “water hole,” and variants thereof; and all features classified as a “Reservoir” in the GNIS database. The GNIS Feature Search query tool (https://geonames.usgs.gov/apex/f?p=138:1:5023515502654) was then used to check each of the ~200 remaining Lake/Pond features in satellite imagery. Features were identified as a playa or playa lake if the satellite imagery indicated that it was endorheic, i.e., located in a topographic depression with no surface outlet and either (a) not an artificial feature, including anything created by a dam or excavation; or (b) not a floodplain or sinkhole lake, many of which are reported in the literature reviewed during the pre-assessment phase of the REA. This filtering identified 104 “Lake/Pond” features as playas or playa lakes, all of which also were included in the mapping of this Conservation Element, with a 16-m buffer around each feature.

2. National Gap Analysis Program (GAP) Land Cover (primary classes). The vegetation associated with playas and playa lakes was mapped based on National GAP Land Cover distribution data (USGS 2011, Gergely and McKerrow 2016) for four ecological systems: North American Warm Desert Playa, Western Great Plains Saline Depression, North American Warm Desert Interdunal Swale Wetland, and Western Great Plains Closed Depression Wetland. Only two of these four types were found to occur in the U.S. portion of the ecoregion, North American Warm Desert Playa and Western Great Plains Saline Depression Wetland. The Pre-Assessment Report (Unnasch et al. 2017), Chapter 11, provides further information on the selection of these Ecological System types as the primary vegetation types for playas and playa lakes. The latter three types consist of playa-like ecological communities in smaller closed depressions. Occurrences (30-m pixels) of North American Warm Desert Playa and Western Great Plains Saline Depression Wetland were included in the mapped distribution of playas and playa lakes only when they occur within 500 m of the edge of the buffered edge of an NHD playa. The 500 m distance was selected through trial and error to find a distance that produced results most consistent with ecological descriptions of well-known playa/playa lake sites in the ecoregion, Alkali Flat and Lake Lucero, Lordsburg Playa, Isaacks Lake, and Playas Lake (Unnasch et al. 2017).

3. Existing Vegetation Type (EVT) dataset from LANDFIRE 2016. A review of LANDFIRE EVT (2016) and National GAP Land Cover (USGS 2011) data for “barren” land cover types indicated that this cover type in the U.S. portion of the ecoregion often occurs where frequent wetting/drying and associated high soil salt contents, and/or frequent eolian reworking of the soils (especially in dunes) prevent the establishment of vegetation. These two processes are common around playas and playa lakes. Occurrences (30-m pixels) of this general land cover type (EVT, CLASSNAME = “Barren”) were included in the mapped distribution of playas and playa lakes when they occurred within 500 m of pixels identified by the first two types of data listed above. See above for the rationale for the 500 m distance.

4. National Gap Analysis Program (GAP) Land Cover (additional classes). Five additional ecological system types can form around and interact strongly with playas and playa lakes in the desert southwest: North American Warm Desert Active and Stabilized Dune, North American Warm Desert Pavement, North American Warm Desert Riparian Woodland and Shrubland, North American Arid West Emergent Marsh, Chihuahuan-Sonoran Desert Bottomland and Swale Grassland. Two other ecological systems – Western Great Plains Open Freshwater Depression Wetland and North American Warm Desert Cienega – also may form in these settings, but do not occur in the National GAP Land Cover database for the U.S. portion of the ecoregion. The Pre-Assessment Report (Unnasch et al. 2017), Chapter 11, provides further information on the five additional ecological system types that may occur in association with playas and playa lakes in the U.S. portion of the ecoregion. These additional five ecological system types may develop around the margins of – and extend outward from – playa and playa lakes, but also may occur in other settings in the ecoregion. Occurrences (30-m pixels) of these five additional ecological system types were included in the mapped distribution of the Playas and Playa Lakes CE type only when they occurred within 500 m of pixels identified by the first two types of data listed above. See above for the rationale for the 500 m distance.

5. National Hydrography Dataset (NHD) "Waterbodies" (USGS-NGP 2017). The NHD includes the feature type "Swamp/Marsh" (466). Publications reviewed during development of the Playas and Playa Lakes conceptual ecological model for the Pre-Assessment Report (Unnasch et al. 2017) showed that some playas may incorporate areas of vegetated wetland. The NHD potentially could identify such areas as separate "Swamp/Marsh" features. NHD "Swamp/Marsh" features were included in the mapped distribution of the Playas and Playa Lakes CE type only when they occur within 500 m of pixels identified by the first two types of data listed above. See above for the rationale for the 500 m distance.

8.2.5 Aquatic-Wetland Conservation Element Distribution Results

The stream lines mapped in Figure 8-1 for the three large rivers in the U.S. portion of the ecoregion are those recorded in the NHD as of May 2017, as noted above. Similarly, the stream lines and flow status mapped in Figure 8-1 for the perennial streams in the U.S. portion of the ecoregion – perennial, intermittent, ephemeral – are those recorded in the NHD as of May 2017; and the spring locations included in the present assessment (Figure 8-1, Figure 8-2) also are those known at the times of compilation of the included datasets. Users of these maps and their underlying data should bear in mind that the rivers, perennial streams, and springs in the U.S. portion of the ecoregion are highly valued and heavily exploited resources. The cumulative effects of exploitation affect present ability to map these ecological systems.

Historically, the Gila River, Rio Grande, and Pecos River within the U.S. portion of the ecoregion exhibited seasonally varying flows, as discussed in the Pre-Assessment Report (Unnasch et al. 2017). All three rivers receive most of their natural inflows in their headwaters to the north, outside the ecoregion, and all three experienced losses to evapotranspiration and infiltration as they flowed through the ecoregion. The Rio Grande in particular experienced significant losses to infiltration as it flowed through the Mesilla Valley, a wide basin lying between Radium Springs, New Mexico, and El Paso, Texas, recharging a large basin-fill aquifer (Hogan 2013). Surface diversions, groundwater pumping, and channel modifications on all three rivers, and impoundments and associated evaporative losses on the Rio Grande and Pecos Rivers, have significantly altered flow regimes and channel morphology. Many of these changes predate development of the NHD. The mapped distributions of the three large river-floodplain systems also are noteworthy for their limited and highly fragmented riparian vegetation. Section 8.3, below, discusses the estimated extent of loss of riparian vegetation largely as a result of floodplain development and inundation.

Historically, perennial streams in the U.S. portion of the ecoregion also included both gaining and losing reaches, as discussed in the Pre-Assessment Report (Unnasch et al. 2017). That is, these streams consisted of reaches along which surface runoff and groundwater inputs exceeded losses to evapotranspiration and infiltration versus reaches along which these losses exceeded those inputs. Losses to evapotranspiration and infiltration may sometimes have been large enough to eliminate perennial surface flow along some stream channels at lower elevations. Flow in the affected channels connected only intermittently with a large river, other stream, or a playa lake downstream during times of substantial runoff. The development of water resources in the ecoregion in turn has further fragmented the perennial stream network. Surface diversions, groundwater pumping, and channel modifications have converted most perennial streams into strings of alternating perennial, intermittent, and artificial stream segments. The present assessment sought to identify all perennial streams, even when today they consist only of strings of segments of such varying condition. Subsequent analyses assess the extent of human modification and fragmentation along each stream (see below, this chapter). However, it is important to recognize that the NHD provides a record of stream conditions at the time of its compilation. If a formerly (historically) perennial stream no longer sustained perennial flow along any segment by the time the NHD was compiled, that stream does not appear as a perennial feature in the present assessment. The mapped distributions of the perennial stream systems also are noteworthy for their limited and highly fragmented riparian vegetation. Section 8.3, below, discusses the estimated extent of loss of riparian vegetation.

Historically, too, springs in the U.S. portion of the ecoregion may have flowed either intermittently (e.g., seasonally or during wet periods) or perennially, as discussed in the Pre-Assessment Report (Unnasch et al. 2017). Groundwater pumping and altered recharge due to changes in ground cover (see below, this chapter) potentially have eliminated discharge at some former springs. If a historic spring no longer sustained even intermittent flow by the time the datasets were compiled, on which the present assessment rests, that spring does not appear in the present assessment.

The differentiation of the 35 perennial streams into the montane- versus lowland-headwater types should be considered a hypothesis. As noted above, it was not always clear which type to assign to some streams, because they may receive at least seasonally significant inputs from runoff, shallow groundwater, and deeper groundwater sources at both montane and lowland elevations. The distinction remains useful for the present assessment, to distinguish perennial streams that at least historically included both significant contributions of runoff (from rainfall and snowmelt at higher elevations) and aquifer discharge to sustain in their flow regimes. Land-use practices would be expected to have different effects on such streams, compared to streams that receive most of their waters from bedrock and basin-fill aquifers at lower elevations.

8.3 Conservation Element Current Conditions

The assessment evaluated the current condition of the five aquatic-wetland ecological system CEs in two ways, qualitatively through an examination of the spatial relationships between Change Agents and the five CEs, and quantitatively through analyses of a small number of indicators. The indicators were selected through a comparison of the Key Ecological Attributes for each of the five CE types, identified during the Pre-Assessment phase of the REA (Unnasch et al. 2017), and lists of potentially available data on these attributes. The quantitative assessment of condition among the five aquatic-wetland ecological system CEs focused on five indicators, most of which pertain only to the rivers and streams. Similar or equivalent systematic geospatial data on these indicators were not identified for springs-emergent wetlands or for playas and playa lakes. The five indicators are:

1. Current versus likely historic extent of riparian habitat.
2. Current extent of modification or conversion of natural river/stream channel to artificial hydrologic features.
3. Current extent of water quality impairment as defined under state water quality standards.
4. Current versus historic distribution of sensitive native fish species.
5. Current distribution of the Chihuahuan Desert amphibian assemblage.

8.3.1 Relative Distribution of Change Agents

Chapter 4, above, addresses the ways in which climate change potentially will affect the five aquatic-wetland ecological system CEs. The discussion of potential impacts to the aquatic-wetland ecological system CEs in Chapter 4 reviews information from the Pre-Assessment report (Unnasch et al. 2017, Chapters 8-11) in light of the forecasts of climate change presented earlier in Chapter 4. The information available suggests that recharge, runoff, and upstream discharge along the Gila River, Rio Grande, and Pecos River mainstems will all decrease due to increased evapotranspiration and reduced contributions of snowfall and snowmelt across all watersheds, and increased evapotranspiration losses from water bodies and their associated aquatic and riparian vegetation. The forecasted higher temperatures could also lead to increased consumption of surface water and groundwater by farms, livestock, and people. This increased consumption will likely also affect the aquatic-wetland ecological system CEs (see below).

Chapter 5, above, discusses the present and forecasted future distribution of development within the analysis extent. Residential, commercial, industrial, and irrigated agricultural development has already eliminated natural wetland and floodplain habitat along a large fraction of the Gila River, Rio Grande, and Pecos River riparian corridors and elsewhere within the analysis extent. Additional analyses later in the present chapter provide more specific information on these impacts. Water consumption and water management systems associated with residential, commercial, irrigated agricultural, and industrial development, including oil and gas production, have altered surface water hydrology and groundwater storage. Further development will necessarily cause additional alterations, as may changes in water-use efficiency. For example, the Gila River presently has no dams along its mainstem, and diversions along the mainstem within the U.S. portion of the ecoregion deliver water only to local users. However, as noted above (e.g., see Chapter 2), efforts are ongoing to permit construction of a large diversion facility somewhere along the Gila River mainstem immediately upstream from the present analysis extent, under the terms of the New Mexico-Arizona Water Settlement Act of 2004 (New Mexico Interstate Stream Commission 2017). Any such diversion will reduce the total volume of discharge of the river and affect the hydrograph in different ways depending on the design and operational rules of the diversion.

Chapter 5, above, also discusses the distribution of grazing allotments on U.S. Forest Service and BLM lands within the REA analysis extent in Arizona and New Mexico. These allotments include nearly every occurrence of the Montane-Headwater Perennial Streams, Lowland-Headwater Perennial Streams, and Springs-Emergent Wetlands CEs, and many Playas and Playa Lakes as well. As noted in Chapter 5, however, the REA was not able to acquire any data on grazing intensity or impacts within the allotments or on the large expanses of private land used for livestock grazing in New Mexico and Texas. As a result, it is not possible in this REA to assess the potential direct impacts of grazing on any of the aquatic-wetland ecological system CEs.

Chapter 6, above, discusses the distribution of invasive plants and animals across the REA analysis extent, based on both county-scale and georeferenced observation data. The data presented in Chapter 6 indicate that aquatic-wetland invasive plants, notably Russian olive and tamarisk (aka salt cedar) are present throughout the analysis extent. They are widely regarded as threats to native ecological communities and to the hydrology of the aquatic-wetland communities they invade (see Pre-Assessment report, Unnasch et al. 2017, Chapters 8-11). Other invasive species affecting the aquatic-wetland ecological system CEs have more limited distributions, as presented in Chapter 6. However, the records assessed in Chapter 6 do not represent the results of systematic surveys to map the distributions of these invasive species. As a result, it is not possible to assess how well they represent actual conditions.

Chapter 6 also discusses possible changes in wildfire patterns across the watersheds of the aquatic-wetland ecological system CEs across the analysis extent. Table 8-1 shows the distribution of LANDFIRE vegetation departure (VDEP) values (LANDFIRE 2016) by percentile for the aquatic-wetland ecological system CEs – with the two perennial stream CEs combined – based on the data displayed in Chapter 6, Figure 6-14. VDEP values, largely but not exclusively a consequence of altered fire patterns, are mostly low across the areas (30-m pixels) classified as parts of Montane-Headwater or Lowland-Headwater Perennial Stream CE occurrences, with nearly 75% exhibiting VDEP values ≤ 50%. VDEP values are only slightly higher across the areas classified as parts of Large River-Floodplain CE occurrences, with more than 60% exhibiting VDEP values ≤ 50%. In contrast, VDEP values are higher across the areas classified as parts of Springs-Emergent Wetland CE occurrences, with more than 53% exhibiting VDEP values > 50%; and even higher across the areas classified as parts of the Playas and Playa Lakes CE occurrences, with more than 57% exhibiting VDEP values > 50%. Section 8.4, below, examines the possible impacts of altered wildfire on the aquatic-wetland ecological system CEs further.

Finally, Chapter 6 also discusses the distribution of landscape restoration treatments across the analysis extent. The data presented in Chapter 6 do not indicate the vegetation type(s) that each restoration treatment sought to restore. Table 8-2 shows the percentage of each treatment type (by area) that took place across 30-m pixels classified as occurrences of the aquatic-wetland ecological system CEs – with the two perennial stream CEs combined – based on the BLM vegetation treatment data presented in Chapter 6, Figure 6-18. The LANDFIRE Vegetation Disturbance (VDIST) data shown in Chapter 6, Figure 6-19, include both prescribed fires and wildfires, and therefore are not included in Table 8-2. Both chemical and prescribed fire treatments have been applied heavily to playas and playa lake occurrences. Both prescribed fire treatments and, especially, physical (mechanical) treatments have been applied heavily to the riparian corridors of the large river-floodplain systems.

Table 8-1. Vegetation Departure (VDEP) percentile distributions by aquatic-wetland ecological system CE.

CE➔ VDEP Percentile🡻	Perennial Streams	Large River-Floodplain Systems	Springs-Emergent Wetlands	Playas and Playa Lakes
0-10%	1.36%	3.71%	4.65%	8.79%
11-20%	2.64%	1.18%	9.37%	1.09%
21-30%	58.91%	41.12%	17.61%	12.45%
31-40%	8.24%	11.97%	11.01%	5.14%
41-50%	3.35%	2.16%	4.15%	15.27%
51-60%	9.77%	5.05%	27.30%	12.36%
61-70%	5.58%	9.56%	17.23%	12.31%
71-80%	6.16%	6.17%	3.40%	7.33%
81-90%	1.60%	0.67%	3.90%	3.86%
91-100%	2.40%	18.42%	1.38%	21.40%
Total	100.00%	100.00%	100.00%	100.00%

Table 8-2. Distribution of landscape restoration treatment types by aquatic-wetland ecological system CE.

Treatment type➔ CE🡻	Chemical Treatments	Prescribed Fire Treatments	Physical Treatments
Perennial Streams	23.92%	10.38%	12.12%
Large River-Floodplain Systems	18.73%	48.32%	71.93%
Springs-Emergent Wetlands	0.09%	0.05%	0.05%
Playas and Playa Lakes	57.27%	41.26%	15.90%

8.3.2 Current versus Likely Historic Extent of Riparian Habitat

The present assessment used the LANDFIRE "Biophysical Settings" (BpS) dataset for riparian vegetation in the ecoregion (LANDFIRE 2016; GroupVeg = "Riparian") to estimate the likely historic extent of this category of vegetation for comparison to its present extent. BpS models estimate the likely spatial distributions of historic ecosystems prior to Euro-American settlement based on their geophysical requirements. Figure 8-3 shows the distribution of 30-m pixels where, based on the LANDFIRE BpS layer, (1) riparian vegetation existed historically but current data indicate it no longer exists; (2) where riparian vegetation existed historically and current data indicate it still exists; and (3) where riparian vegetation historically did not exist but current data indicate it does now.

Figure 8-3. Current versus LANDFIRE Biophysical Setting estimated riparian vegetation distribution.

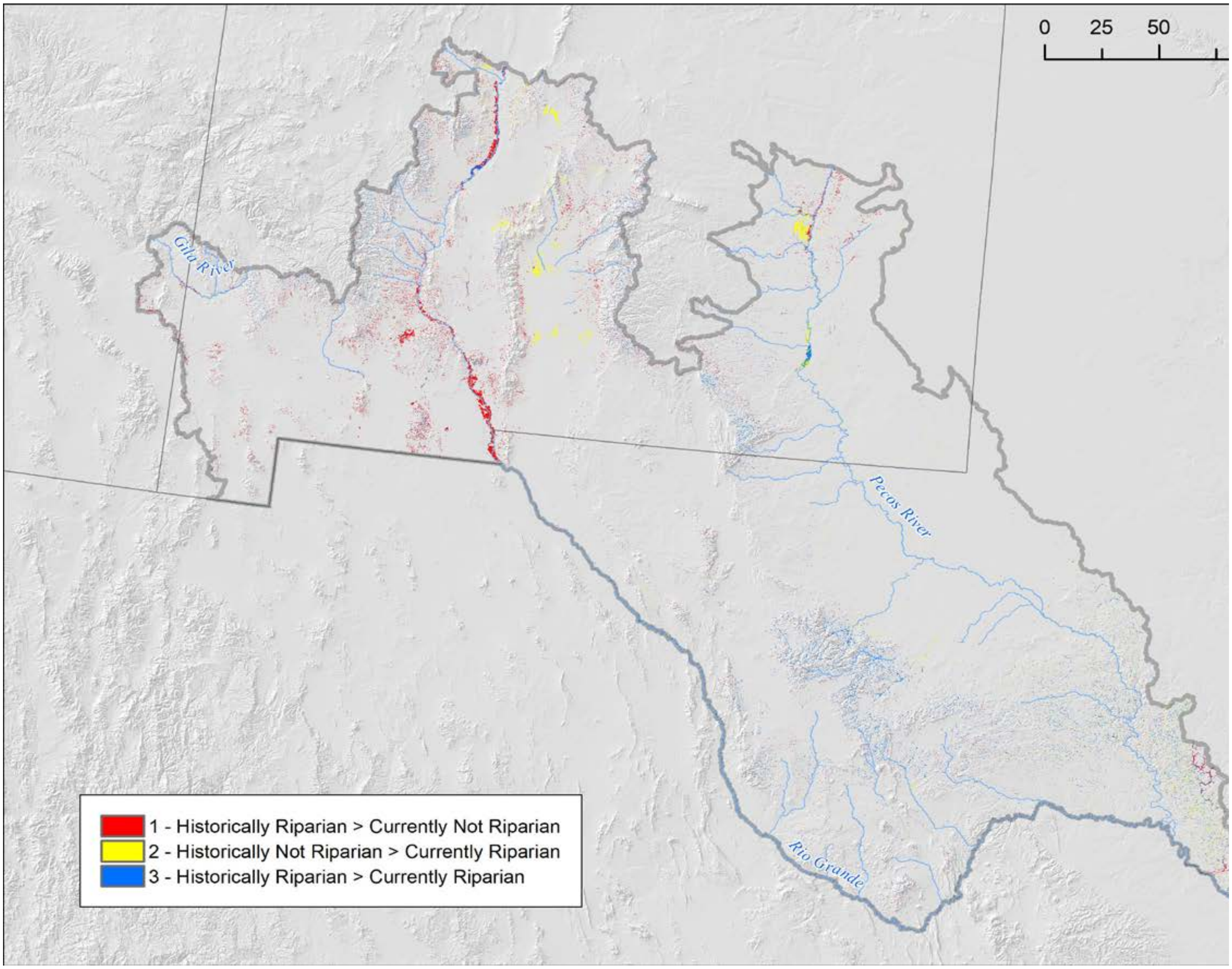


Figure 8-3 uses the LANDFIRE riparian Existing Vegetation Type (EVT) dataset (LANDFIRE 2016; EVT_PHYS = "Riparian") as the source of information about the current distribution of riparian vegetation, rather than using the data displayed in Figure 8-1. The LANDFIRE BpS and EVT datasets have a common methodological foundation, and so are more comparable. The LANDFIRE EVT distribution for riparian vegetation differs from the distribution shown in Figure 8-1. methodologically in two respects. First, the EVT distribution includes riparian vegetation wherever it occurs, while Figure 8-1. includes riparian vegetation only when it occurs as part of one of the five aquatic-wetland CEs. Second, the river and perennial stream CE distributions shown in Figure 8-1. include areas classified by the NHD as "Lake/Pond", "Reservoir", and "Swamp/Marsh" when these occur within 5 km of an associated flowline. These areas largely occur in association with reservoirs along the Pecos River and Rio Grande. The LANDFIRE EVT distribution for riparian vegetation does not include these areas.

Riparian vegetation can disappear as a result of land development and/or altered hydrology, and can appear or expand around reservoirs and in irrigated locations. Figure 8-3 shows extensive losses of riparian vegetation along the former riparian corridor of the Rio Grande from the vicinity of El Paso, Texas, northward. Figure 8-3 also shows substantial loss along the Pecos River riparian corridor from the vicinity of Roswell, New Mexico, northward. Two other areas of loss stand out prominently in Figure 8-3: (1) a compact, isolated area northwest of Las Cruces, New Mexico, on the west and northwest flanks of Las Uvas Mountains, where irrigated agricultural development has replaced riparian cover; and (2) an area of river meanders in the extreme southeastern-most corner of the ecoregion, east of the Pecos River. These latter patches represent areas of former riparian vegetation along the lower Devil's River, which the AMT chose not to include in the REA (Unnasch et al. 2017).

Figure 8-3 also shows several distinct, substantial areas where the LANDFIRE EVT dataset indicates that riparian vegetation currently occurs but where the BpS model estimates that it historically would not have occurred. One such large area occurs adjacent to the north side of the city of Roswell, New Mexico, an area of intensive irrigation agriculture possibly associated with some riparian vegetation. This may be an area in which the EVT dataset over-represents the current presence of a riparian vegetation community. Several other large areas, where the two datasets suggest the development of riparian vegetation outside of its historic distribution, occur in the Tularosa Basin. These simply may indicate areas where the BpS model does not adequately represent the potential for riparian vegetation around playas and playa lakes. Other such areas similarly also may simply indicate methodological differences between the BpS and EVT datasets.

Finally, Figure 8-3 shows a wide scatter of 30-m pixels away from the large rivers and perennial streams of the region, across the foothills of mountain ranges. This broad distribution indicates that, according to the BpS model, patches of riparian vegetation would have occurred historically along intermittent and ephemeral drainages in and immediately surrounding higher elevations. The EVT data indicate that some of these small patches remain, while others do not.

Overall, the data used to construct Figure 8-3 indicate that riparian vegetation historically would have covered approximately 392,257 hectares within the analysis extent for the REA, of which 179,383 hectares remain, for a loss of 54.27%. This estimate does not take into account any of the gains of riparian vegetation suggested in the data, most of which in any case do not appear to be associated with the riparian corridors of the large river or perennial stream CEs.

8.3.3 Channel Modification and Conversion

Water resource development across the U.S. portion of the ecoregion has resulted in the artificial modification of portions of the Gila River, Pecos River, Rio Grande, and many priority perennial streams from their natural channel configurations. The NHD classifies the individual flowline segments that occur within the ecoregion as follows:

- <u>Stream/River</u> (FType = 460): A natural flowline within a flow network.
- <u>Connector</u> (334): A connection between two nonadjacent segments of a flow network, along which flow is not visible, such as a connection through a dam.

- Canal/Ditch (336): An artificial waterway constructed to convey water, irrigate or drain land, connect two or more waterbodies, or facilitate the movement of watercraft.
- Artificial Path (558): The flowline for a stream or river through a reservoir or along a path determined by artificial structures such as levees.

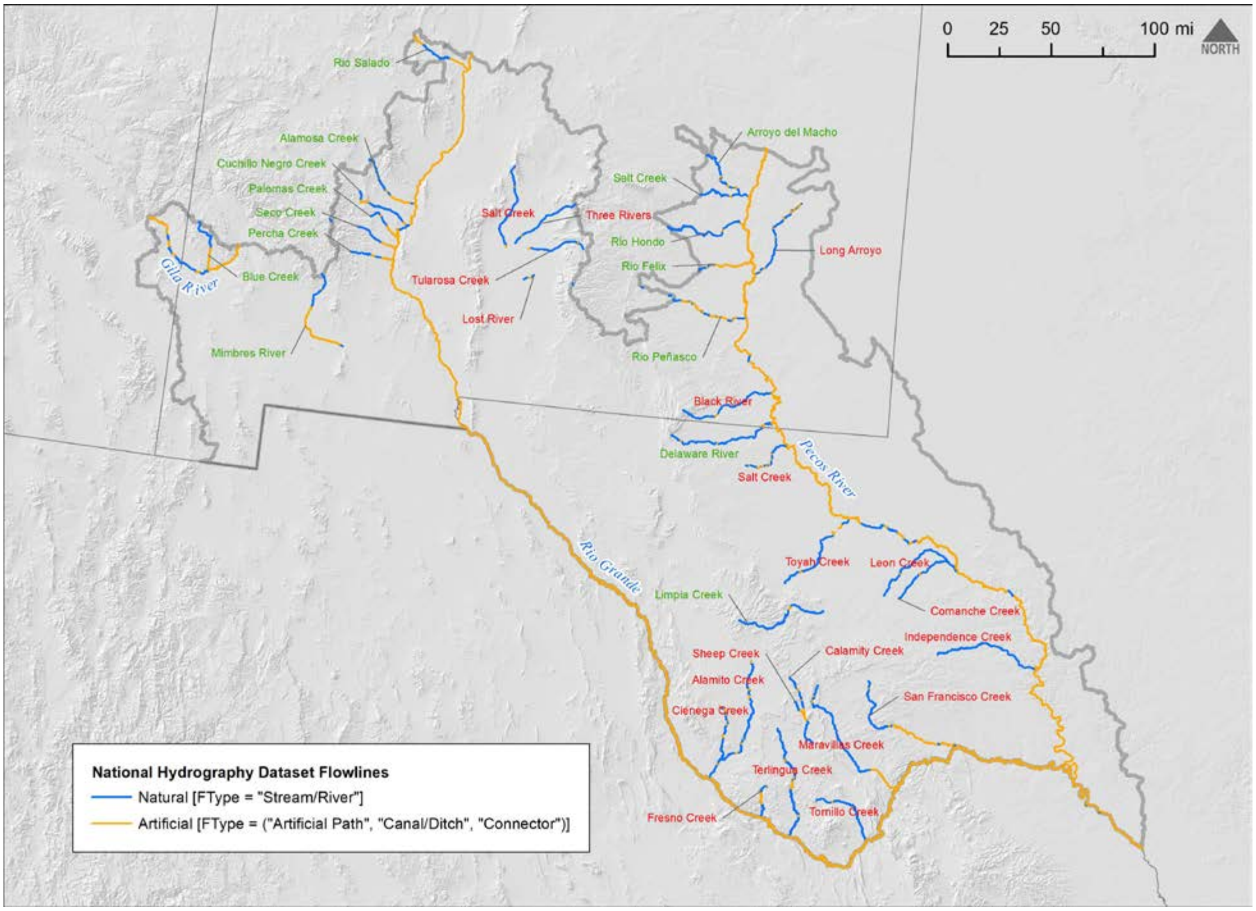
Table 8-3 lists the rivers and streams that make up the Large River-Floodplain Systems and Montane- and Lowland-Headwater Perennial Stream CEs, and tabulates the percentage of each identified as "artificial" – Connector, Canal/Ditch, or Artificial Path – flowline segments rather than as Stream/River flowline segments. Figure 8-4 summarizes the information shown in Table 8-3.

Table 8-3. River and stream flowline conversion to artificial conditions.

CE	River/Stream	Percent Converted by Length
Large River-Floodplain Systems	Gila River	63.6%
	Pecos River	92.3%
	Rio Grande	99.2%
	All Rivers	94.6%
Lowland-Headwater Perennial (LHP) Streams	Alamito Creek	2.5%
	Black River	4.1%
	Calamity Creek	17.1%
	Cienega Creek	9.4%
	Comanche Creek	0.9%
	Fresno Creek	29.5%
	Independence Creek	0.0%
	Leon Creek	0.0%
	Long Arroyo	3.7%
	Lost River	16.2%
	Maravillas Creek	22.4%
	Salt Creek	4.4%
	San Francisco Creek	42.9%
	Sheep Creek	34.1%
	Terlingua Creek	7.5%
	Three Rivers	0.1%
	Tornillo Creek	1.2%
	Toyah Creek	9.3%
	Tularosa Creek	2.8%
	All LHP Streams	9.0%
Montane-Headwater Perennial (MHP) Streams	Alamosa Creek	32.8%
	Arroyo del Macho	8.7%
	Blue Creek	28.5%
	Cuchillo Negro Creek	21.1%
	Delaware River	4.5%
	Limpia Creek	2.0%
	Mimbres River	60.8%
	Palomas Creek	42.2%
	Percha Creek	30.2%
	Rio Felix	63.2%
	Rio Hondo	9.0%
	Rio Peñasco	39.8%

	Rio Salado	46.4%
	Salt Creek	6.2%
	Seco Creek	30.5%
	All MHP Streams	26.3%
All Rivers and Perennial Streams		52.1%

Figure 8-4. River and stream flowline conversion to artificial conditions.



The percentages shown in Table 8-3 indicate the extent of conversion of the channel in each waterbody from a natural channel to an artificial feature, either through mechanical modification or through inundation beneath a reservoir. The results indicate that more than 90% by length of both the Pecos River and the Rio Grande and nearly 64% of the Gila River within the analysis extent for the REA consist of converted flow segments. Lowland-headwater perennial streams have experienced less modification overall (average 9% by length), but the percentage affected varies widely among the individual streams, from 0% along Independence and Leon Creeks to nearly 43% along San Francisco Creek. Montane-headwater perennial streams are moderately altered (average 26.3% by length) but the percentage again varies widely among the individual streams, from 2% along Limpia Creek to nearly 61% along the Mimbres River. Overall, the NHD classifies approximately 52% of the flowline lengths of all Large River-Floodplain Systems and Montane- and Lowland-Headwater Perennial Stream CEs together as artificial.

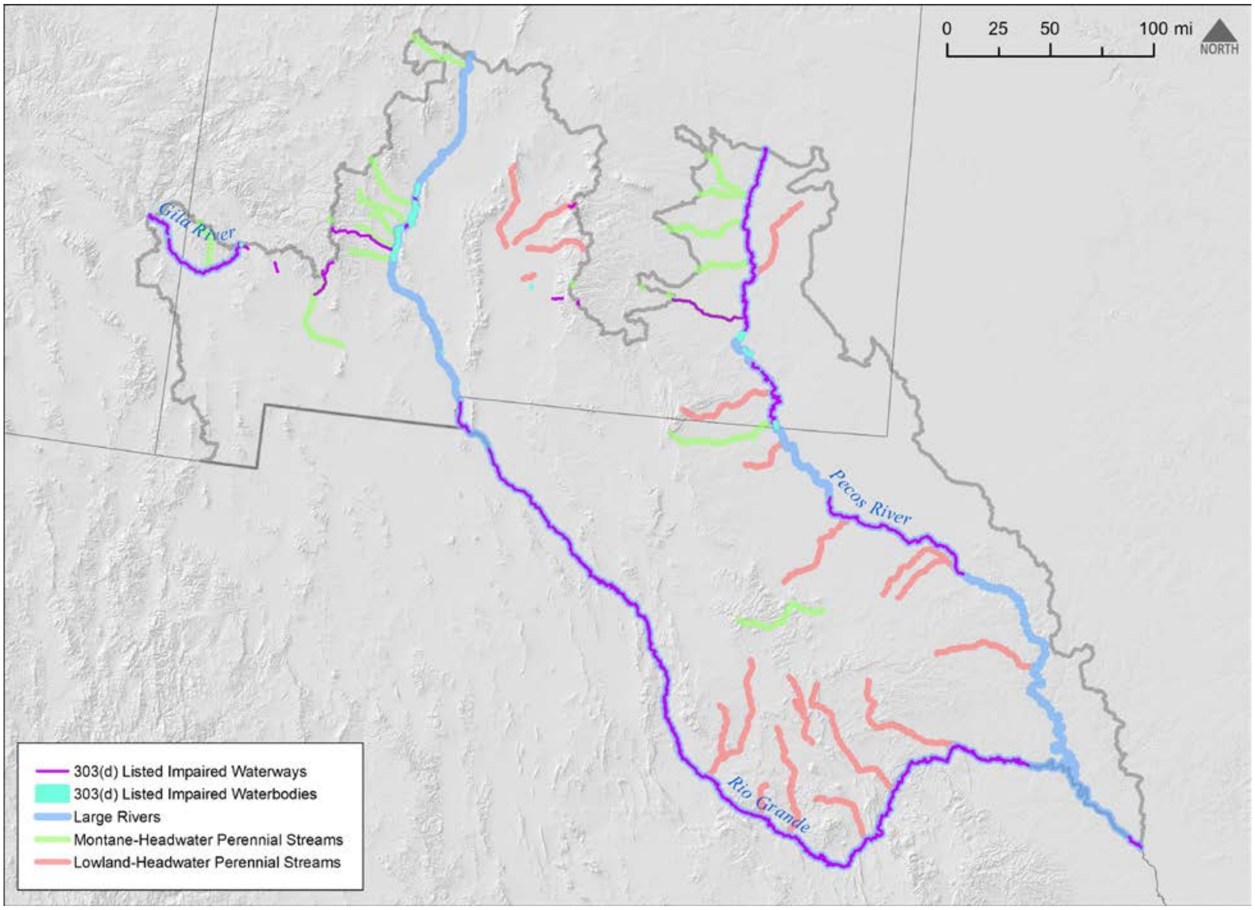
8.3.4 Water Quality Impairment

Section 303(d) of the federal Water Pollution Control Act, 1972 (33 U.S.C. 1251, *aka* the Clean Water Act), requires states and tribes to systematically report information on water quality impairments to the U.S. Environmental Protection Agency (EPA). The resulting list of impaired and threatened waterbodies for a state is known as the "state 303(d) list. States and tribes must submit their 303(d) list to the EPA for approval every two years. An "impaired" waterbody is one that does not meet ("attain") state or tribal water quality standards for the specific uses identified ("designated") by the state or tribe for that waterbody. State- or tribe-designated uses may include public water supply, recreation with versus without significant water contact (e.g., boating versus swimming), fishing, irrigation, etc. States and tribes set their own water quality standards consistent with rules and criteria set by the EPA. States and tribes must information on the pollutant(s) responsible impairing water quality at an individual waterbody in the state or tribal 303(d) list, when known.

State and tribal 303(d) lists identify waterbodies using a state or tribal designation code. The EPA maintains a database that cross-references state waterbody designations with the NHD, and periodically releases a national 303(d) database in which all impairment location data are provided in both state or tribal and NHD formats. The EPA released its most recent nationally cross-referenced database in 2015 The present REA uses these 303(d) data to map the distribution of state-designated water quality impairments within the U.S. portion of the ecoregion, in Arizona, New Mexico, and Texas (USEPA-OW 2015). Figure 8-5 shows river and stream water quality impairments in the U.S. portion of the ecoregion in 2015 based on EPA 303(d) national, cross-referenced data for that year.

Figure 8-5 shows that the three states have identified water quality impairments along essentially all of the New Mexico portion of Pecos River and roughly half the Texas portion within the ecoregion; along the Rio Peñasco, a Pecos River tributary that enters the mainstem from the west roughly half-way between the cities of Roswell and Carlsbad, New Mexico; along all of the Texas portion of the Rio Grande; along the entire length of Elephant Butte Reservoir along the Rio Grande in New Mexico; along Las Animas Creek, a Rio Grande tributary that enters the mainstem from the west near the lower end of Elephant Butte Reservoir; along the upper Mimbres River; and along the entire length of the Gila River mainstem within the analysis extent for the REA, in both Arizona and New Mexico. Small, isolated impaired stream reaches include a small section of Mangas Creek, a tributary to the Gila River, and small sections of two small streams (Three Rivers and unnamed) flowing into the Tularosa Basin from the east. It should also be noted that the Rio Grande in New Mexico, between Elephant Butte Dam and the Texas border, also would be considered highly impaired but for the fact that it runs dry much of the time and only supports irrigation (Hogan 2013).

Figure 8-5. EPA 303(d)-listed impaired waterways and waterbodies (USEPA-OW 2015).



8.3.5 Historic versus Current Native Fish Assemblages

This section presents a comparison of the current versus the historic distributions of native fish species in the U.S. portion of the ecoregion. The AMT posed a Management Question, MQ 10, "how do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?" The assemblages in question consist of endemic species with specialized adaptations to the unique hydrology, water chemistry, and fluvial geomorphology of their respective hydrologic systems. Some of these species are rare, threatened, endangered, or recognized as state Species of Greatest Conservation Need. The process of defining these two assemblages led to the identification and analysis of six "sensitive native fish assemblages" instead of the original two.

8.3.5.1 Background

The Pre-Assessment Report, Chapter 8 (Unnasch et al. 2017) identified the native fish species of the ecoregion and their associations with perennial streams, large rivers, springs, and closed basins. Table 8-4 summarizes this information (see Pre-Assessment Report, Chapter 8 (Unnasch et al. 2017) for information sources). Table 8-4 also indicates the global ("G-Rank") and state ("S-Rank") conservation status of each species as rated by the Natural Heritage Network (NatureServe 2014) and indicates whether New Mexico or Texas identifies the species as a "Species of Greatest Conservation Need"

(SGCN) in the most recent version of each relevant state Comprehensive Wildlife Action Plan (Connally, ed. 2012, NMDGF 2016).

The natural waters of the ecoregion can differ significantly in their characteristic and endemic fish species. Some species native to the Rio Grande are not also native to the Pecos River (e.g., the Rio Grande sucker), or *vice versa* (e.g., the Pecos pupfish). The Gila River basin lies west of the Continental Divide. Its fish assemblage therefore differs significantly from the basins east of the divide. Several fish species native to the rivers east of the Continental Divide that today occur in the Gila River basin are considered non-native species in the latter basin: western mosquitofish, channel catfish, flathead catfish, black bullhead, fathead minnow, and largemouth bass (Gori et al. 2014). The endorheic Mimbres River, which lies immediately along the eastern side of the Continental Divide and, when flowing, discharges into the closed Guzmán Basin, shares fish species with both the Colorado River and Rio Grande basins.

A small number of fish species have native ranges that closely approach but do not or only minimally extend into the U.S. portion of the ecoregion. These species conventionally are not considered native to the ecoregion. However, as described above and in Chapter 2, the analysis extent for the present REA includes all watersheds identified by a 5th-Level (10-digit) Hydrologic Unit Code (HUC) that lie within *or overlap* the boundaries of the Level-III ecoregion. As a result, Table 8-3 includes four fish species that are not conventionally considered native to the ecoregion (Propst 2016): *Notropis buchanani*, ghost shiner; *Oncorhynchus clarki virginalis*, Rio Grande cutthroat trout; *Oncorhynchus gilae*, Gila trout; and *Platygobio gracilis*, flathead chub.

8.3.5.2 Assessment Priorities

The AMT initially proposed the Gila River and Pecos River fish assemblages as separate CEs. The proposed Gila River fish assemblage included the Gila trout (*Oncorhynchus gilae*), loach minnow (*Rhinichthys (aka Tiaroga) cobitis*), and spikedace (*Meda fulgida*), and several other species native to the river and its headwater streams within the ecoregion, including springs that discharge into these streams. Some members of the proposed assemblage also may occur in the adjacent Mimbres River basin, for the reasons stated above. The proposed Pecos River fish assemblage included the gray redhorse (*Moxostoma congestum*), bluntnose shiner (*Notropis simus*), and Pecos pupfish (*Cyprinodon pecosensis*), and several other species native to the Pecos River and its headwater streams within the ecoregion, again including perennially and intermittently tributary springs. Some members of the proposed Pecos River fish assemblage also occur in the Rio Grande, into which the Pecos River flows.

Table 8-4. Fishes native to the U.S. waters of the Chihuahuan desert ecoregion. Geographic Distribution: "P" = Present; "E" = Extirpated. G- and S-Rank Codes: "NA" = Not Applicable; "NR" = Not Yet Ranked; "X" = Presumed Extirpated.

Species	Common Name	Gila River Mainstem	Gila River Tributary	Mimbres River	Rio Grande Mainstem	Rio Grande Tributary	Tularosa Basin	Pecos River Mainstem	Pecos River Tributary	Springs	G-Rank	S-Rank NM	S-Rank TX	SGCN
Agosia chrysogaster	Longfin dace	P	P	P							4	NA		
Anguilla rostrata	American eel				E			E						TX
Aplodinotus grunniens	Freshwater drum				P			P			5	X	5	
Astyanax mexicanus	Mexican tetra				P	P		P	P	P	5	2	5	NM
Atractosteus spatula	Alligator gar							E			3-4		4	TX
Campostoma anomalum pullum	Central stoneroller					P		E	P		5	NA	5	
Campostoma ornatum	Mexican stoneroller				P	P					3-4		1	TX
Carpiodes carpio	River carpsucker				P	P		P	P		5	4	5	
Catostomus clarkii	Desert sucker	P	P								3-4	2		NM
Catostomus insignis	Sonora sucker	P	P								3-4	2		NM
Catostomus plebeius	Rio Grande sucker		P	P	P	P				P	3-4	2		NM
Cichlasoma cyanoguttatum	Rio Grande cichlid					P		P	P		5		5	
Cycleptus elongatus	Blue sucker				P			P	P		3-4	1	3	NM, TX
Cyprinella formosa	Beautiful shiner			E							3	X		
Cyprinella lutrensis	Red shiner				P	P		P	P	P	5	NA	5	
Cyprinella proserpina	Proserpine shiner					P		P	P	P	3		2	TX
Cyprinella venusta	Blacktail shiner				P	P		P	P	P	5		5	
Cyprinodon bovinus	Leon Springs pupfish							E	P	P	1		1	TX
Cyprinodon elegans	Comanche Springs pupfish								P	P	1		1	TX
Cyprinodon pecosensis	Pecos pupfish							P	P	P	2	1	1	NM, TX
Cyprinodon tularosa	White Sands pupfish						P				1	1		NM
Dionda episcopa	Roundnose minnow							P	P	P	4	3	5	TX
Dorosoma cepedianum	Gizzard shad				P	P		P			5	4	5	
Etheostoma grahami	Rio Grande darter							P	P	P	2-3		2	TX
Etheostoma lepidum	Greenthroat darter							E	P	P	3-4	2	3	NM

Species	Common Name	Gila River Mainstem	Gila River Tributary	Mimbres River	Rio Grande Mainstem	Rio Grande Tributary	Tularosa Basin	Pecos River Mainstem	Pecos River Tributary	Springs	G-Rank	S-Rank NM	S-Rank TX	SGCN
Fundulus zebrinus	Plains killifish				P	P		P	P	P	5	4	5	
Gambusia affinis	Western mosquitofish				P	P		P	P	P	5	NA	5	
Gambusia clarkhubbsi	San Felipe gambusia					P				P	1		1	
Gambusia gaigei	Big Bend gambusia									P	1		1	TX
Gambusia nobilis	Pecos gambusia								P	P	2	1	2	NM, TX
Gambusia speciosa	Tex-Mex gambusia					P				P	3Q	NR	3?	
Gila intermedia	Gila chub		P							P	2	1		NM
Gila nigra	Headwater chub		P								2Q	NR		NM
Gila nigrescens	Chihuahua chub			P							1-2	1		NM
Gila pandora	Rio Grande chub					P		P	P		3	3	1	NM, TX
Gila robusta	Roundtail chub		E								3	2		NM
Hybognathus amarus	Rio Grande silvery minnow				P			E			1	1	X	NM, TX
Ictalurus furcatus	Blue catfish				P			P			5	2-3	5	
Ictalurus lupus	Headwater catfish				P	P		P	P		3	1	2	TX
Ictalurus punctatus	Channel catfish				P	P		P	P		5	5	5	
Ictiobus bubalus	Smallmouth buffalo				P			P			5	3	5	
Lepisosteus oculatus	Spotted gar				P			E			5	X	5	
Lepisosteus osseus	Longnose gar				P			P	P		5	2	5	
Lepomis auritus	Redbreast sunfish					P		P	P	P	5		NA	
Lepomis cyanellus	Green sunfish				P	P		P	P	P	5	NA	5	
Lepomis gulosus	Warmouth (*possibly nonnative*)								P	P	5	NA	5	
Lepomis macrochirus	Bluegill				P	P		P	P		5	NA	5	
Lepomis megalotis	Longear sunfish				P			P	P	P	5	NA	5	
Lucania parva	Rainwater killifish							P	P	P	5	3	NR	
Macrhybopsis aestivalis	Rio Grande speckled chub				P	P		P			3-4	2	3-4	TX
Meda fulgida	Spikedace	P	P								2	1		NM
Menidia beryllina	Inland silverside				P			P			5	NA	5	
Micropterus salmoides	Largemouth bass				P			P	P		5	NA	5	

Species	Common Name	Gila River Mainstem	Gila River Tributary	Mimbres River	Rio Grande Mainstem	Rio Grande Tributary	Tularosa Basin	Pecos River Mainstem	Pecos River Tributary	Springs	G-Rank	S-Rank NM	S-Rank TX	SGCN
Morone chrysops	White bass				P			P			5	NA	5	
Moxostoma congestum	Gray redhorse				P			P	P		4	1	3	NM
Notropis amabilis	Texas shiner							P	P	P	4	X	4	
Notropis braytoni	Tamaulipan shiner				P	P		P	P		4		4	TX
Notropis buchanani	Ghost shiner							P			5		5	
Notropis chihuahua	Chihuahua shiner				P	P					3		2	TX
Notropis jemezanus	Rio Grande shiner				P			P			3	2	3	TX
Notropis orca	Phantom shiner				E			E			XQ	X	X	
Notropis simus	Bluntnose shiner				E			P			2	2	X	NM, TX
Notropis stramineus	Sand shiner				P			P	P		5	4	3	
Oncorhynchus clarki virginalis	Rio Grande cutthroat trout					P					4T3	2		TX
Oncorhynchus gilae	Gila trout	E	P	P							3	1		NM
Percina macrolepida	Bigscale logperch				P			P			5	2	5	NM
Pimephales promelas	Fathead minnow				P	P		P	P		5	NA	5	
Pimephales vigilax	Bullhead minnow				P	P		P	P		5	NA	5	
Platygobio gracilis	Flathead chub				P			P			5	4	2	
Poeciliopsis occidentalis	Gila topminnow		P								3	X		NM
Ptychocheilus lucius	Colorado pikeminnow	E									1	X		
Pylodictis olivaris	Flathead catfish				P	P		P			5	2	5	
Rhinichthys cataractae	Longnose dace				P	P		P			5	NA	2	TX
Rhinichthys cobitis	Loach minnow	P	P								2	2		NM
Rhinichthys osculus	Speckled dace	P	P								5	3		
Xyrauchen texanus	Razorback sucker	E									1	1		NM

The AMT subsequently agreed to a recommendation from the Technical Team to treat the two fish assemblages not as separate CEs, but as indicators of the condition of the aquatic-wetland system types with which they are associated, to avoid redundancy. The AMT retained MQ 10 to ensure that the assemblages received close attention. However, because the species of concern occur in such a wide range of settings, this MQ implicitly pertains not only to the Gila and Pecos Rivers but to all five of the aquatic-wetland system CE types. (*Cyprinodon tularosa*, the White Sands pupfish, can occur in playa lake waters incidentally to its obligate relationship to springs that sometimes discharge sufficiently to flow into Lake Lucero).

Analysis of the information in Table 8-4 identified all fish species native to each major basin in the U.S. portion of the ecoregion with an S-Rank of 2 or less or that either New Mexico or Texas lists as an SGCN in its Comprehensive State Wildlife Action Plan. An S-Rank of 2 or less indicates that the Natural Heritage Network considers the species imperiled (S2) or critically imperiled (S1). Table 8-4 indicates that the Pecos River and Rio Grande basins share several sensitive native fish species in common, but also harbor several species that are native to only one basin or the other. The present assessment therefore addresses six “sensitive native fish assemblages,” shown in Table 8-5. The Gila River, Mimbres River, Tularosa, Pecos River, and Rio Grande Basin sensitive native fish assemblages consist of species native to each basin alone within the U.S. portion of the ecoregion. The Pecos-Rio Grande Basin sensitive native fish assemblage consists of species native to both river basins within the U.S. portion of the ecoregion.

Table 8-5 indicates that two of the nine fish species in the Gila River Basin sensitive native fish assemblage, the Rio Grande sucker and Gila trout, also are members of the Mimbres River Basin sensitive native fish assemblage. The Rio Grande sucker is also a member of the Rio Grande sensitive native fish assemblage.

Table 8-5 indicates that two species in the Mimbres basin assemblage also occur in the Gila basin assemblage (*Catostomus plebeius*, Rio Grande sucker, and *Oncorhynchus gilae*, Gila trout). However, the Mimbres assemblage also includes an additional, very rare, endemic species (*Gila nigrescens*, Chihuahua chub), and lacks several other sensitive native species that are present in the Gila basin assemblage. Table 8-5 also indicates that the Rio Grande sucker, which occurs in both the Gila and Mimbres basin assemblages, also occurs in the Rio Grande basin assemblage. However, the Rio Grande basin assemblage also includes numerous species not found in either the Gila or Mimbres basin assemblages, and vice versa. As noted above, too, the Rio Grande and Pecos River basin assemblages share several sensitive native fish species in common. This is not surprising given that the Pecos is a major tributary to the Rio Grande. However, the smaller Pecos River basin harbors several sensitive native fish species that do not occur in the Rio Grande, and the Rio Grande basin upstream from the Pecos River confluence similarly harbors several sensitive native fish species that do not occur in the Pecos basin. As indicated in Table 8-4, the species unique to each of these two basins mostly consist of small fishes adapted to hydro-geo-chemically unique tributaries.

Table 8-5. Sensitive native fish assemblages by basin, species name, and common name.

Basin	Species Name	Common Name
Gila River Basin	*Catostomus clarkii*	Desert sucker
	Catostomus insignis	Sonora sucker
	Catostomus plebeius	Rio Grande sucker
	Gila intermedia	Gila chub
	Gila nigra	Headwater chub
	Meda fulgida	Spikedace
	Oncorhynchus gilae	Gila trout
	Poeciliopsis occidentalis	Gila topminnow
	Rhinichthys cobitis	Loach minnow
Mimbres River Basin	*Catostomus plebeius*	Rio Grande sucker
	Gila nigrescens	Chihuahua chub
	Oncorhynchus gilae	Gila trout
Tularosa Basin	*Cyprinodon tularosa*	White Sands pupfish
Pecos River Basin	*Cyprinodon bovinus*	Leon Springs pupfish
	Cyprinodon elegans	Comanche Springs pupfish
	Cyprinodon pecosensis	Pecos pupfish
	Dionda episcopa	Roundnose minnow
	Etheostoma grahami	Rio Grande darter
	Etheostoma lepidum	Greenthroat darter
	Gambusia nobilis	Pecos gambusia
	Notropis simus	Bluntnose shiner
Rio Grande Basin	*Campostoma ornatum*	Mexican stoneroller
	Catostomus plebeius	Rio Grande sucker
	Gambusia clarkhubbsi	San Felipe gambusia
	Gambusia gaigei	Big Bend gambusia
	Hybognathus amarus	Rio Grande silvery minnow
	Notropis chihuahua	Chihuahua shiner
	Oncorhynchus clarki virginalis	Rio Grande cutthroat trout
Pecos-Rio Grande Basin	*Astyanax mexicanus*	Mexican tetra
	Cycleptus elongatus	Blue sucker
	Cyprinella proserpina	Proserpine shiner
	Gila pandora	Rio Grande chub
	Ictalurus furcatus	Blue catfish
	Ictalurus lupus	Headwater catfish
	Lepisosteus osseus	Longnose gar
	Macrhybopsis aestivalis	Rio Grande speckled chub
	Moxostoma congestum	Gray redhorse
	Notropis braytoni	Tamaulipan shiner
	Notropis jemezanus	Rio Grande shiner
	Percina macrolepida	Bigscale logperch
	Platygobio gracilis	Flathead chub
	Pylodictis olivaris	Flathead catfish
	Rhinichthys cataractae	Longnose dace

8.3.5.3 Data and Assessment Process

The data for the assessment of the native fish assemblages in the U.S. portion of the ecoregion consist of records in the FishNet 2 Portal (http://www.fishnet2.net/; accessed February 9, 2017) (**Table 8-1**). The database records observations of species by date, time, location, collection methods and other details, and the handling and curation of reference specimens. The database seeks to provide a comprehensive record of observations of fishes through a collaborative effort across numerous institutions.

Table 8-1. Fishnet record date ranges for Chihuahuan Desert sensitive native fishes.

Assemblage➔ Species🡻	Gila Basin	Mimbres Basin	Tularosa Basin	Pecos Basin	Rio Grande Basin	Pecos-Rio Grande
Astyanax mexicanus						1938-2012
Campostoma ornatum					1952-2011	
Catostomus clarki	1949-2010					
Catostomus insignis	1949-2013					
Catostomus plebeius		1964-1964			1981-1981	
Cycleptus elongatus						1947-2009
Cyprinella proserpina						1951-2011
Cyprinodon bovinus				1971-1980		
Cyprinodon elegans				1929-1995		
Cyprinodon pecosensis				1940-2013		
Cyprinodon tularosa			1947-2008			
Dionda episcopa				1940-2009		
Etheostoma grahami				1951-2011		
Etheostoma lepidum				1940-2015		
Gambusia clarkhubbsi					1997-2003	
Gambusia gaigei					1954-1992	
Gambusia nobilis				1936-2012		
Gila pandora						1975-2008
Hybognathus amarus					1938-2011	
Ictalurus furcatus						1892-2011
Ictalurus lupus						1940-2012
Lepisosteus osseus						1940-2012
Macrhybopsis aestivalis						1891-2011
Meda fulgida	1949-2002					
Moxostoma congestum						1947-2009
Notropis braytoni						1938-2011
Notropis chihuahua					1938-2009	
Notropis jemezanus						1938-2011
Notropis simus				1944-2013		
Oncorhynchus gilae	1985-1985					
Percina macrolepida						1948-2006
Platygobio gracilis						1964-2004
Poeciliopsis occidentalis	2011-2011					
Pylodictis olivaris						1944-2011
Rhinichthys cataractae						1944-2011
Rhinichthys cobitis	1949-2013					

Data were downloaded from the Fishnet database on all species in the six assemblages and filtered to remove all observations outside the analysis extent based on the locational data in the individual records. However, the filtering retained all records fishes along the Rio Grande with geospatial coordinates that place the observation in Mexico, whenever the record identified the source waterbody as the Rio Grande. As shown in Table 8-1, the resulting dataset includes observations on only six of the nine species identified as members of the Gila River Basin assemblage, only one of the three species identified as members of the Mimbres River Basin assemblage, and only six of the seven species identified as members of the Rio Grande River Basin assemblage. The filtered database includes all members of the other three basin assemblages. The resulting fish dataset includes records from 19 institutions, four of which, the University of New Mexico Museum of Southwestern Biology, Texas Natural History Science Center, Tulane University Museum of Natural History, and Texas A&M University Biodiversity Research and Teaching Collection, contributed 97% of the records.

Table 8-1 summarizes information on observation date ranges in the Fishnet data used in the present analysis, for each species. The present assessment used all records dated to the calendar year 2000 and later for each species to represent the current distribution of that species, and used the complete dataset of all records for a species, from all years, to represent the historic distribution of the species. The analysis excluded individual observations of fishes from any of the six assemblages, when the observation fell outside the basin(s) where the species is native. Such observations could represent errors in spatial coordinates, errors of species identification, or artificial translocations.

8.3.5.4 Results

Figure 8-6, Figure 8-7, and Figure 8-8 show the distributions of the fishes that comprise the Gila and Mimbres Basin, Tularosa and Pecos Basin, and Rio Grande and Pecos-Rio Grande Basin sensitive native fish assemblages, respectively.

The six maps in Figure 8-6 – Figure 8-8 show the locations of all historic and recent records of observation of members of each assemblage and the 5th-Level (10-digit) watersheds in which these observations occur. The fill color in each watershed polygon indicates the percentage of assemblage species recorded in the historic dataset for the watershed that are also recorded in the recent dataset, i.e., the percentage of assemblage members currently still present. Note that most of the 5th-Level watersheds include both tributary and mainstem waters. The individual record locations make it possible to distinguish conditions in the three large rivers from conditions in their tributaries.

- Nine species make up the Gila River Basin sensitive native fish assemblage but only six are represented in the Fishnet database within the analysis extent for the REA. Four of the six 5th-Level watersheds in the Gila River Basin that fall within the REA analysis extent have >67% of their historic complements of these six species, with most historic observations falling along the mainstem. In contrast, one watershed within the basin, the furthest downstream and straddling the Arizona-New Mexico border, has no species remaining of its historic complement of species in this assemblage, again with most historic observations falling along the mainstem. One tributary has <50% of its historic complement of species in this assemblage.

Figure 8-6. Current versus historic distributions of Gila (top) and Mimbres Basin (bottom) sensitive native fish species assemblages.

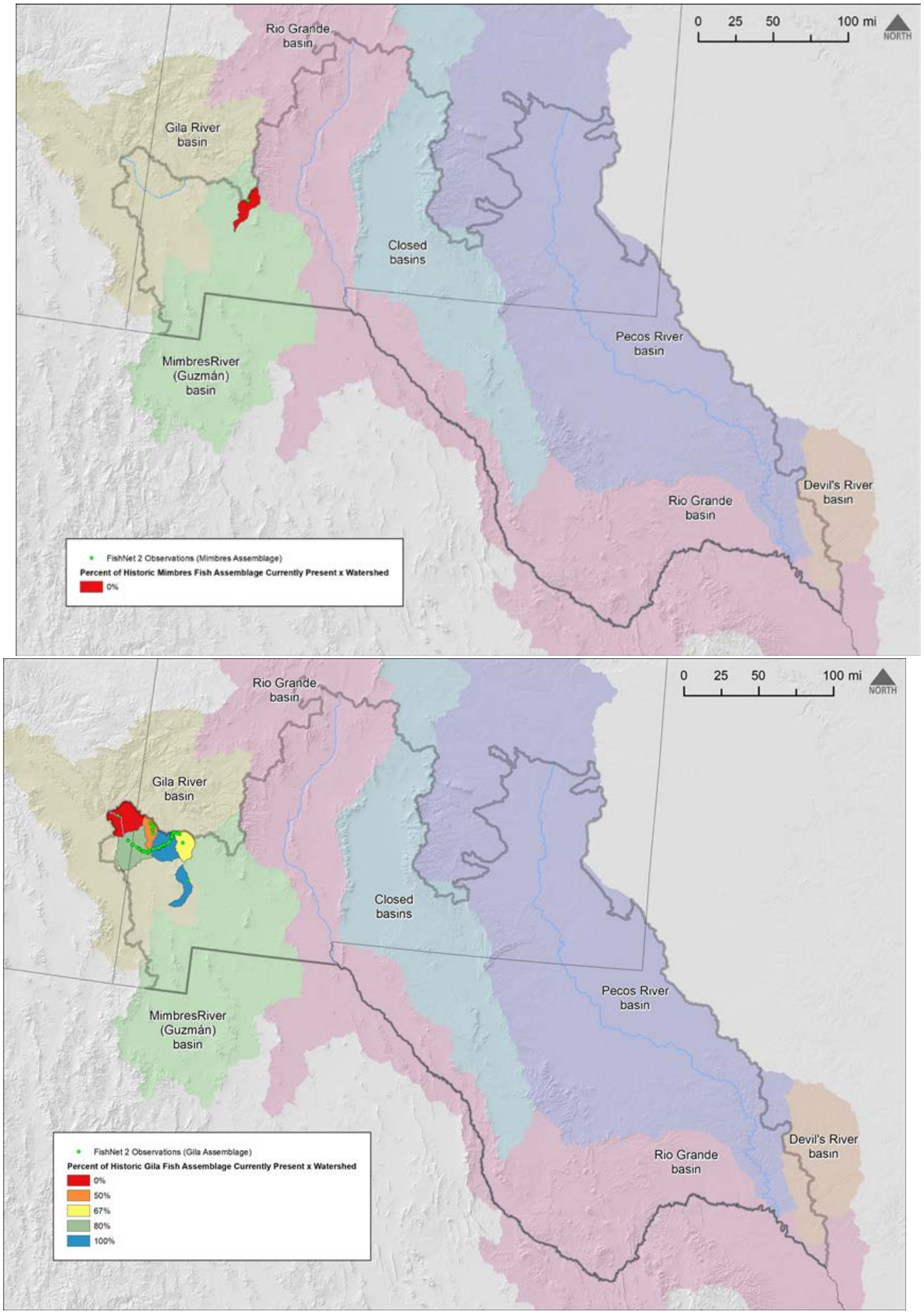
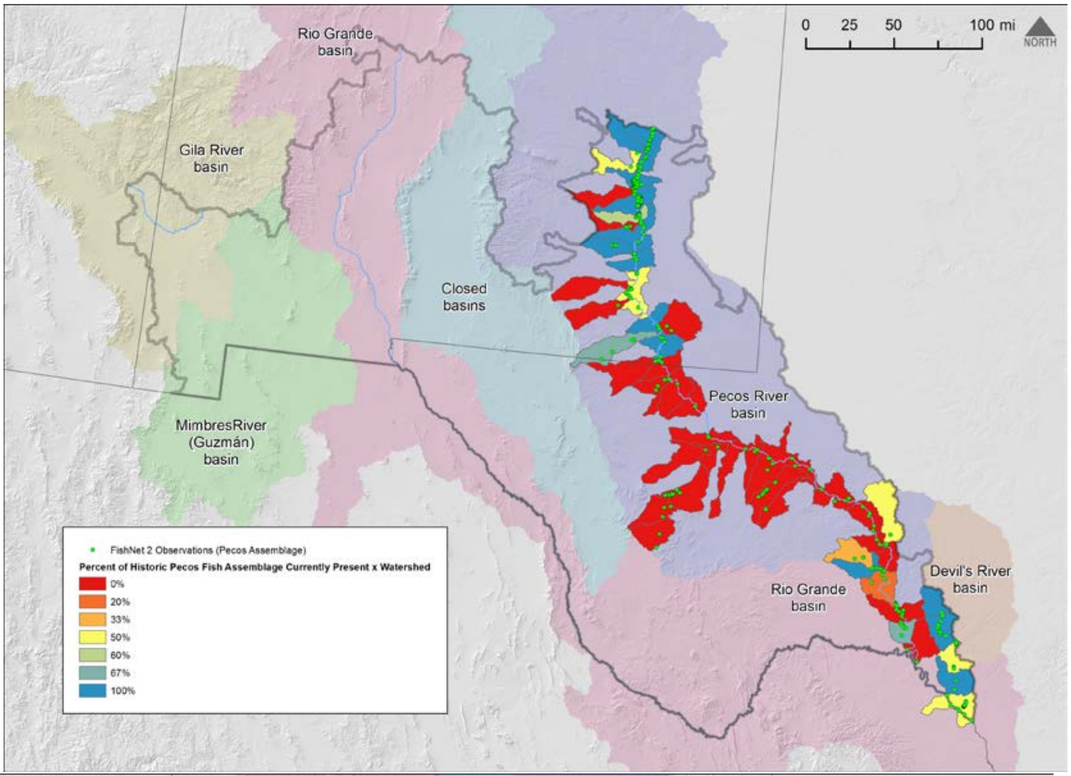


Figure 8-7. Current versus historic distributions of Tularosa (top) and Pecos Basin (bottom) sensitive native fish species assemblages.



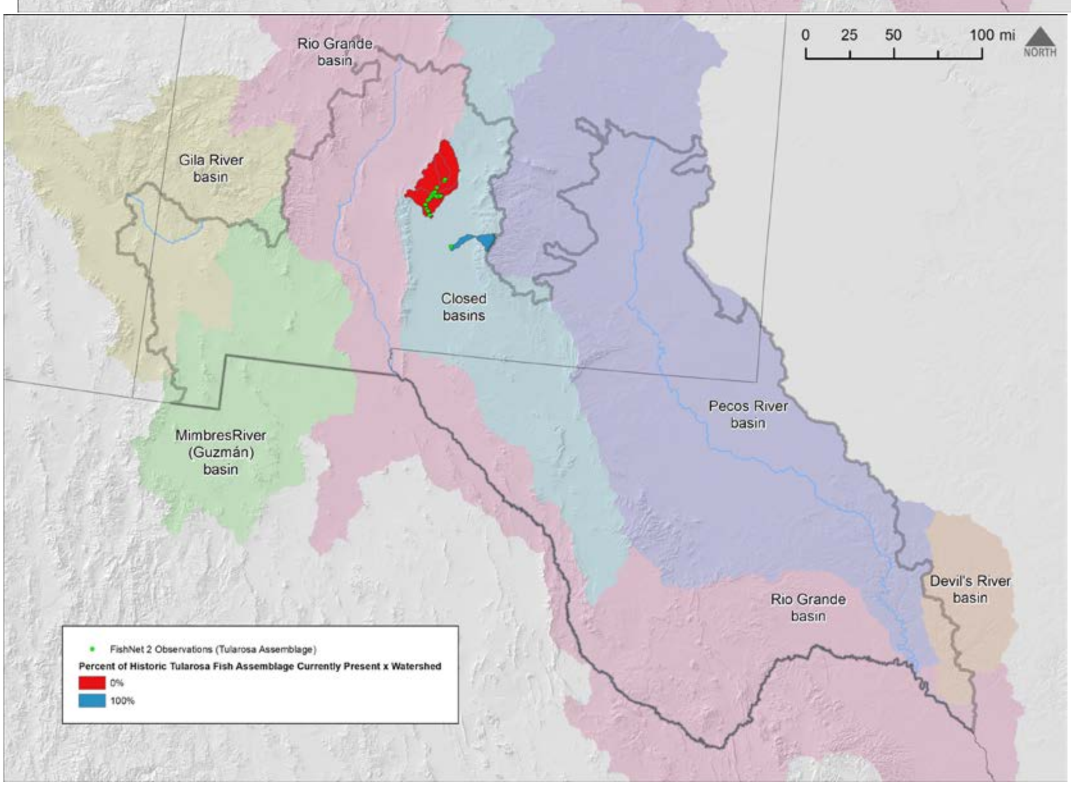
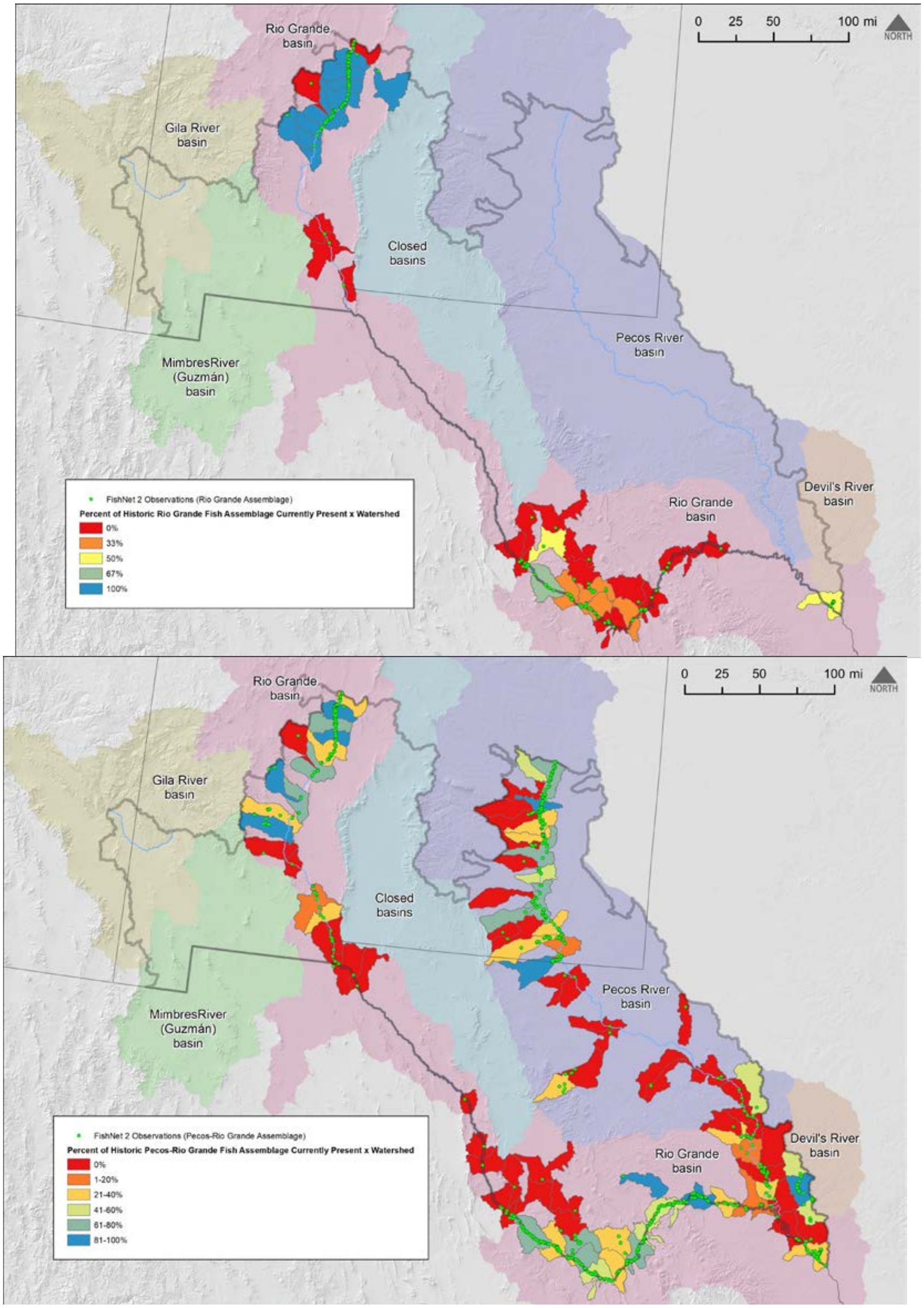


Figure 8-8. Current versus historic distributions of Rio Grande (top) and Pecos-Rio Grande Basin (bottom) sensitive native fish species assemblages.



- Three species make up the Mimbres River Basin sensitive native fish assemblage but only one is represented in the Fishnet database within the analysis extent. This species historically occurred in a single 5th-Level watershed and the dataset contains no recent records of its presence.
- The Tularosa Basin sensitive native fish assemblage consists of a single species, the White Sands pupfish. Historically, the species occurred in four 5th-Level watersheds, three in the northwest quadrant of the basin and one on the east side. Currently the fish occurs only in the east-side watershed. The dataset contains no recent records of the species in any of the three west-side watersheds.
- Eight species make up the Pecos River Basin sensitive native fish assemblage, all of which are represented in the Fishnet database within the analysis extent. Historically, these eight species occurred in 50 watersheds in the basin that fall within the analysis extent. Currently, 13 of these watersheds retain 100% of their historic complements of species in this assemblage, 10 retain 20-67% of their historic complements of species in this assemblage, and the remaining 27 watersheds – more than 50% of all historically occupied watersheds – retain no species from their historic complements. The historic observations in the Upper Pecos Basin fall mostly along the mainstem, while roughly half the historic observations in the Lower Pecos Basin fall along tributaries. Several of the species in the Pecos River Basin sensitive native fish assemblage in fact are strongly associated with springs that formerly or still discharge into tributaries.
- Seven species make up the Rio Grande Basin sensitive native fish assemblage but only six are represented in the Fishnet database within the analysis extent. Historically, these six species occurred in 31 watersheds in the basin that fall within the analysis extent. Geographically, these 31 watersheds fall into three groups: 11 in New Mexico north of the present-day location of Elephant Butte Dam, 3 between the present-day locations of Elephant Butte Dam, New Mexico, and El Paso, Texas, and 17 in Texas distributed exclusively in and downstream from the Big Bend region. Currently, 9 of the northern, historically occupied watersheds retain 100% of their historic complements of species in this assemblage while the other 2 northern watersheds retain none. None of the historically centrally located watersheds currently contains any of their historic assemblage complements. In turn, none of the southern, historically occupied watersheds retain all of their historic complements of species in the assemblage, 3 retain 50-67%, 4 retain only 33%, and the remaining 10 retain none. Most observations in each cluster fall along the mainstem but a few, especially in the southern cluster, fall along tributaries. Several species in the Rio Grande Basin sensitive native fish assemblage in fact are strongly associated with springs that formerly or still discharge into tributaries in the Big Bend region.
- Fifteen species make up the Pecos-Rio Grande Basin sensitive native fish assemblage, all of which are represented in the Fishnet database within the analysis extent. Historically, these fifteen species occurred in 90 watersheds in the combined basin that fall within the analysis extent. Currently, 9 watersheds retain 81-100% of their historic complements of species in this assemblage, 19 watersheds retain 41-80%, 20 watersheds retain only 12-40%, and 42 (47% of all watersheds) retain none of their historic complements of species in the assemblage. The observations for this assemblage fall heavily along the mainstem Pecos River and Rio Grande,

but also include both a few montane and lowland, spring-fed tributaries, particularly in the Big Bend region and in the Lower Pecos Basin.

- Overall, 49% of the watersheds that historically supported species in these six sensitive native fish assemblages currently no longer support any of these species and only 17% support all of their of their historic complements of species. It should also be noted that these results represent only species presence versus absence, not relative abundance. The fact that several of these species are listed as endangered (Table 8-4) indicates that they currently have greatly reduced abundances as well as constricted spatial distributions.

8.3.6 Chihuahuan Desert Amphibian Assemblage

The Chihuahuan Desert amphibian assemblage, as assessed for this REA, consists of four species, the Arizona toad (*Anaxyrus microscaphus*), Chiricahua leopard frog (*Lithobates (*aka *Rana) chircahuaensis*), northern leopard frog *(L. pipiens*), and Yavapai leopard frog (*L. yavapaiensis*). The Pre-Assessment Report, Chapter 3 (Unnasch et al. 2017), explains the reasoning for the focus on these four species. The assessment of the current distribution of the assemblage used National GAP species distribution data (https://gapanalysis.usgs.gov/species/) (USGS 2011, Gergely and McKerrow 2013). The National GAP species website (https://gapanalysis.usgs.gov/species/data/) defines a species distribution as *"… the spatial arrangement of environments suitable for occupation by a species. In other words, a species distribution is created using a deductive model to predict areas suitable for occupation within a species range…. It should be noted that all our range and distribution models are predictions about the occurrence of a species within the U.S. GAP ranges and distribution models are intended for use at the landscape scale (i.e., areas the size of square kilometers). They are not intended to be precise predictions of species occurrence/absence at local scales (areas the size of square meters). It is important for GAP data users to evaluate the suitability of the data for their intended purpose… GAP aims to use the best available information to create species ranges and distribution models. GAP relies on existing data and expert opinions from partners and collaborators (e.g., State Natural Heritage Programs)… All of GAP's ranges and distribution models have been reviewed by experts and compared to other data sources for accuracy. The accuracy of the species ranges and distribution models varies from species to species in part because habitat preferences and behaviors vary seasonally and annually… However, those species for which thorough knowledge of habitat preferences exists are better represented than those for which little is known (i.e., rare or small populations) or vary widely both spatially and temporally. Species with highly restrictive distributions are very difficult to model accurately because their habitat cannot be predicted within the 30 m resolution of our land cover data and distribution maps. We accept the uncertainty within some ranges and distribution models because we believe these data provide basic information and serve an important purpose by highlighting where more data are needed. Despite these limitations, we believe GAP species ranges and distribution models are valuable and relevant for addressing broad landscape level conservation questions and research*."

Figure 8-9 and Figure 8-10 show the current distributions of the four individual species included in the Chihuahuan Desert amphibian assemblage, as assessed for this REA. The Arizona toad occurs along limited sections of the Rio Grande floodplain but otherwise occurs within the U.S. portion of the ecoregion only at higher elevations in the Gila River Basin and the northwestern margins of the Rio Grande Basin. The Chiricahua leopard frog occurs more commonly along the Rio Grande floodplain, compared to the Arizona toad, significantly less commonly at the higher elevations along the northwestern margins of the Rio Grande Basin, and both along the mainstem Gila River and across higher-elevation tributary watersheds in the Gila River Basin. The northern leopard occurs along the Rio Grande floodplain, less commonly than the Chiricahua leopard frog but more commonly than the Arizona toad. It occurs less commonly than either the Chiricahua leopard frog or Arizona toad at the higher elevations along the northwestern margins of the Rio Grande Basin, and nowhere in the Gila River Basin. It also occurs in scattered locations in and along the eastern side of the Tularosa Basin and to its south in New Mexico and far western Texas, including the southern end of the Guadalupe Mountains. The distribution of the Yavapai leopard frog differs significantly from that of the other three species. It occurs only in the Gila River Basin and western-most, lower-elevation watersheds of the Mimbres River Basin, in a band straddling the Arizona-New Mexico.

Figure 8-11 shows the combined distribution of the four individual species that make up the Chihuahuan Desert amphibian assemblage, as assessed for this REA. The combined distribution within the analysis extent includes the Rio Grande floodplain, roughly northward from the vicinity of El Paso, Texas, to the ecoregional boundary; the watersheds that make up the northwestern margins of the Rio Grande Basin in New Mexico; the Gila River mainstem and its tributary watersheds; western-most, lower-elevation watersheds of the Mimbres River Basin; and scattered locations in and along the eastern side of the Tularosa Basin and areas to its south in New Mexico and far western Texas, including the southern end of the Guadalupe Mountains.

The combined distribution of the four individual species includes habitat along the Rio Grande floodplain. Indeed, within the U.S. portion of the ecoregion, the Chiricahua leopard frog and northern leopard frog strongly prefer habitat along this floodplain corridor. As a result, the assemblage in general and these two species in particular are vulnerable to development along this corridor. As discussed in Chapter 5, above, this corridor has experienced considerable agricultural, residential, commercial, and industrial development. The extent of this development also is forecasted to increase, although this expansion will largely involve the conversion of agricultural lands to residential, commercial, and industrial uses. Water quality impairments and channel modifications are also widespread along this corridor, as discussed above, this chapter. On the other hand, the four species in the assemblage – particularly the Arizona toad and Yavapai leopard frog – also occupy habitat away from the Rio Grande, where they may be vulnerable to more diffuse forms of land use. Protected areas along the Rio Grande floodplain also provide safe harbors for the Chiricahua leopard frog and northern leopard frog (USFWS 2012).

Figure 8-9. Current distributions, (top) Arizona toad and (bottom) northern leopard frog.

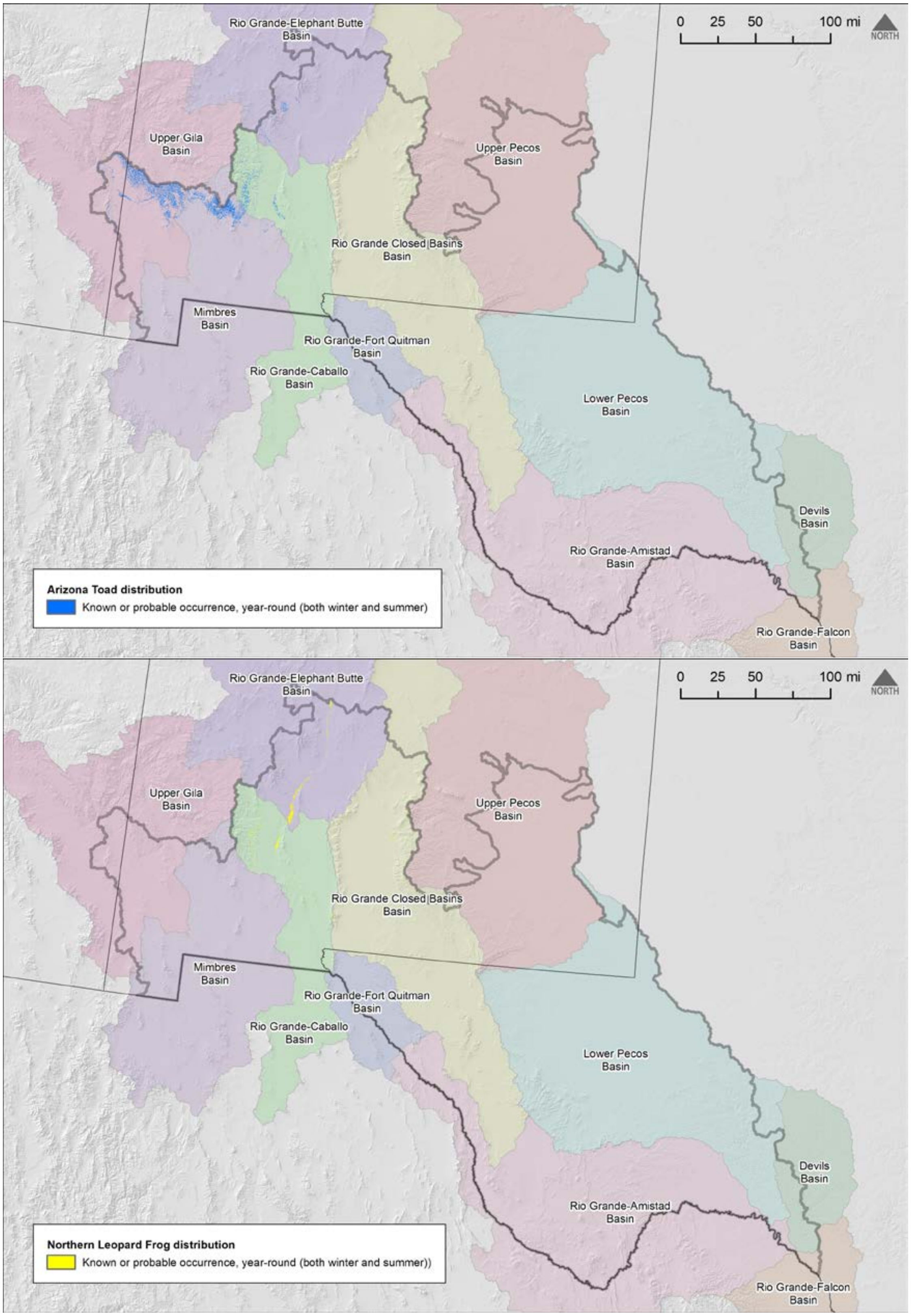


Figure 8-10. Current distributions, (top) Chiricahua leopard frog and (bottom) Yavapai leopard frog.

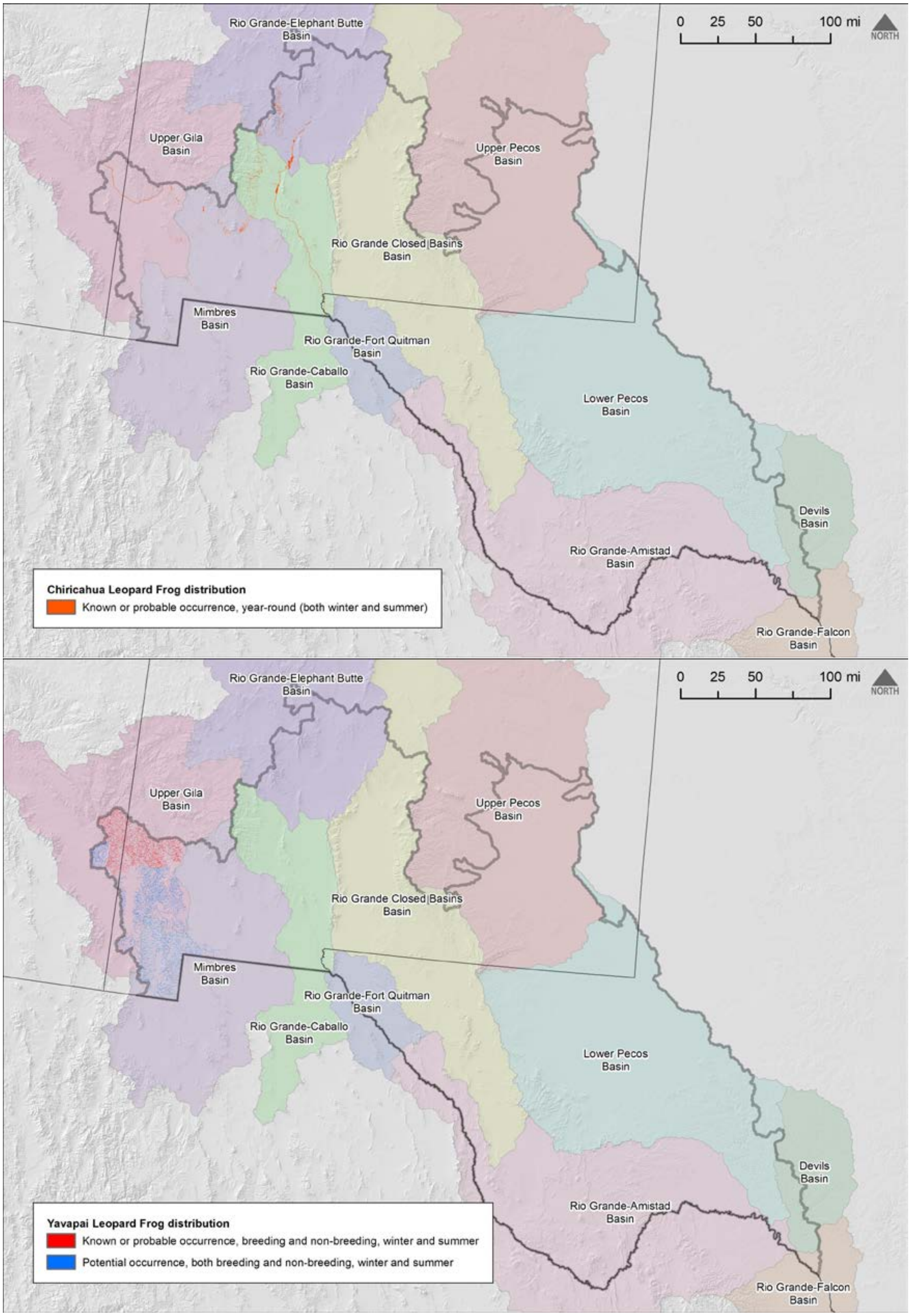
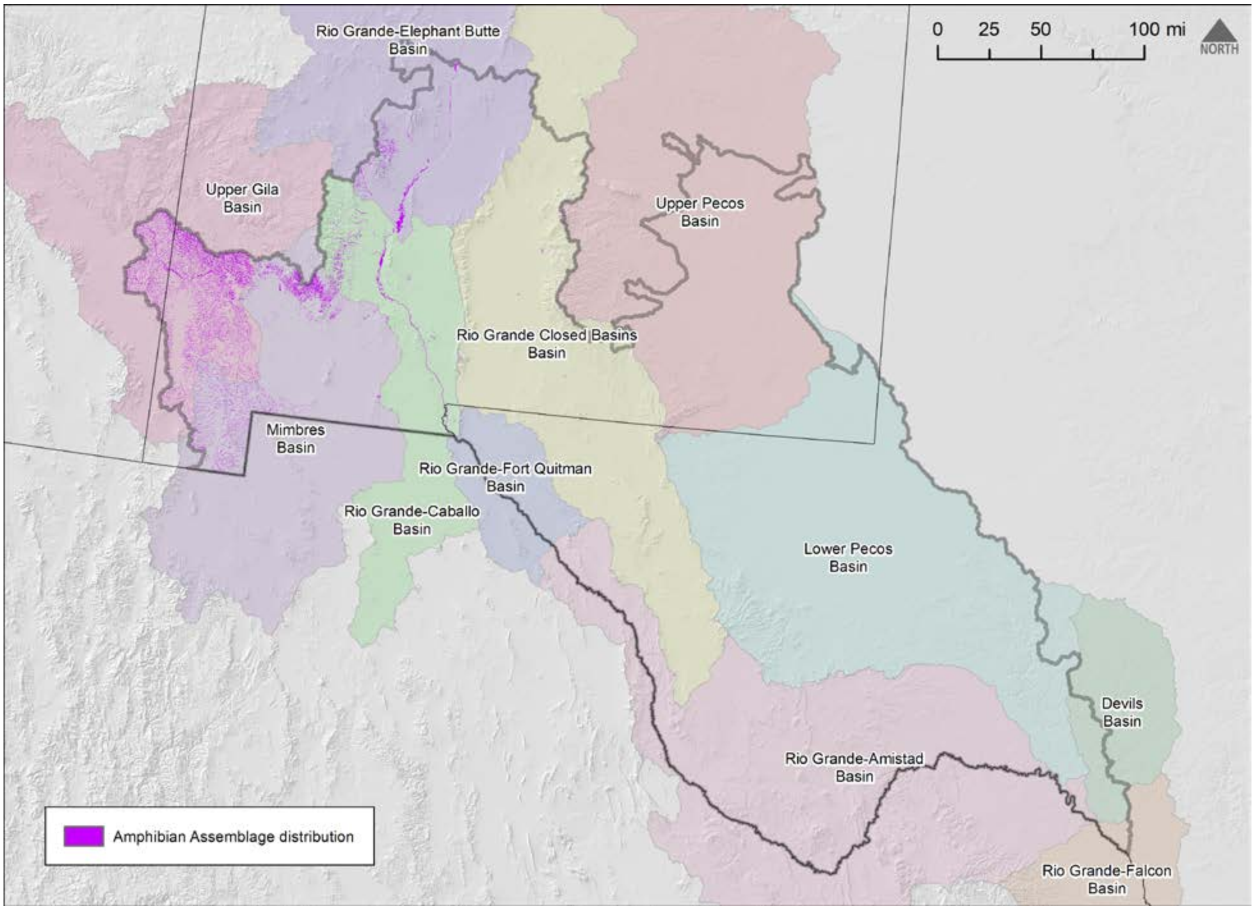


Figure 8-11. Current overall distribution, Chihuahuan Desert amphibian assemblage.



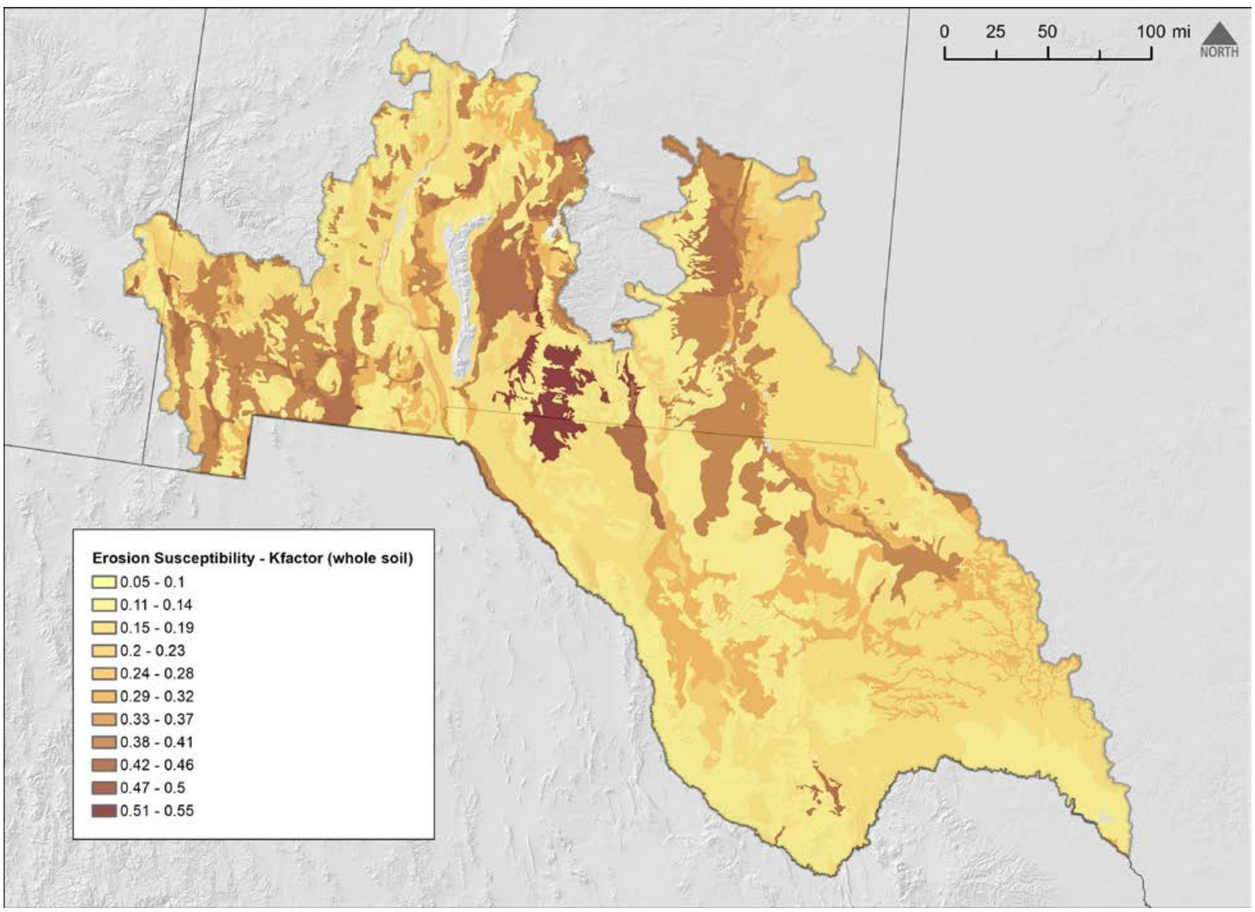
8.4 *Potential Impacts of Wildfire on Sedimentation to Aquatic-Wetland Systems*

MQ 3 asks where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems. As discussed in detail in the Pre-Assessment Report (Unnasch et al. 2017), in the conceptual models for the terrestrial and aquatic-wetland ecological system CEs, uncharacteristic wildfire patterns can alter the rate of soil erosion off watersheds by removing vegetation cover, increasing the vulnerability of upland soils to erosion. Uncharacteristic wildfire at the watershed scale also can alter watershed hydrology, alter the amounts of organic matter and soluble nutrients carried off by runoff, and alter the frequency and intensity of wildfire directly along riparian corridors. However, MQ 3 does not concern these other potential effects.

The entire U.S. portion of the ecoregion is susceptible to wildfire, as discussed in Chapters 2, 3, 6 and 7, above, and in the conceptual ecological models for the three terrestrial ecological system CEs in the Pre-Assessment Report (Unnasch et al. 2017). As a result, the assessment of MQ 3 focuses on identifying watersheds that (a) contain any of the five aquatic-wetland ecological system CEs and (b) have soils with high risks of watershed erosion. Landscape erosion in these watersheds would pose greater threats to the aquatic-wetland CEs than would landscape erosion in other watersheds. Soils with high risks of watershed erosion consist of soils with high inherent erodibility located on steep slopes.

The U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey (USDA NRCS 2017b), maintains data on the susceptibility of soil particles to detachment and movement by sheet and rill runoff (USDA NRCS 2017b). These data include a variable designated as "Erosion factor K." This variable "… is one of six factors used in the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) to predict the average annual rate of soil loss by sheet and rill erosion in tons per acre per year. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and saturated hydraulic conductivity (Ksat), and also take into account the slope of the ground surface. Values of K range from 0.02 to 0.69. Other factors being equal, the higher the value, the more susceptible the soil is to sheet and rill erosion by water." Erosion factor K has several variants, including Erosion factor "Kw" the value of the factor for the entire soil profile, including rock fragments. Figure 8-12 shows the spatial distribution of Kw values across the analysis extent (USDA NRCS 2015).

Figure 8-12. Soil erosion susceptibility based on whole-soil K factor (Kw).



Chapter 6, above, introduced and described the "Wildfire Hazard Potential" indicator (WHP), as calculated in 2014 by the U.S. Department of Agriculture, Forest Service, Fire Modeling Institute (Dillon

2015, Dillon et al. 2015, USDA FS 2015). As quoted in Chapter 6, the WHP data depict “the relative potential for wildfire that would be difficult for suppression resources to contain. To create the 2014 version we built upon spatial estimates of wildfire likelihood and intensity generated in 2014 with the Large Fire Simulator (FSim) for the Fire Program Analysis system (FPA), as well as spatial fuels and vegetation data from LANDFIRE 2010 and point locations of fire occurrence from FPA (ca. 1992 - 2012)… Areas mapped with higher WHP values represent fuels with a higher probability of experiencing torching, crowning, and other forms of extreme fire behavior under conducive weather conditions, based primarily on 2010 landscape conditions” (USDA FS 2015). Chapter 6, Figure 6-17 shows the distribution of WHP values for 2014 across the analysis extent. Combined with the Kw soil data, the WHP values together (Figure 8-13) provide a means for addressing MQ3, i.e., for identifying where uncharacteristic wildfire potentially could result in increased sedimentation and loss of habitat among the aquatic-wetland ecological systems.

Figure 8-13. Watersheds potentially sensitive to sedimentation of aquatic/wetland habitat.

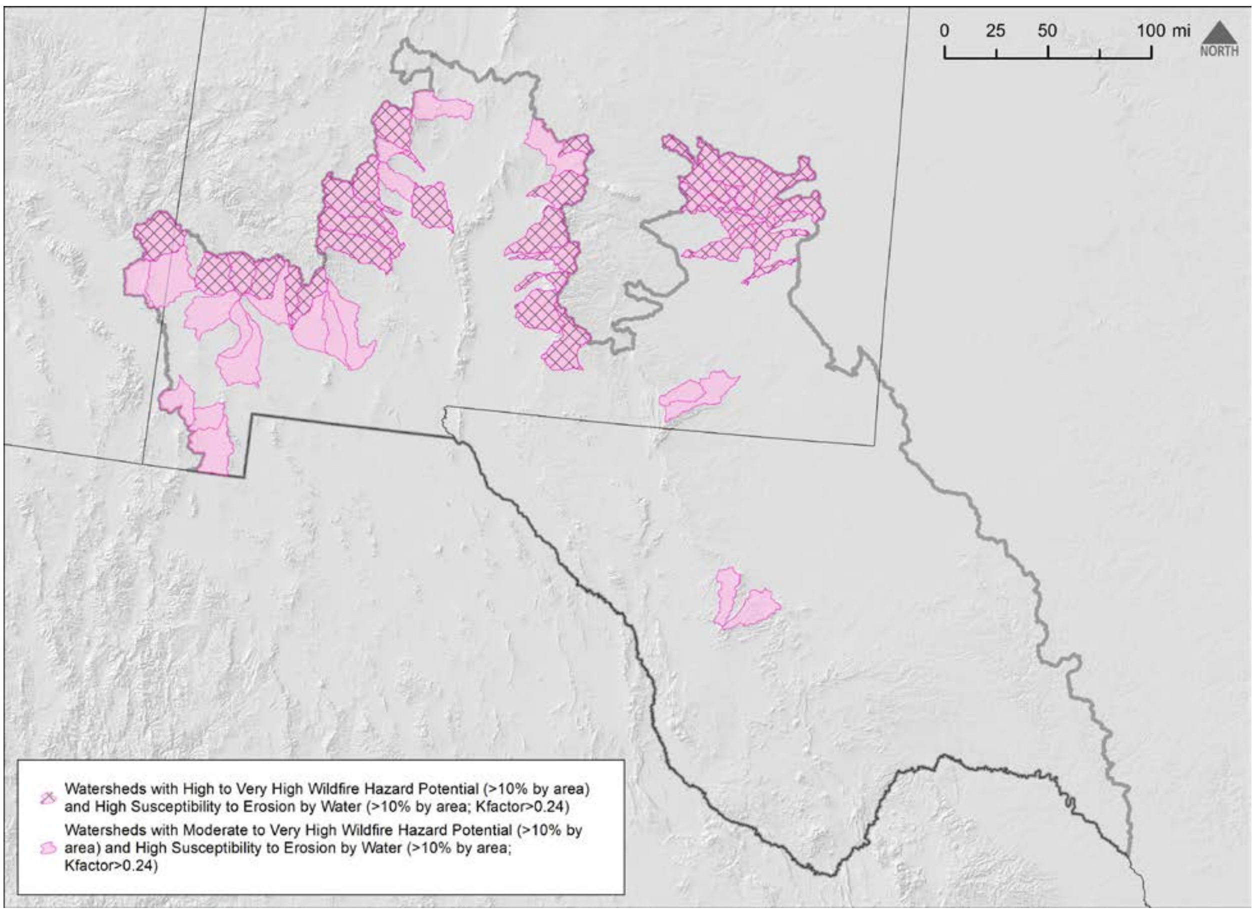


Figure 8-13 identifies 5th-Level watersheds that meet two criteria: (1) Kw > 0.24 (roughly the median Kw value for the analysis extent) over > 10% of the watershed area, and (2) WHP is rated as Moderate, High, or Very High over > 10% of the watershed area. Figure 8-13 also identifies those watersheds for which WHP is rated only High or Very High over > 10% of the watershed area, indicating a potential higher hazard potential. Based on the definitions of Kw and WHP, these watersheds are proposed as catchments across which the elimination of ground cover by severe wildfires could result in significant soil erosion during subsequent runoff events, resulting in sedimentation and loss of habitat among aquatic-wetland ecological system occurrences into which the runoff flows.

Figure 8-1, above, indicates that several occurrences of the Montane- and Lowland-Headwater Perennial Stream and Playa-Playa Lake CEs lie within the watersheds identified in Figure 8-13, including: Blue Creek, flowing into the Gila River from the north; catchments affecting the Lordsburg and Playas Lake playa complexes in far western New Mexico; the upper Mimbres River; Alamosa, Cuchillo Negro, Palomas, Seco, and Percha Creeks, flowing into the Rio Grande from west, from the Black Range; the headwaters of Three Rivers, Tularosa Creek, and Lost River, flowing westward out of the Sacramento Mountains in the Tularosa Basin toward the basin's large playa-playa lake complex; Arroyo del Macho, Salt Creek, and Rio Hondo, flowing eastward out of the Sacramento Mountains into the Pecos River; and Limpia Creek, flowing westward out of the Davis Mountains.

8.5 Aquifers and Recharge Zones Supporting Aquatic-Wetland Systems

MQ 9 asks what and where are the aquifers and their recharge zones that support the wet systems. Knowledge of the aquifers and their recharge zones that support aquatic-wetland resources in an ecoregion almost always comes from hydrogeological studies focused on individual aquatic-wetland resources of interest. Such studies typically involve groundwater flow modeling and geochemical investigations at a geographic scale appropriate to the particular river, stream, wetland, or spring(s) of interest. Examples of such studies within the U.S. portion of the Chihuahuan Desert ecoregion include studies of groundwater dynamics in the Animas and Lordsburg Basins and their associated playas (Johnson and Rappuhn 2002), groundwater dynamics affecting the Salt Basin straddling the New Mexico-Texas border immediately west of the Guadalupe Mountains (Huff and Chace 2006, Szynkiewicz et al. 2012, Sigstedt et al. 2016), the origins of the San Solomon Spring system in the Toyah Creek watershed in Texas (Chowdhury et al. 2004), the geochemistry of Bitter Lake National Wildlife Refuge (Land and Huff 2010, Partey et al. 2011), the geochemistry of the Rio Grande (Szynkiewicz et al. 2015a, 2015b), and the groundwater systems feeding springs in west Texas (Sharp et al. 2003). Such studies often show that individual flow paths may depend on the presence and orientation of bedrock fault and fracture systems, which may act as either barriers or conduits to groundwater movement. The resulting patchwork of local studies does not lend itself to the kind of geospatial analysis appropriate for an REA. At most, such studies identify the aquifers and groundwater flow paths that support only a handful of the river or stream reaches or springs and emergent wetlands in the ecoregion.

However, it is possible to approach MQ 9 from a different angle appropriate for an REA. Groundwater recharge occurs in a generally well understood geographic pattern in the ecoregion. Mapping this pattern can provide guidance on where recharge may be vulnerable to the effects of change agents. Figure 8-14 and Figure 8-15 present the relevant information for addressing MQ 9 from this alternative approach.

Groundwater recharge in the Southwest takes place in two general settings: across mountain ranges and their foothills, and along river and stream corridors (Flint et al. 2004, Scanlon et al. 2005, Serrat-Capdevila et al. 2007, Stonestrom et al., ed. 2007, Wolaver et al. 2008, Magruder et al. 2009, USBR 2011b, Szynkiewicz et al. 2012, 2015a, 2015b, Sheng 2013, Friggens and Woodlief 2014, Meixner et al. 2016). Recharge takes place across mountain ranges and their foothills in the region because these are zones of greater precipitation and lower rates of evapotranspiration, often with coarser soils that allow for greater rates of infiltration. Recharge rates in these settings vary with the amount of precipitation received, whether the precipitation occurs as rain or snow (melting snow recharges more effectively than does rainfall), and air temperature through its effect on evapotranspiration. Recharge also takes place at lower elevations, focused along stream and river courses and across their floodplains, and along permeable irrigation ditches, whenever the water table lies lower than the elevation of the surface water along these flow paths, i.e., during runoff and flood events and during irrigation delivery and return flows. Recharge rates in these latter settings vary with the amount of water present (e.g., from runoff) and air temperature through its effect on evapotranspiration (see also Scott et al. 2004, 2008, Price et al. 2005, Stromberg et al. 2006, Webb and Leake 2006, Hatler and Hart 2009, Kennedy and Gungle 2010, Hogan 2013). Figure 8-14 presents an estimate of the distribution of these two settings.

Figure 8-14 specifically estimates the distributions of the two general settings for recharge in the U.S. portion of the ecoregion based on the types of vegetation associated with these geophysical settings. Areas of mountain recharge are mapped based on the distribution of conditions suitable for montane conifer and hardwood woodlands, which also require the greater magnitudes of precipitation and cooler temperatures that occur in these orographic settings. Areas where focused, lower-elevation recharge may occur are mapped based on the distribution of conditions suitable for riparian vegetation. Both zones are mapped based on the distribution of conditions *suitable* for these broad types of vegetation, in order to represent the zones as they would exist in the absence of impacts from development. The data sources for these distributions are the LANDFIRE "Biophysical Setting" (BpS) models for conifer and hardwood woodlands and for riparian vegetation in the ecoregion (LANDFIRE 2016). BpS models estimate the likely historic spatial distributions of ecosystems prior to Euro-American settlement, based on their geophysical requirements.

The distribution of estimated recharge areas in Figure 8-14 captures all of the mountain recharge zones identified in individual hydrogeological studies in the region. These include the Sacramento Mountains, recharge across which is estimated to support groundwater flows to the Tularosa Basin, the Salt Basin immediately west of the Guadalupe Mountains (Huff and Chace 2006, Szynkiewicz et al. 2012, Sigstedt et al. 2016), and Bitter Lake National Wildlife Refuge (Land and Huff 2010, Partey et al. 2011). The recharge areas estimated in Figure 8-14 also include the Guadalupe and Davis Mountains, recharge from which is estimated to support groundwater flows to numerous springs in west Texas (Sharp et al. 2003), including the San Solomon Spring complex in the Toyah Creek watershed (Chowdhury et al. 2004); and the mountains in the extreme west of the U.S. portion of the ecoregion in both New Mexico and Arizona, recharge from which supports the groundwater systems of the Animas and Lordsburg Basins and their associated playas (Johnson and Rappuhn 2002).

Figure 8-14. Groundwater recharge zones based on surrogate distributions of vegetation.

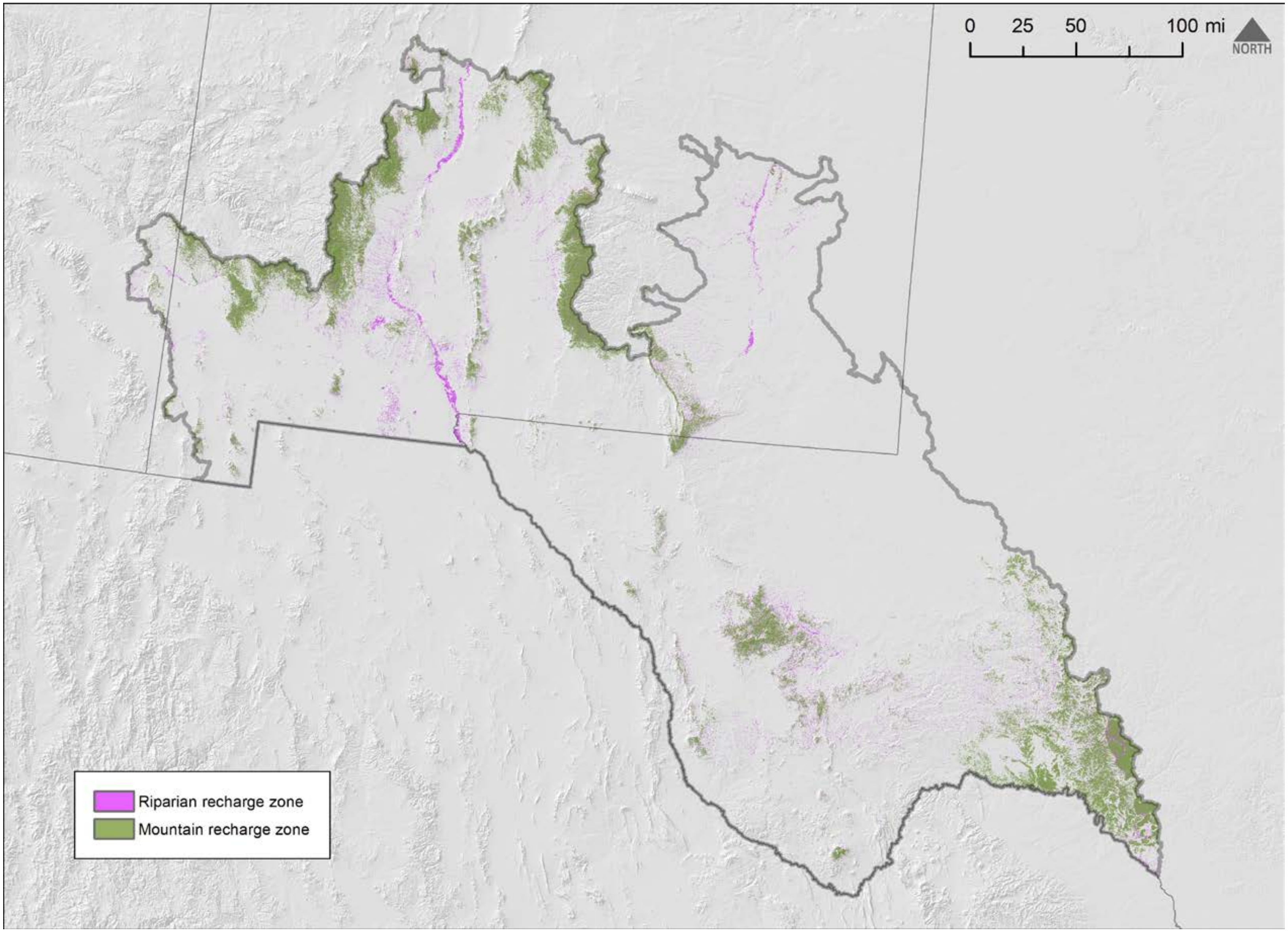


Figure 8-15. Major aquifer systems.

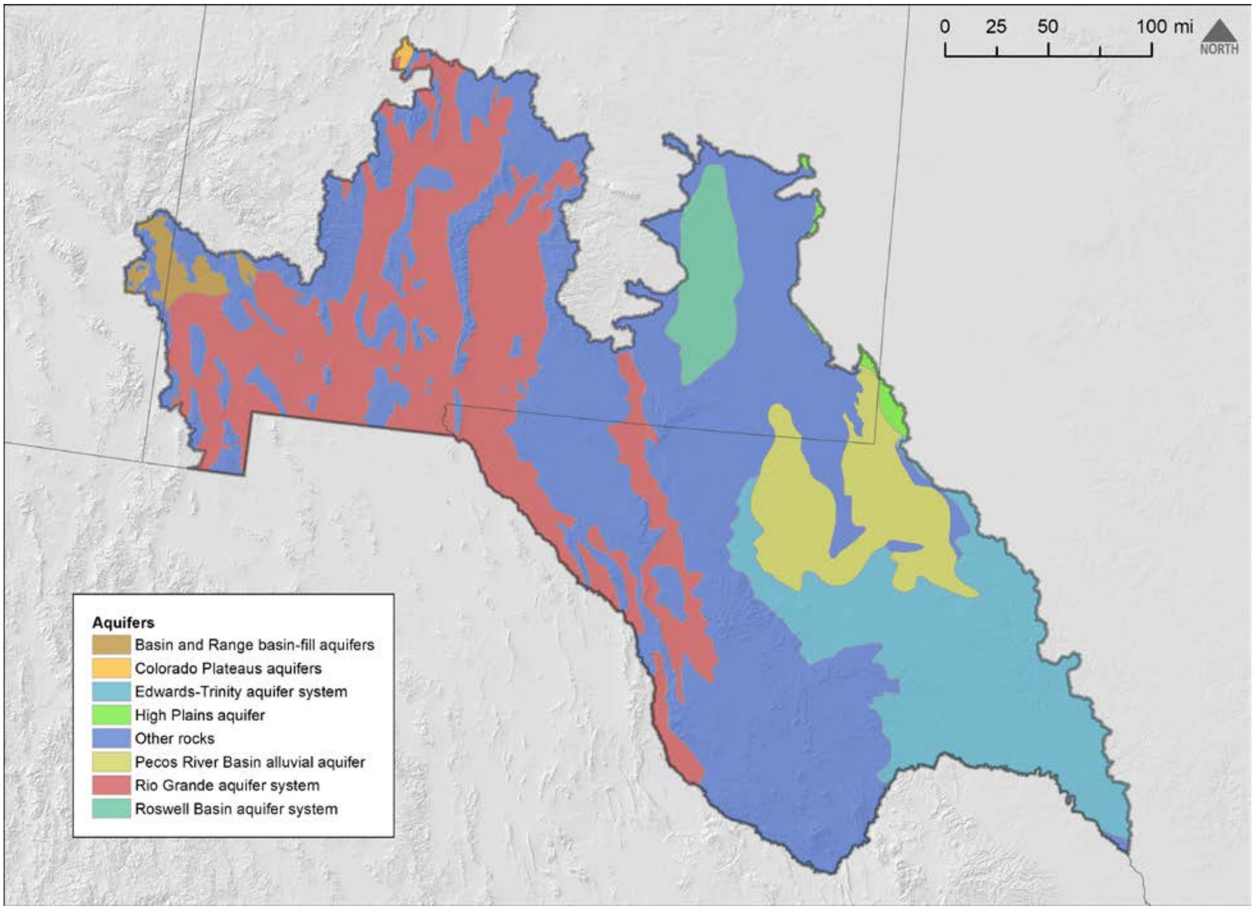


Figure 8-14 also identifies several river valley sections as areas of focused recharge, prominently including the Rio Grande along the Mesilla Valley. Several studies in fact have examined recharge along this river reach from both river and irrigation water. These studies note that the reach also receives some groundwater from surrounding bedrock aquifers recharged in the adjacent mountain ranges (Hogan 2013; see also Szynkiewicz et al. 2015a, 2015b).

Figure 8-15 in turn shows the major shallow aquifer systems recognized within the analysis extent for the REA, as documented in the Ground Water Atlas of the United States (USGS 1995). Figure 8-15 is included here primarily to show that the aquifer systems within the U.S. portion of the ecoregion do not align well with the distribution of recharge areas estimated in Figure 8-14. The estimated distribution of recharge aligns with orography and surface hydrology, while the distribution of aquifers depends on subsurface bedrock and basin-fill geology.

8.6 Aquatic-Wetland Systems Invasive Plant Management

MQ 12 asks whether there are areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession.

Figure 8-16 shows the history of the spread of tamarisk beetles (*Diorhabda* spp.) across the region, based on data assembled by the Tamarisk Coalition (2016; http://www.tamariskcoalition.org/).

Figure 8-16. Cumulative distribution of impacts of tamarisk beetles based on Tamarisk Coalition data.

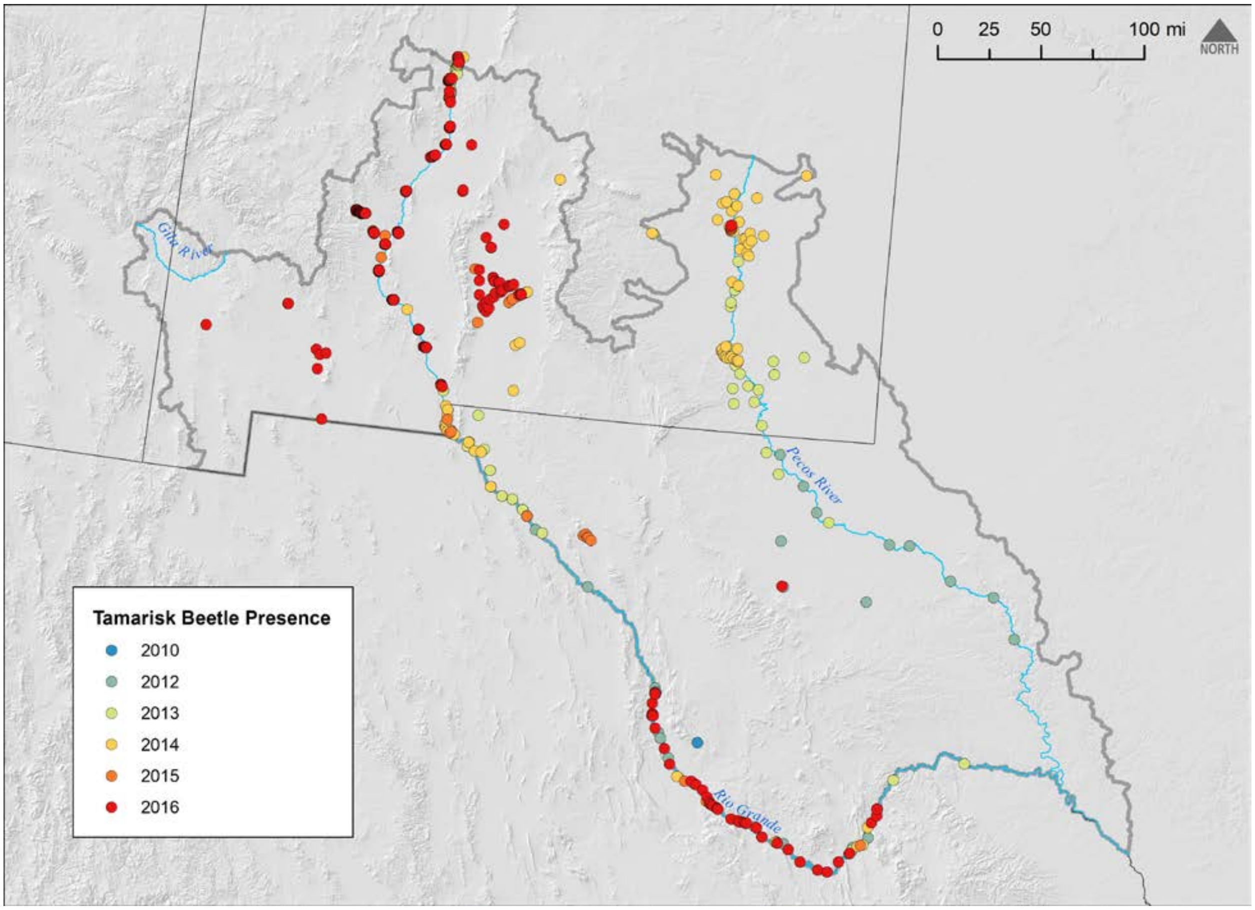
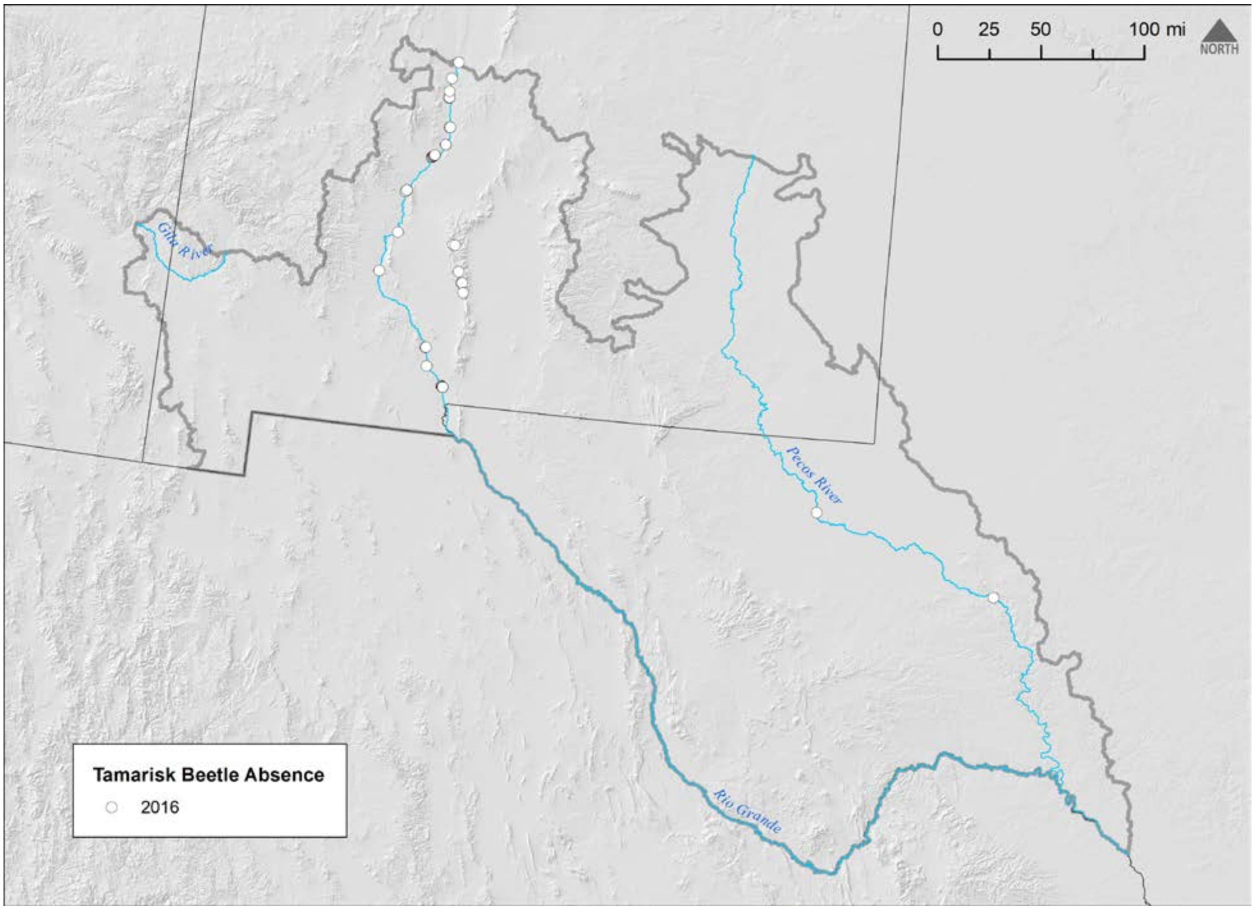


Figure 8-16 indicates that first observations of tamarisk beetles (*Diorhabda* spp.) within the U.S. portion of the ecoregion date to 2010 along the Rio Grande in the Big Bend region. The beetle population expanded along the Rio Grande and Pecos River and some of their tributaries as well as into the Tularosa Basin in 2012-2014; and then expanded again in 2016 in the Tularosa Basin, along the Rio Grande, and westward toward the Arizona border.

Figure 8-17, in turn, shows locations where beetles previously had occurred but were no longer present in 2016. These locations in the Tularosa Basin and along the Rio Grande and Pecos River potentially indicate sites where the beetles have at least temporarily exhausted the supply of salt cedar on which they feed and which they thereby defoliate. The beetles potentially could also soon exhaust the supply of salt cedar in adjacent locations where they have fed for multiple years. Managers could target such sites of completed or imminent defoliation as areas potentially warranting restoration or efforts to control succession.

Figure 8-17. Records of tamarisk beetle absence in 2016 based on Tamarisk Coalition data.



The data on beetle absence in Figure 8-17 need to be viewed with care. Ben Bloodworth (Tamarisk Coalition Program Coordinator, personal communication, June 27, 2017) provided the following commentary on these data: “Obviously this changes from year to year and does not really make much sense on its own, without the corresponding year's presence data. It is useful for us in helping folks prepare for the beetles' arrival, but again, only in that year in which it is current. I already know from monitoring reports this year [2017] that several areas we consider ‘key’ in southward expansion in AZ that have been absence points in all years prior, will be presence points this year… [E]ven if nobody finds beetles while looking at previously occupied sites, it is highly likely that there are still a few in the area (thus maintaining presence even if not in observable numbers).”

8.7 Distribution and Impacts of Gypsum in Soil and Water

Figure 8-18 compares the current distributions of the five aquatic-wetland ecological system CEs (Figure 8-1., see above) with the distribution of watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations (see Chapter 7, above).

Figure 8-18. Current distribution of aquatic-wetland ecological system Conservation Elements relative to watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations.

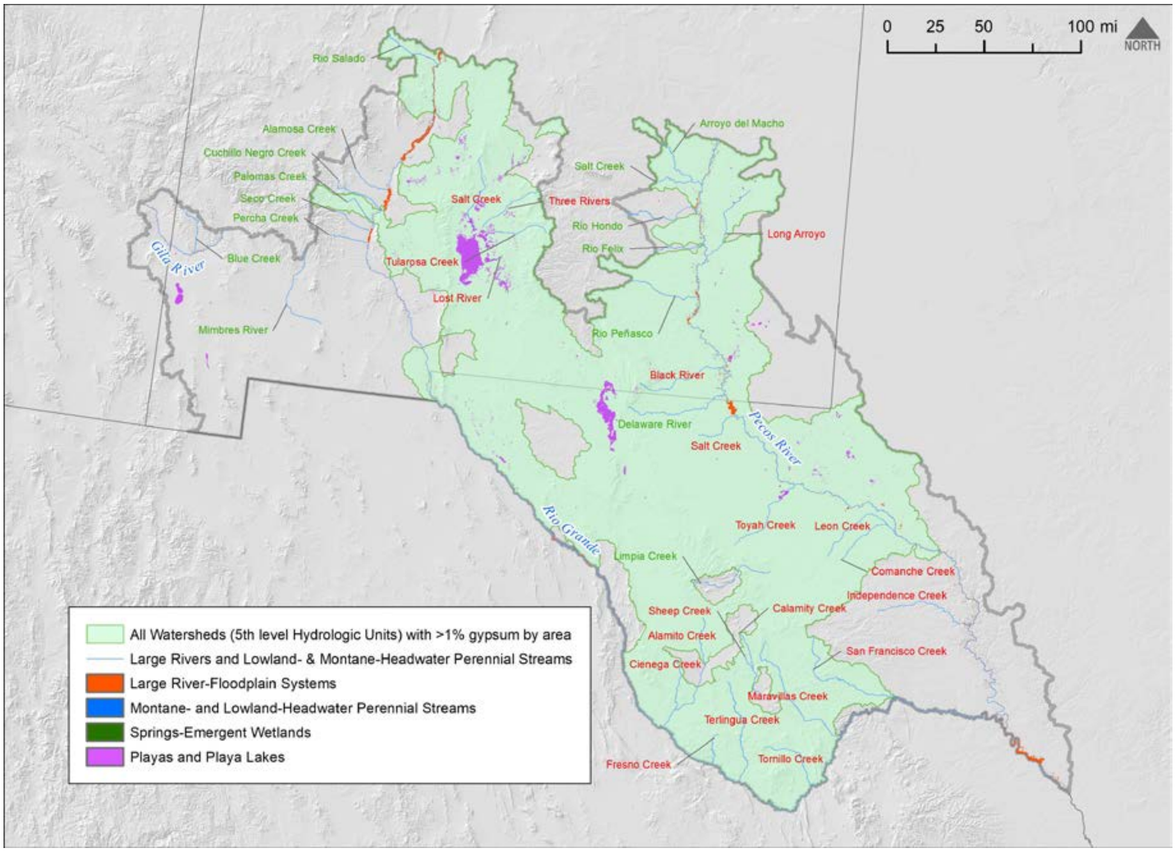


Figure 8-18 indicates that gypsic soils and bedrock likely affect water chemistry throughout the Pecos River and Tularosa basins, as numerous studies have documented (e.g., Yuan and Miyamoto 2005; see Pre-Assessment report, Unnasch et al. 2017, Chapters 9 and 11); and also likely affect water chemistry strongly along the Rio Grande in Texas and to a somewhat lesser extent in New Mexico, as is also widely documented (see Pre-Assessment report, Unnasch et al. 2017, Chapter 9). The native fishes in these three basins include many species adapted to the unique water chemistries created by this highly reactive geology (see the Pre-Assessment Report, Unnasch et al. 2017, Chapters 9 and 11). As also noted in numerous studies, water management practices have increased the salinity of the Pecos River and Rio Grande, including the concentration of sulfates. The possible impacts of this increase on native fishes and other aquatic-wetland biota are matters of ongoing concern (see the Pre-Assessment Report, Unnasch et al. 2017, Chapters 9 and 11).

Figure 8-18 is also consistent with the general lack of documented effects of gypsic soils and bedrock in the Mimbres and Gila River basins. Further, it is perhaps noteworthy that the Chihuahuan Desert amphibian assemblage discussed above (this Chapter), occurs almost exclusively in those portions of the present ecoregion in the U.S. where gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations do not occur.

9 Individual Species Conservation Elements

9.1 Introduction

This chapter presents the assessments focused on the four individual species Conservation Elements (CEs), the Pronghorn, Mule Deer, Banner-tailed Kangaroo Rat, and Black-tailed Prairie Dog. Eight Management Questions (MQs) concern or include one or more of these four CEs, as follows:

MQ A: What is the geographic distribution of each CE?
MQ B: What is the current condition of each CE across its geographic distribution?
MQ C: What is the current geographic distribution of the impacts of each Change Agent (CA) in relation to each CE?
MQ D: What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?
MQ 4: What areas of potential black-tailed prairie dog habitat would support restoration?
MQ 5: Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?
MQ 11: Where are the breeding, winter, and year-around habitats for pronghorn and mule deer?
MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Chapter 4, above, addresses the forecasted impacts of climate change on individual species Conservation Elements, part of the subject of MQ D. Chapters 5 and 6, above, address the current impacts of the other CAs, the subject of MQ C. Chapter 10, below, presents the assessment of MQ 5, which takes into account not only the four individual species but also the individual species that make up the two grassland species assemblages and the species that make up the Chihuahuan Desert amphibian assemblage addressed in Chapter 8. Section 9.4 in the present chapter addresses MQ 4, concerning areas of potential black-tailed prairie dog habitat that might support restoration. Section 9.5 in the present chapter addresses MQ 11, concerning the breeding, winter, and year-around habitats for pronghorn and mule deer. Finally, Section 9.6 addresses MQ 13, concerning the distribution of the impacts of gypsic soil and water on ecological conditions. Chapter 7, above, presents the full assessment of the current geographic distribution of potential impacts of gypsum in the soil and water in general, as well as in relation to the three dryland ecological system CEs and their associated Change Agents. The present chapter does not repeat that background information and focuses only on the geographic distribution of the impacts of gypsum in the soil and water on the four individual species CEs.

9.2 Conservation Element Distributions

The data used to map the current distributions of the four individual species Conservation Elements (Figure 9-1 and Figure 9-2) mostly consist of National Gap Analysis Program (National GAP) species distribution data (USGS-GAP 2005, http://swregap.nmsu.edu/habitatreview/ModelQuery.asp; USGS-GAP 2011, https://gapanalysis.usgs.gov/species/data), Gergely and McKerrow 2013) with a 30 m resolution. Exceptions arose for the pronghorn, mule deer, and banner-tailed kangaroo rat.

The National GAP species website (https://gapanalysis.usgs.gov/species/data/) defines a species distribution as *"… the spatial arrangement of environments suitable for occupation by a species. In other words, a species distribution is created using a deductive model to predict areas suitable for occupation within a species range…. It should be noted that all our range and distribution models are predictions about the occurrence of a species within the U.S. GAP ranges and distribution models are intended for use at the landscape scale (i.e., areas the size of square kilometers). They are not intended to be precise predictions of species occurrence/absence at local scales (areas the size of square meters). It is important for GAP data users to evaluate the suitability of the data for their intended purpose… GAP aims to use the best available information to create species ranges and distribution models. GAP relies on existing data and expert opinions from partners and collaborators (e.g., State Natural Heritage Programs)… All of GAP's ranges and distribution models have been reviewed by experts and compared to other data sources for accuracy. The accuracy of the species ranges and distribution models varies from species to species in part because habitat preferences and behaviors vary seasonally and annually… However, those species for which thorough knowledge of habitat preferences exists are better represented than those for which little is known (i.e., rare or small populations) or vary widely both spatially and temporally. Species with highly restrictive distributions are very difficult to model accurately because their habitat cannot be predicted within the 30 m resolution of our land cover data and distribution maps. We accept the uncertainty within some ranges and distribution models because we believe these data provide basic information and serve an important purpose by highlighting where more data are needed. Despite these limitations, we believe GAP species ranges and distribution models are valuable and relevant for addressing broad landscape level conservation questions and research*."

The National GAP species distribution data for pronghorn cover only Arizona and New Mexico. As an alternative, the present assessment used polygon data on the pronghorn range in Texas from the International Union for Conservation of Nature (IUCN 2008; http://www.iucnredlist.org/technical-documents/spatial-data). The IUCN range polygons were converted to 30-m raster data for analysis. Figure 9-1(top) shows the resulting map of the current distribution of the pronghorn across the U.S. portion of the ecoregion. The pronghorn distribution in Arizona and New Mexico roughly resembles the distribution of the Chihuahuan Desert Grasslands CE, discussed in Chapter 7, above, but also includes areas with Pinyon-Juniper Woodlands cover. The pronghorn current distribution along the northeastern edge of the analysis extent includes other ecological systems – Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe – that are not components of the Chihuahuan Desert Grasslands CE but nevertheless also are grasslands (see Chapter 2, above, and the Pre-Assessment report, Unnasch et al. 2017, Chapter 2). The IUCN polygon for the pronghorn range in the Texas portion of the analysis extent is difficult to interpret, because it has no internal detail. However, the polygon does encompass all of the higher elevations in this portion of the ecoregion, where the Chihuahuan Desert Grasslands and Pinyon-Juniper Woodlands CEs are more common than elsewhere in the Texas portion of the analysis extent.

Figure 9-1. Current distributions, (top) pronghorn and (bottom) mule deer

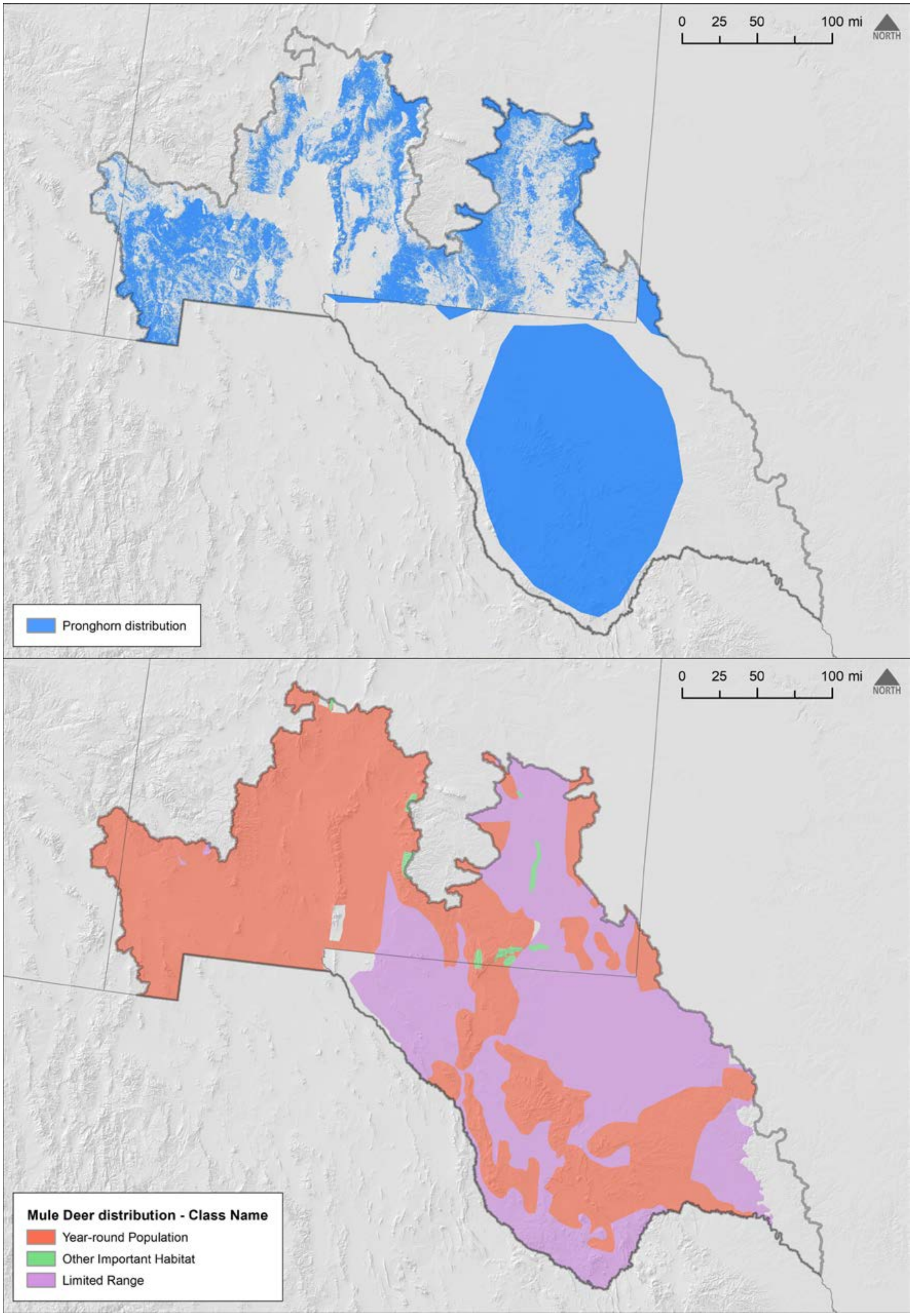
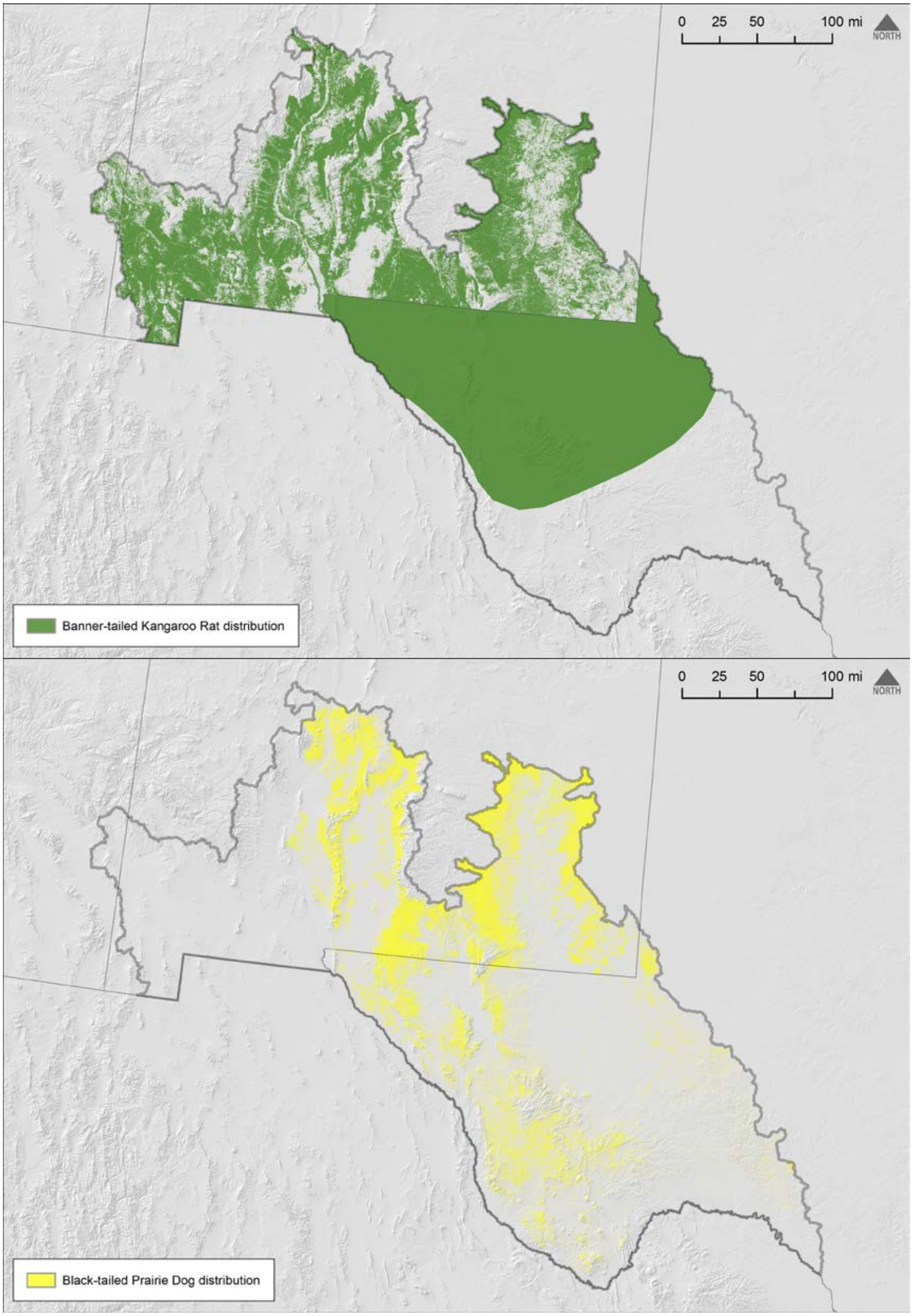


Figure 9-2. Current distributions, (top) banner-tailed kangaroo rat and (bottom) black-tailed prairie dog.



The National GAP species program does not provide either distribution or range data for mule deer in Arizona, New Mexico, or Texas. The distribution of mule deer therefore was mapped based on a range dataset compiled by the Western Association of Fish and Wildlife Agencies (WAFWA Mule Deer Working Group 2005; http://www.gis.usu.edu/projects/mule-deer-mapping-project/). Figure 9-1(bottom) shows the resulting map of the current range of the mule deer across the U.S. portion of the ecoregion, which includes separate polygons for "year-round distribution," "other important habitat," and "limited range." The WAFWA polygons for the mule deer distribution are difficult to interpret, because they provide little internal detail. However, the "year-round distribution" polygons do encompass all areas included in the Pinyon-Juniper Woodlands CE within the analysis extent, as well as most areas of Chihuahuan Desert Grasslands along with a few areas of Chihuahuan Desert Scrub. In contrast, the "limited range" polygons mostly cover areas of Chihuahuan Desert Scrub. The WAFWA polygons along the northeastern margin of the analysis extent also include other grassland ecological systems – Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe – that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands (see Chapter 2, above, and the Pre-Assessment report, Unnasch et al. 2017, Chapter 2). The WAFWA data also identify riparian areas as mule deer habitat, most substantially along the Pecos River between Roswell and Carlsbad, New Mexico, which the WAFWA data designate as "other important habitat."

The National GAP species distribution data for the banner-tailed kangaroo rat within the analysis extent cover only Arizona and New Mexico. As an alternative, the present assessment used polygon data on the banner-tailed kangaroo rat range in Texas available from the International Union for Conservation of Nature (IUCN 2008). The IUCN range polygon was converted to 30-m raster data for analysis. Figure 9-2(top) shows the resulting map of the current distribution of the banner-tailed kangaroo rat across the U.S. portion of the ecoregion. The National GAP data indicate that the species occurs across approximately the lower elevations of occurrence of the Chihuahuan Desert Grasslands CE and the higher elevations of occurrence of the Chihuahuan Desert Scrub CE in Arizona and New Mexico, including areas in which these two CEs intermix. Along the northeastern margin of the analysis extent the banner-tailed kangaroo rat distribution also includes other ecological systems – Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe – that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands (see Chapter 2, above, and the Pre-Assessment report, Unnasch et al. 2017, Chapter 2). The IUCN polygon for the banner-tailed kangaroo rat distribution in the Texas portion of the analysis extent is difficult to interpret, because it has no internal detail, but it does exclude the lowest elevations of the ecoregion.

The current distribution of the black-tailed prairie dog was mapped in Arizona, New Mexico, and Texas entirely using National GAP species distribution data with a 30-m resolution. Figure 9-2(bottom) shows the resulting map of the current distribution of the black-tailed prairie dog across the U.S. portion of the ecoregion. The National GAP data indicate that the species occurs almost exclusively in areas extensively covered by the Chihuahuan Desert Grasslands CE without intermixtures of either the Chihuahuan Desert Scrub or Pinyon-Juniper Woodlands CE. The species distribution along the northeastern margin of the analysis extent also includes other ecological systems – Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe – that are not components of the Chihuahuan Desert Grasslands

CE but nevertheless are extensive grasslands (see Chapter 2, above, and the Pre-Assessment report, Unnasch et al. 2017, Chapter 2). In contrast, the National GAP distribution data within the present analysis extent do not include any lands in or west of the Rio Grande valley.

9.3 Conservation Element Current Conditions

The assessment evaluated the current condition of the four individual species CEs only qualitatively, through an examination of the spatial relationships between Change Agents and the four CEs. It was not possible to evaluate their current conditions quantitatively through analyses of any other indicators. A comparison of the Key Ecological Attributes for each of the four CE types, identified in the Pre-Assessment report of the REA (Unnasch et al. 2017), and lists of potentially available data on these attributes, did not identify any systematic geospatial data suitable for use in an REA to assess CE condition for these four species.

Chapter 4, above, addresses in detail the ways in which climate change potentially will affect the present locations of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs, and potentially affect their future distributions. As discussed above, the Chihuahuan Desert Grasslands CE provides the majority of habitat for the four individual species CEs. The information presented in Chapter 4, concerning the effects of climate change on the Chihuahuan Desert Grasslands CE, therefore also provides a general picture of potential effects on habitat for the four individual species CEs. The forecasts of a significant contraction of the distribution of the Chihuahuan Desert Grasslands CE and its replacement largely by Chihuahuan Desert Scrub by 2050 and 2070 are also forecasts of a significant contraction of the distributions of all four individual species CEs. The forecasted changes in temperatures and moisture availability discussed in Chapter 4 presumably also could affect organism health. Chapters 12-15 in the Pre-Assessment report (Unnasch et al. 2017) provide extended discussions of the ways in which climate change potentially could affect the health and distribution of each of the four individual species CEs.

Chapter 5, above, discusses the present and forecasted future distribution of development within the analysis extent. Residential, commercial, industrial, and irrigated agricultural development, mostly concentrated along the large river valleys, has not substantially eliminated habitat for any of the four individual species CEs. However, development does overlap or conflict with species habitat in several individual areas. Specifically, development along the west slope of the Sacramento Mountains, along the east side of the Tularosa Basin, overlaps with the distributions of all four individual species CEs. Development along the Pecos River valley in New Mexico, from Roswell to the New Mexico-Texas state border, overlaps with the distributions of the pronghorn and banner-tailed kangaroo rat, and with the mule deer, including “other important habitat.” And the large area of oil and gas production across southeastern New Mexico and western Texas includes portions of the distributions of all four species. The ICLUS forecasts and the projections for oil and gas production indicate that development will expand in all of these areas of overlap.

Chapter 5, above, also discusses the distribution of grazing allotments on U.S. Forest Service and BLM lands within the REA analysis extent in Arizona and New Mexico. These allotments include significant fractions of the distributions of all four individual species CEs in these two states, within the analysis extent. As noted in Chapter 5, however, the REA was not able to acquire any data on grazing intensity or impacts within the allotments or on the large expanses of private land used for livestock grazing in New Mexico and Texas. As a result, it is not possible in this REA to assess the potential direct impacts of grazing on any of the individual species CEs.

Chapter 6, above, discusses the distribution of invasive terrestrial plants across the REA analysis extent based on county-scale data. As discussed in Chapter 7, above, the data presented in Chapter 6 indicate that invasive terrestrial plants occur widely across the entire analysis extent. As a result, invasive terrestrial plants occur widely across the entire areas of distribution of all four individual species CEs. However, the records assessed in Chapter 6 do not represent the results of systematic surveys to map the distributions of these invasive species. As a result, it is not possible to assess how well they represent actual conditions that affect these four species. Chapters 12-15 in the Pre-Assessment report (Unnasch et al. 2017) provide extended discussions of the ways in which invasive species potentially affect habitat quality and diet for each of the four individual species CEs.

Chapter 6 also discusses possible changes in wildfire patterns across the analysis extent. Table 9-1 shows the distribution of LANDFIRE vegetation departure (VDEP) values (LANDFIRE 2016; see Chapter 6, above, Figure 6-14) by percentile, across the 30-m pixels identified as occurrences of the pronghorn, banner-tailed kangaroo rat, and black-tailed prairie dog, and across the WAFWA polygons for mule deer. As noted above, National GAP 30-m distribution data for the pronghorn and banner-tailed kangaroo rat cover only Arizona and New Mexico, within the analysis extent, but cover the black-tailed prairie dog across all three states. Table 9-1 does not address VDEP values across species occurrences for which only IUCN range polygon data were available.

Table 9-1. Vegetation Departure (VDEP) percentile distributions by individual species CE.

CE➔ VDEP Percentile🡻	Pronghorn	Mule deer (all distribution areas)	Banner-tailed kangaroo rat	Black-tailed prairie dog
0-10%	3.55%	8.54%	5.09%	5.22%
11-20%	3.40%	6.81%	1.16%	3.78%
21-30%	11.98%	10.36%	11.57%	5.10%
31-40%	5.62%	4.47%	3.46%	5.47%
41-50%	5.61%	3.96%	5.35%	1.67%
51-60%	24.65%	13.62%	19.21%	18.56%
61-70%	20.64%	27.21%	19.20%	39.20%
71-80%	6.23%	13.43%	9.01%	10.63%
81-90%	11.55%	5.81%	16.02%	6.19%
91-100%	6.75%	5.80%	9.93%	4.18%
Total	100.00%	100.00%	100.00%	100.00%

Table 9-1 shows that, across the areas (30-m pixels) in which the Pronghorn CE occurs, nearly 70% has a VDEP value > 50%. The comparable values for the areas (30-m pixels) in which the other three species CEs occur are 66% for the mule deer, 73% of the black-tailed kangaroo rat, and 79% for the black-tailed prairie dog. All four species CE distributions thus are moderately highly disturbed.

Finally, Chapter 6 also discusses the distribution of landscape restoration treatments across the analysis extent. The data presented in Chapter 6 do not indicate the vegetation type(s) that each restoration treatment sought to restore. Table 9-2 shows the percentage of each treatment type (by area; see BLM vegetation treatment data discussion and Figure 6-18 in Chapter 6) that took place across 30-m pixels classified as occurrences of the pronghorn, banner-tailed kangaroo rat, and black-tailed prairie dog, and across the WAFWA polygons for mule deer. The LANDFIRE Vegetation Disturbance (VDIST) data shown in Chapter 6, Figure 6-19, include both prescribed fires and wildfires, and therefore are not included in Table 9-2. As noted above, National GAP 30-m distribution data for the pronghorn and banner-tailed kangaroo rat cover only Arizona and New Mexico, within the analysis extent, but cover the black-tailed prairie dog across all three states. Table 9-2 does not address VDEP values across species occurrences for which only IUCN range polygon data were available.

Table 9-2 shows that, among all land treatments, physical (mechanical) treatments have been used more often across the areas (30-m pixels) in which the pronghorn CE occurs. In contrast, chemical treatments have been used more often across the areas (30-m pixels) in which the mule deer, banner-tailed kangaroo rat, and black-tailed prairie dog CEs occur. Chemical treatments are the second most common treatment on pronghorn habitat, while prescribed fire treatments are the second most common treatment on mule deer, banner-tailed kangaroo rat, and black-tailed prairie dog habitat.

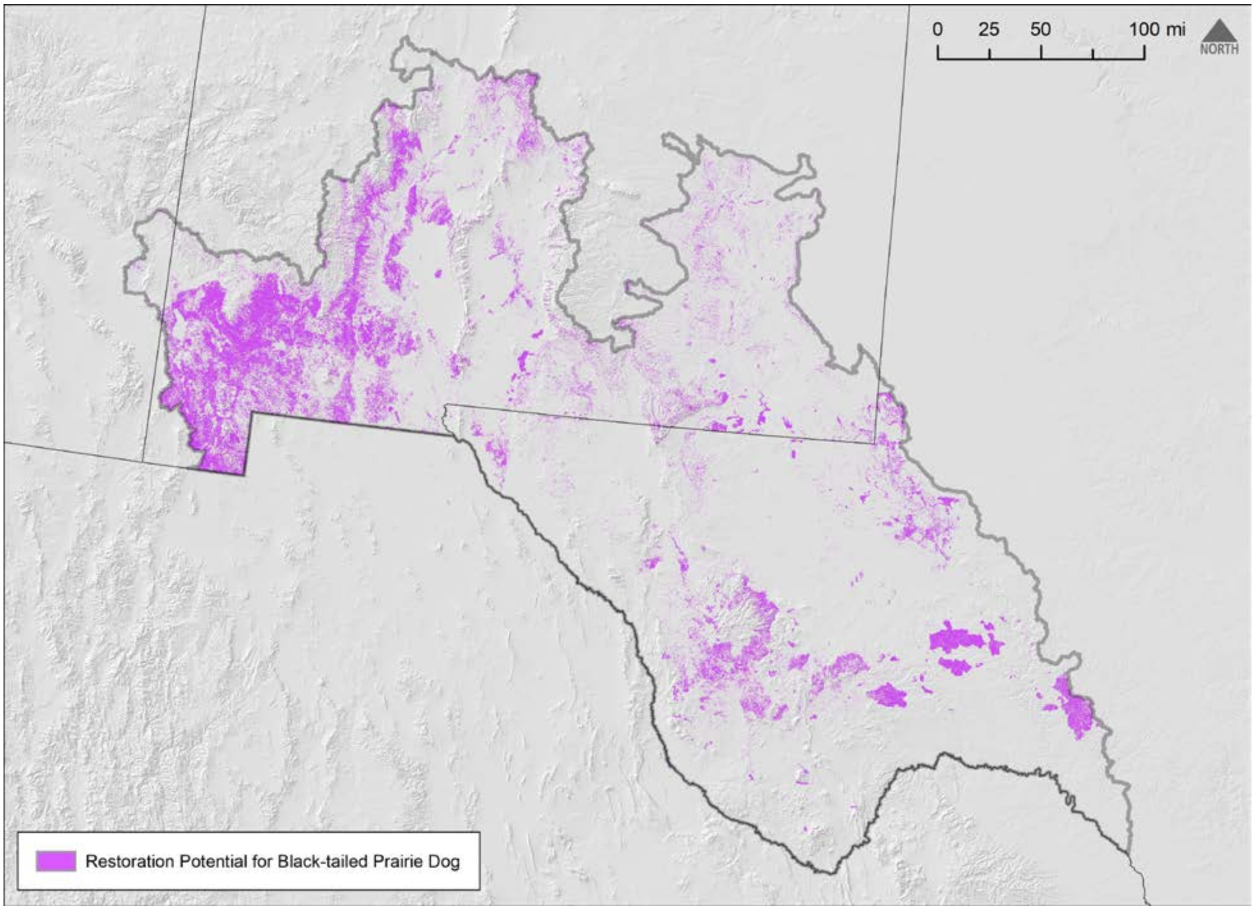
Table 9-2. Distribution of landscape restoration treatment types by individual species CE.

CE➔ Treatment type 🡇	Pronghorn	Mule deer (all distribution areas)	Banner-tailed kangaroo rat	Black-tailed prairie dog
Chemical Treatments	15.14%	86.73%	89.31%	84.02%
Prescribed Fire Treatments	0.55%	11.86%	10.11%	15.50%
Physical Treatments	84.30%	1.41%	0.58%	0.48%
Total, all treatments	100%	100%	100%	100%

9.4 Black-Tailed Prairie Dog Habitat Restoration Potential

MQ 4 asks what areas of potential black-tailed prairie dog habitat potentially could support restoration. The present assessment identifies such areas at the ecoregional scale based on four criteria, as follows: (1) The current ground cover at the location (30 m pixel) consists of grassland, including not only the Chihuahuan Desert Grassland CE but other types of grassland such as Western Plains grasslands, which the black-tailed prairie dog may inhabit as well. (2) The location falls within the species range (USGS-GAP 2011) but (3) does not fall within the current distribution of the species (USGS-GAP 2011), indicating unoccupied habitat. (4) The location is not developed. That is, the assessment defined “areas of potential black-tailed prairie dog habitat potentially could support restoration” as locations within the species range with grassland as the dominant current cover type that are not already occupied and are not developed. Figure 9-3 shows the results of an analysis applying these criteria.

Figure 9-3. Current distribution of potential black-tailed prairie dog habitat that would support restoration.



The analysis underlying Figure 9-3 identifies "grassland" based on the LANDFIRE Existing Vegetation Type (EVT; LANDFIRE 2016), which includes all types of grasslands in the region, not just the specific grassland ecological systems included in the definition of the Chihuahuan Desert Grassland CE. Figure 9-3 indicates a substantial concentration of areas with restoration potential in the far west of the analysis extent, from the western margins of the Rio Grande valley westward to the far edge of the analysis extent in New Mexico but not significantly into Arizona. An arc of substantial areas potentially suitable for restoration extends eastward from the foothills of the Davis Mountains to the eastern edge of the analysis extent in Texas. Other areas of potential interest exist east and southeast of the vicinity of Kermit, Texas, and southeast to southwest of Carlsbad, New Mexico. Resource managers presumably would apply additional criteria to narrow down the resulting pool of locations, possibly including factors such as distance from local threats, accessibility for restoration and protection, available contiguous area, and others.

9.5 Pronghorn and Mule Deer Breeding, Winter, and Year-Around

Habitat

MQ 11 asks, where are the breeding, winter, and year-around habitats for pronghorn and mule deer? Unfortunately, the REA did not locate any systematic geospatial data with which to differentiate breeding, winter, and year-round habitats for these two species, other than the WAFWA polygon data for mule deer, shown above in Figure 9-1(bottom). Chapters 12 and 13 in the Pre-Assessment report (Unnasch et al. 2017) provide narrative presentations on seasonal habitat preferences in the two species.

9.6 Distribution and Impacts of Gypsum in Soil and Water

Chapter 7 discusses the methods used in the present REA to estimate the distribution of watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations. Chapter 7, Figure 7-8 shows the resulting estimated distribution, and Figure 7-10 compares that map to the distributions of the three terrestrial ecological system CEs. Comparison of the current distributions of the four individual species CEs (Figure 9-1 and Figure 9-2, above) with the results presented in Chapter 7 indicate that the distributions of the four individual species CEs are spatially independent of the distribution of gypsic conditions, at least at the scale of the data assessed here. As noted in Chapter 7, the evidence presented by Moore and Jansen (2007) indicates that soils with elevated soil gypsum levels that select for gypsophilous vegetation occur only in discrete patches ("islands" in their terminology) within larger areas of grasslands and scrub, although gypsovagous vegetation occurs more widely. The geologic and soils data appropriate for a rapid ecoregional assessment are not suitable for identifying locations of individual potential islands of local soils with elevated soil gypsum levels and gypsophilous vegetation. Similarly, as described earlier, National GAP species distribution data also are not suitable for analysis at a fine spatial scale. The present data therefore do not allow for a comparison of species distributions with the distribution of local soils with elevated soil gypsum levels and gypsophilous vegetation, to determine whether any of the four individual species CEs preferentially use or avoid such distinctive patches within the ecoregion.

10 Species Assemblage Conservation Elements

10.1 Introduction

This chapter presents the assessments focused on the two species assemblage Conservation Elements (CEs), the Grassland Bird Assemblage and the Grassland Small Mammal Assemblage. Seven Management Questions (MQs) concern or include one or both of these two CEs, as follows:

MQ A: What is the geographic distribution of each CE?
MQ B: What is the current condition of each CE across its geographic distribution?
MQ C: What is the current geographic distribution of the impacts of each Change Agent (CA) in relation to each CE?
MQ D: What are the forecasted geographic distributions of development and climate change impacts in relation to each CE?
MQ 5: Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?
MQ 8: How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?
MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

Chapter 4, above, addresses the forecasted impacts of climate change on individual species Conservation Elements, part of the subject of MQ D. Chapters 5 and 6, above, address the current impacts of the other CAs, the subject of MQ C. Chapter 5 also addresses MQ 8, concerning how urban and industrial growth potentially could alter the geographic distribution of the grassland bird assemblage. Section 10.4 in the present chapter addresses MQ 5, concerning the geography of faunal species biodiversity among the four species CEs (see Chapter 9) and two species assemblage CEs taken together. Finally, Section 10.5 addresses MQ 13, concerning the distribution of the impacts of gypsic soil and water on ecological conditions. Chapter 7, above, presents the full assessment of the current geographic distribution of potential impacts of gypsum in the soil and water in general, as well as in relation to the three dryland ecological system CEs and their associated Change Agents. The present chapter does not repeat that background information and focuses only on the geographic distribution of possible ecological impacts of gypsum in the soil and water on the two species assemblage CEs.

10.2 Conservation Element Distributions

The distributions of the two species assemblages are mapped based on the combined distributions of the individual species that make up each assemblage. The data used to map the distributions of the individual species in the Grassland Bird Assemblage and Grassland Small Mammal Assemblage consist exclusively of U.S. Geological Survey Gap Analysis Program (GAP) species distribution data (USGS-GAP 2005, http://swregap.nmsu.edu/habitatreview/ModelQuery.asp; USGS-GAP 2011, https://gapanalysis.usgs.gov/species/data); Gergely and McKerrow 2013), for reasons explained below.

The National GAP species website (https://gapanalysis.usgs.gov/species/data/) defines a species distribution as *"… the spatial arrangement of environments suitable for occupation by a species. In other words, a species distribution is created using a deductive model to predict areas suitable for occupation within a species range…. It should be noted that all our range and distribution models are predictions about the occurrence of a species within the U.S. GAP ranges and distribution models are intended for use at the landscape scale (i.e., areas the size of square kilometers). They are not intended to be precise predictions of species occurrence/absence at local scales (areas the size of square meters). It is important for GAP data users to evaluate the suitability of the data for their intended purpose… GAP aims to use the best available information to create species ranges and distribution models. GAP relies on existing data and expert opinions from partners and collaborators (e.g., State Natural Heritage Programs) … All of GAP's ranges and distribution models have been reviewed by experts and compared to other data sources for accuracy. The accuracy of the species ranges and distribution models varies from species to species in part because habitat preferences and behaviors vary seasonally and annually… However, those species for which thorough knowledge of habitat preferences exists are better represented than those for which little is known (i.e., rare or small populations) or vary widely both spatially and temporally. Species with highly restrictive distributions are very difficult to model accurately because their habitat cannot be predicted within the 30 m resolution of our land cover data and distribution maps. We accept the uncertainty within some ranges and distribution models because we believe these data provide basic information and serve an important purpose by highlighting where more data are needed. Despite these limitations, we believe GAP species ranges and distribution models are valuable and relevant for addressing broad landscape level conservation questions and research*."

The Grassland Bird Assemblage consists of five species: Arizona grasshopper sparrow, *Ammodramus savannarum ammolegus*; Baird's sparrow, *Ammodramus bairdii*; Cassin's sparrow, *Aimophila cassinii*; Chestnut-collared longspur, *Calcarius ornatus*; and Scaled quail, *Callipepla squamata*. National GAP data are available for analysis for all five individual species from all three states, at a 30-m resolution.

The Grassland Small Mammal assemblage consists of five species: Chihuahua deer mouse, *Peromyscus maniculatus blandus*; Hispid cotton rat, *Sigmodon hispidus*; Southern Plains woodrat, *Neotoma micropus*; Tawny-bellied cotton rat, *Sigmodon fulviventer*; and Yellow-nosed cotton rat, *Sigmodon ochrognathus*. Each of these species poses special constraints for mapping, as follows:

1. No distribution data were identified for the Chihuahua deer mouse, a sub-species of the widely distributed Deer mouse.
2. The distribution of the hispid cotton rat is mapped based on National GAP species distribution data for Arizona and New Mexico, which have a 30-m resolution. National GAP data for this species for Texas were not available for analysis. As with the individual species Conservation Elements, polygon data on the hispid cotton rat range in Texas are available from the International Union for Conservation of Nature (IUCN 2008; http://www.iucnredlist.org/technical-documents/spatial-data). However, the IUCN range polygon for this species in Texas covers all lands within the state that fall within the analysis extent. The same situation occurs with the southern plains woodrat (see below). Including the IUCN range data for these two species in the mapping of this species assemblage therefore

renders the resulting compilation useless for distinguishing conditions within Texas. For this reason, and for data consistency, the assessment of the grassland small mammal assemblage does not include IUCN range data for any of the individual species included in this assemblage.

3. The distributions of the Southern Plains woodrat, tawny-bellied cotton rat, and yellow-nosed cotton rat are mapped based on National GAP species distribution data for Arizona and New Mexico for each species, which have a 30 m resolution. No National GAP data were available any of these three species for Texas. As with the hispid cotton rate, polygon range data for these three species in Texas are available from the International Union for Conservation of Nature (IUCN 2008; http://www.iucnredlist.org/technical-documents/spatial-data). However, for the reasons stated above, the IUCN range data were not included in the assessment of the grassland small mammal assemblage for any of the individual species included in this assemblage.

Figure 10-1(top and bottom), Figure 10-2(top and bottom) and Figure 10-3(top) show the distributions of the five individual species that comprise the grassland bird assemblage. Figure 10-3(bottom) shows the resulting composite current distribution of the Grassland Bird Assemblage CE.

Figure 10-1(top and bottom), Figure 10-2(top and bottom) and Figure 10-3(top) show that Cassin's sparrow is widely distributed, occurring year-round across almost the entire analysis extent. The scaled quail also is widely distributed, including in areas such as the Tularosa Basin and the northernmost portion of the Pecos River valley within the analysis extent, but not the lower Pecos River valley. The other three grassland bird species in the Grassland Bird Assemblage CE have more restricted distributions. However, none of these other three included species occurs in any area that is not also within the distribution of Cassin's sparrow or scaled quail. As a result, as shown in Figure 10-3(bottom), the combined distribution of the five species that comprise the Grassland Bird Assemblage CE covers the entire analysis extent, except for the highest elevations and a few barren areas. Thus, although selected for their strong association with grasslands in the ecoregion, the species in the Grassland Bird Assemblage CE are not limited to grasslands but also occur across shrublands and woodlands within the ecoregion. The chestnut-collared longspur occurs in riparian vegetation, as well. Among the five species, the Arizona grasshopper sparrow and Baird's sparrow appear to have the closest associations with grassland habitat (see Chapter 7). Except for its occurrence along riparian corridors and at higher elevations, the chestnut-collared longspur also mostly occurs in grassland habitat. The inclusion of Cassin's sparrow and the scaled quail in the assemblage masks the grassland associations of these other three species.

Figure 10-4(top and bottom) and Figure 10-5(top and bottom) show the distributions of the four individual species that comprise the Grassland Small Mammal Assemblage CE for which data are available. Figure 10-6 shows the resulting overall current distribution of the Grassland Small Mammal Assemblage CE.

Figure 10-1. Current distributions, (top) Arizona grasshopper sparrow and (bottom) Baird's sparrow.

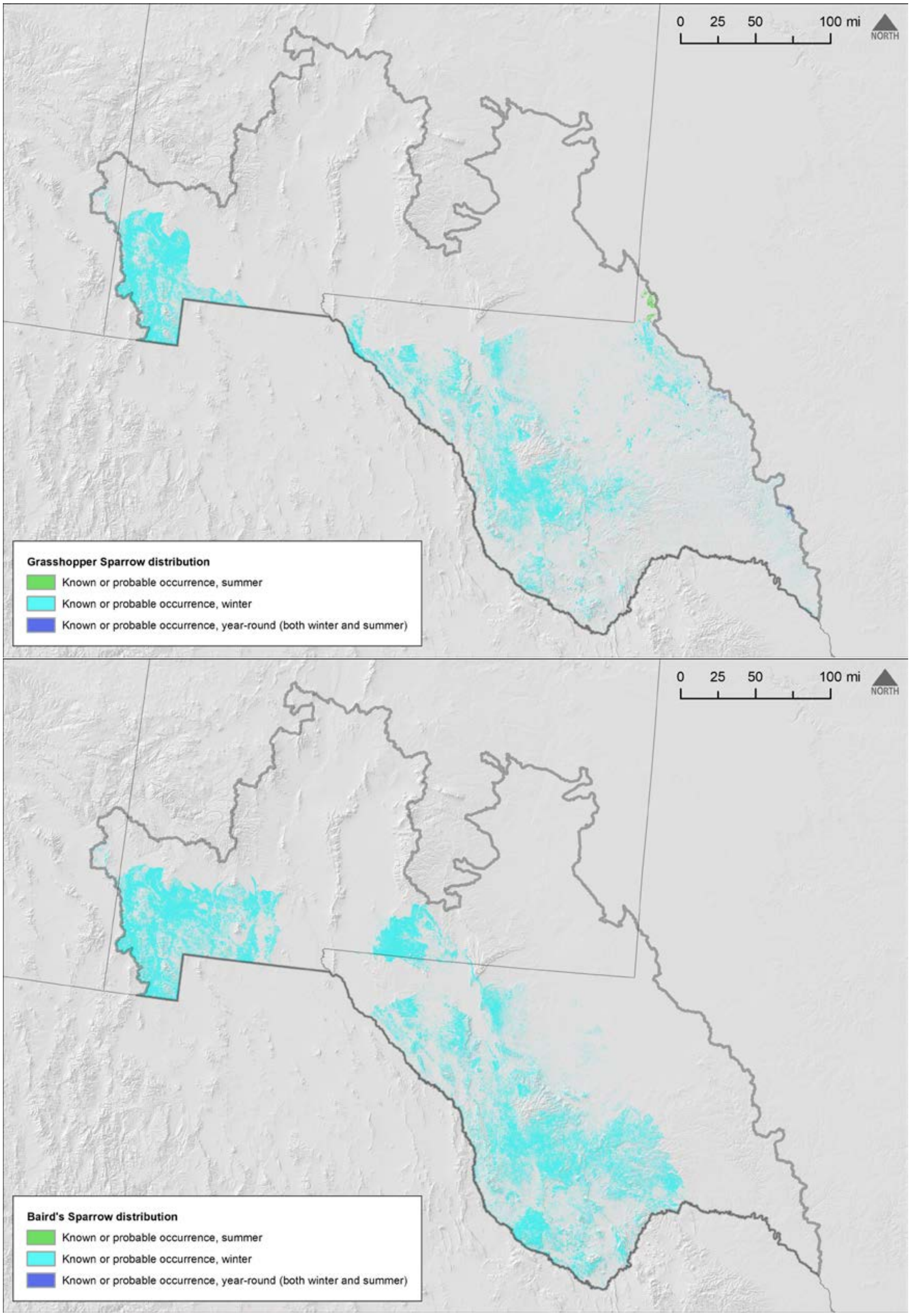


Figure 10-2. Current distributions, (top) Cassin's sparrow and (bottom) chestnut-collared longspur.

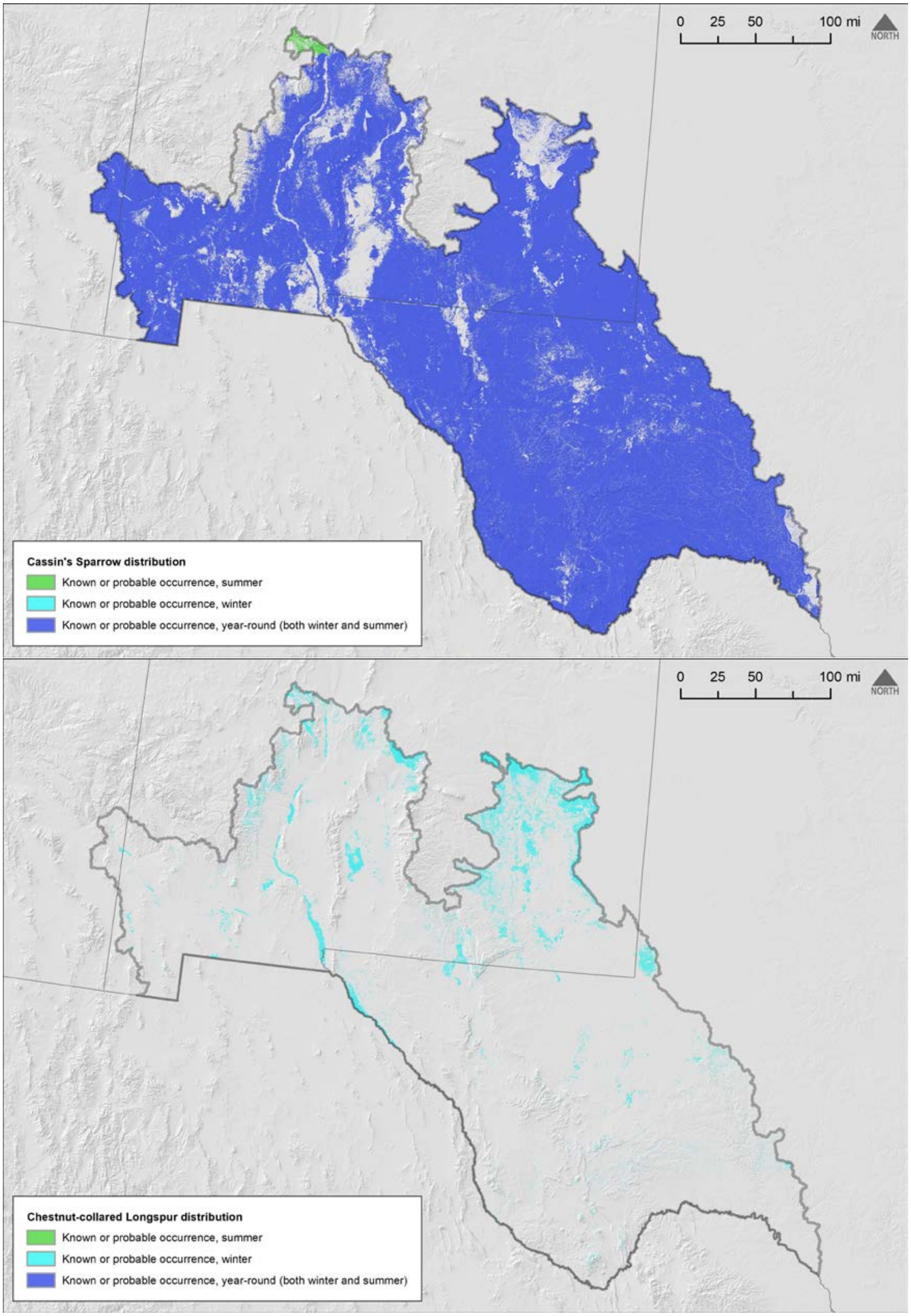


Figure 10-3. Current distributions, (top) scaled quail and (bottom) entire Grassland Bird Assemblage.

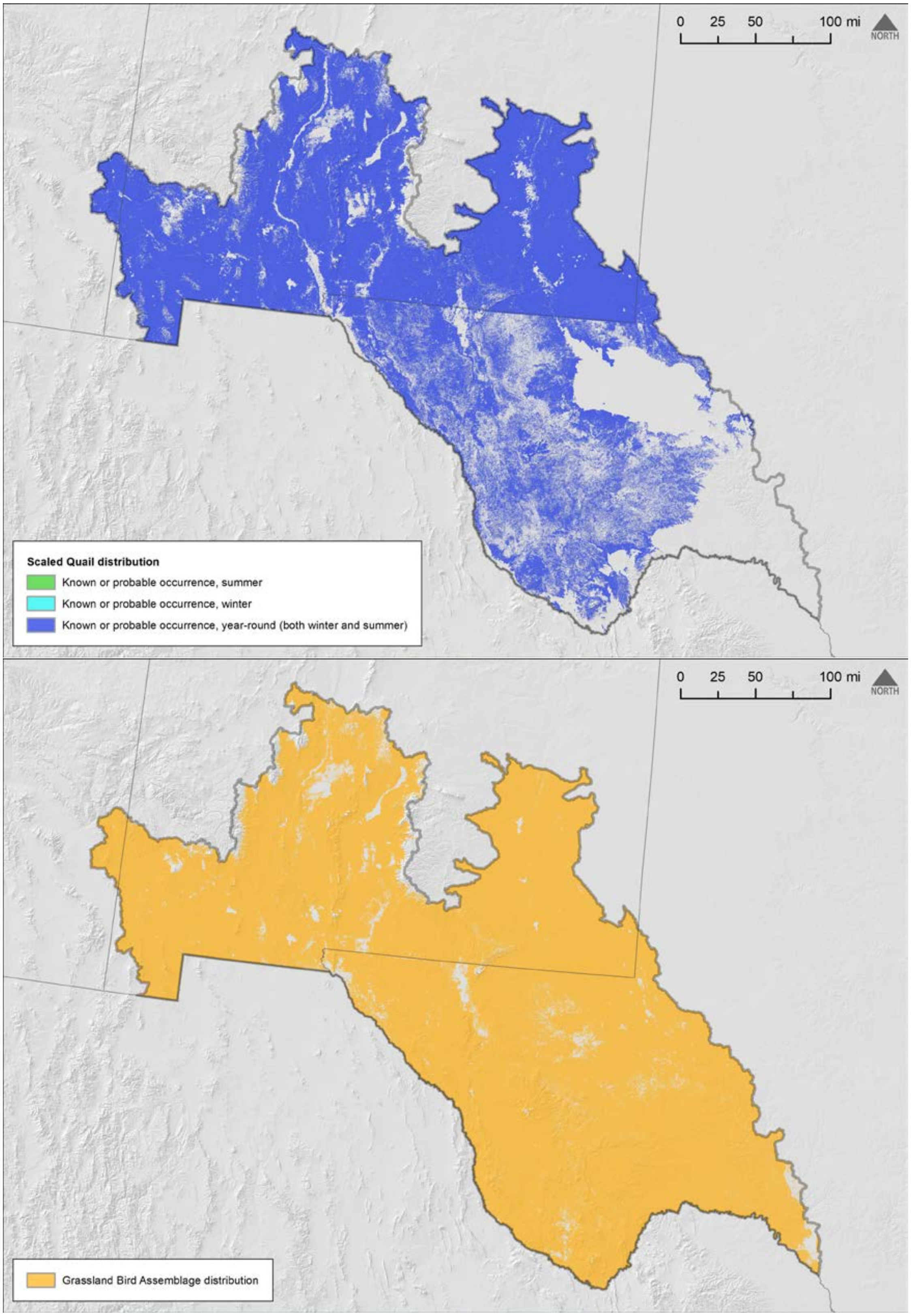


Figure 10-4. Current distributions, (top) hispid cotton rat and (bottom) southern plains woodrat.

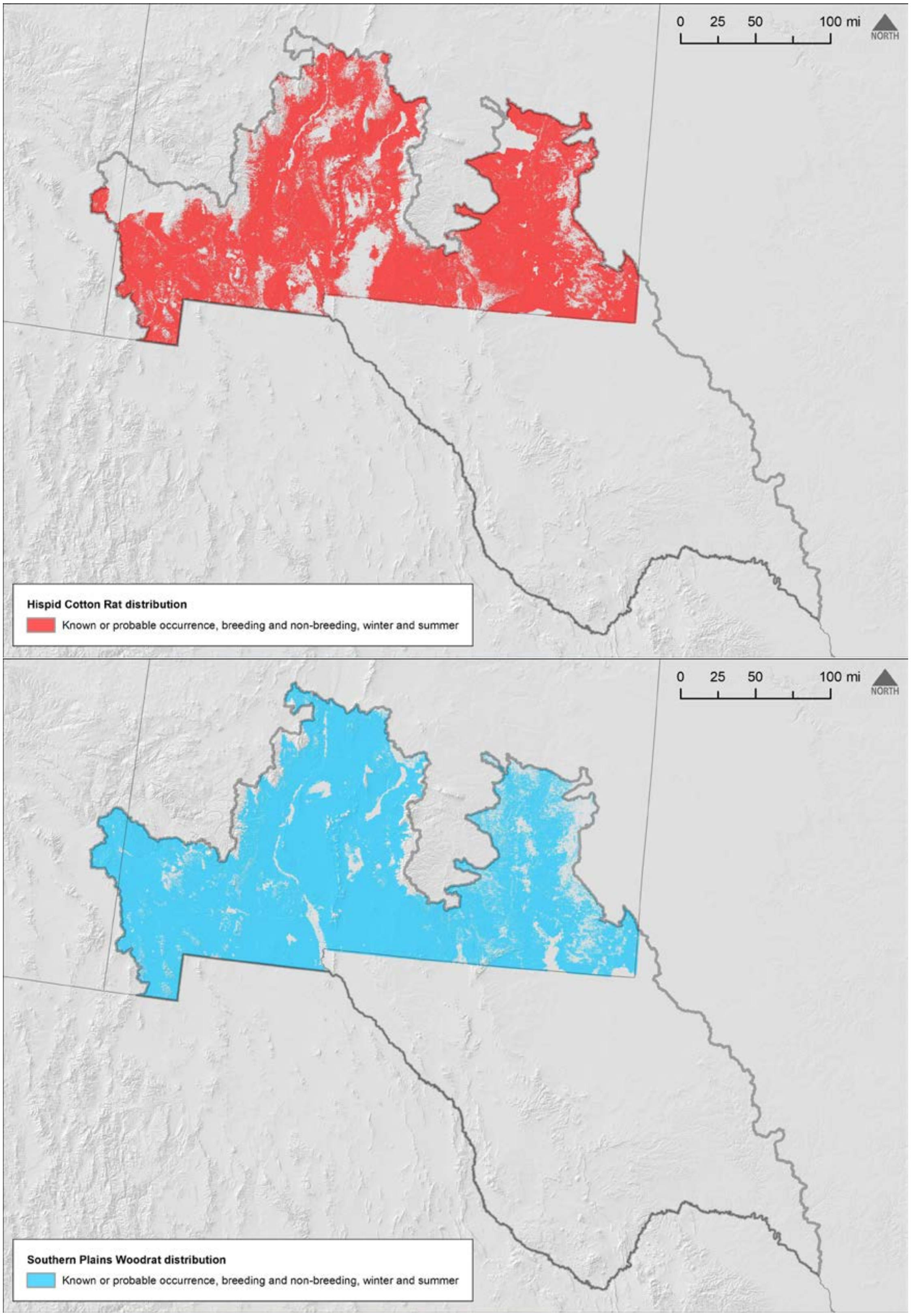


Figure 10-5. Current distributions, (top) tawny-bellied and (bottom) yellow-nosed cotton rats.

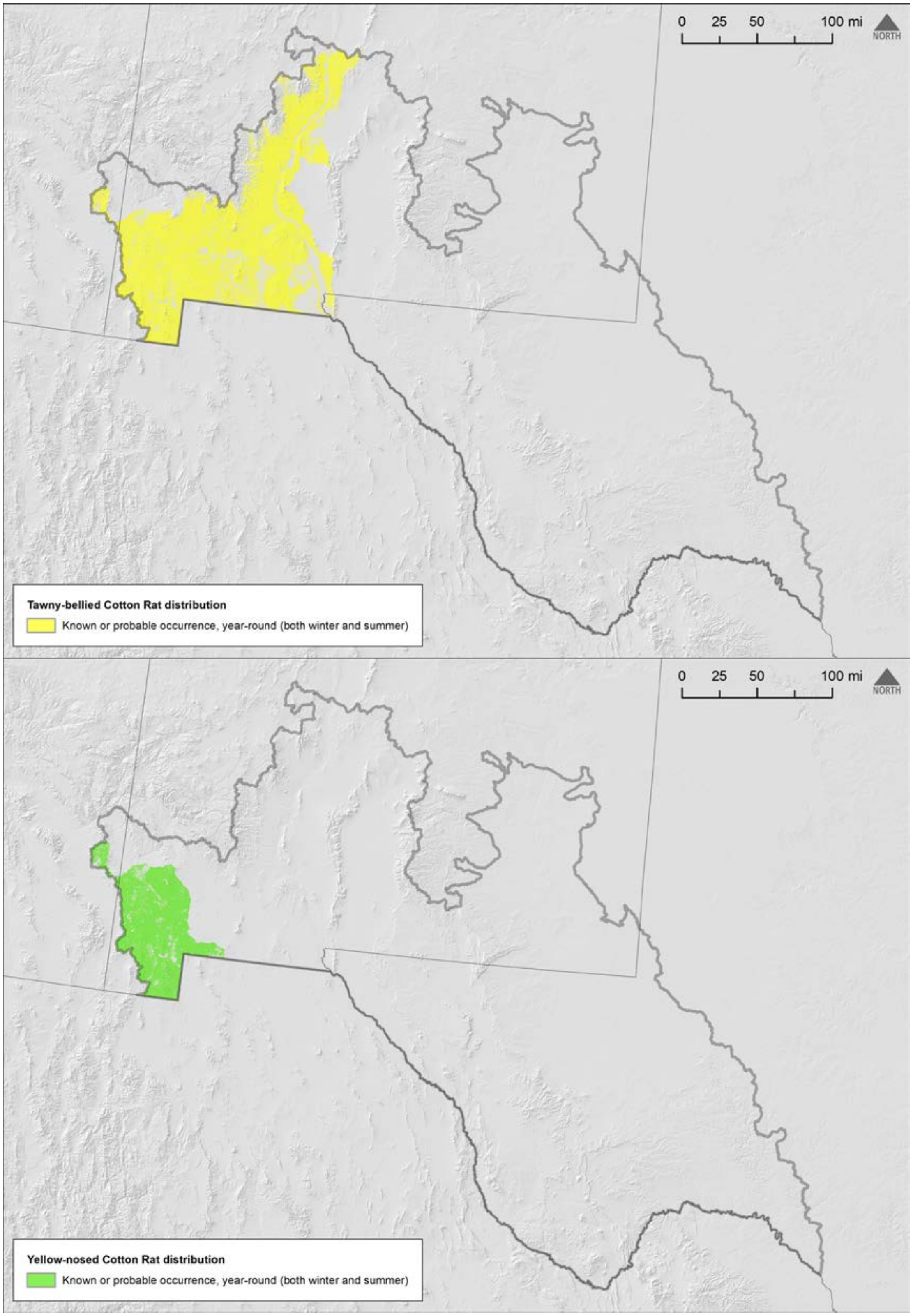


Figure 10-6. Current distributions, entire Grassland Small Mammal Assemblage.

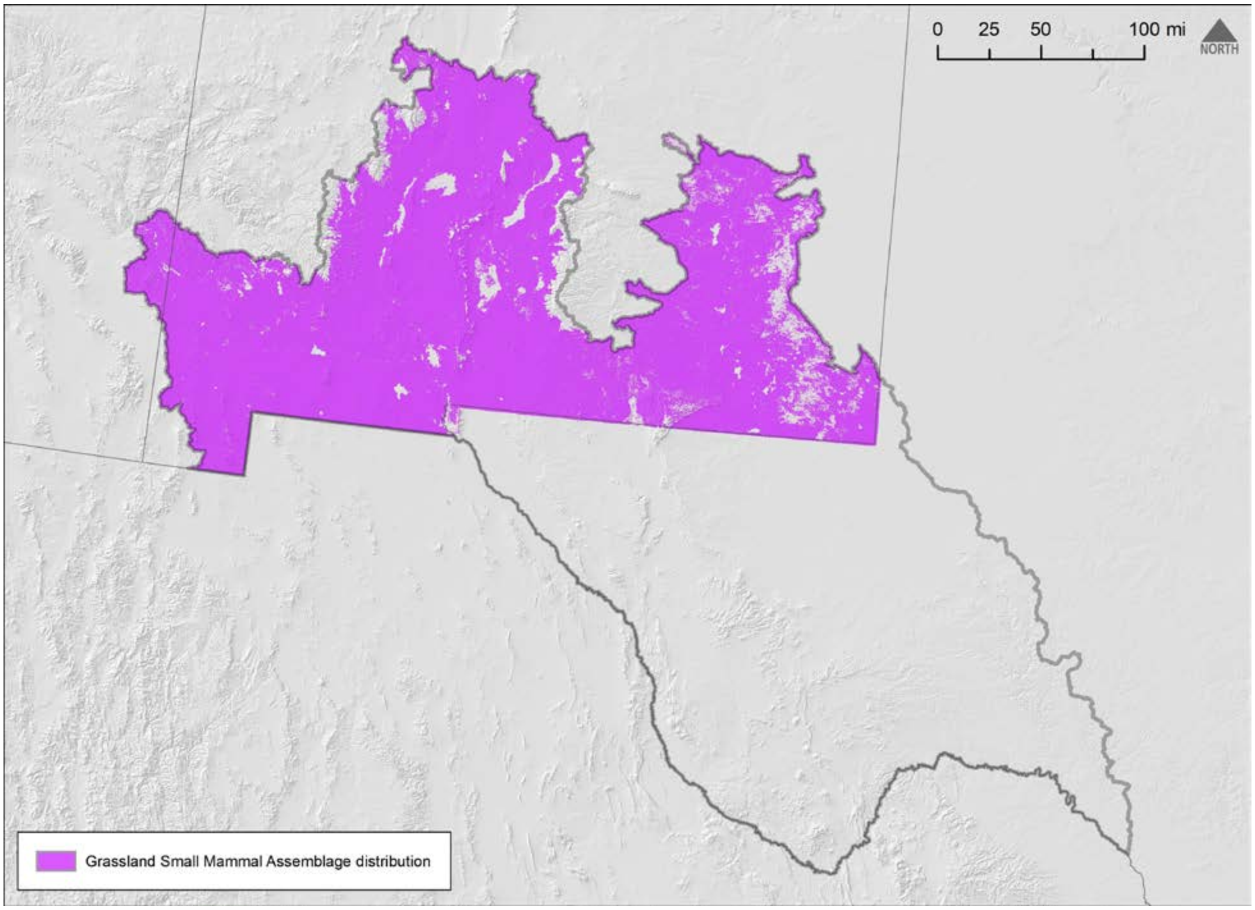


Figure 10-4(top and bottom) and Figure 10-5(top and bottom) show that the Southern Plains woodrat occurs almost everywhere within the analysis extent in Arizona and New Mexico. However, the species appears to avoid riparian corridors, the extreme northeastern margin of the Pecos River valley, and some higher elevations. The hispid cotton rat also occurs almost everywhere within the analysis extent in Arizona and New Mexico, but avoids higher elevations to a greater extent than does Southern Plains woodrat. Further, unlike the Southern Plains woodrat, the hispid cotton rat also occupies riparian corridors.

The distributions of both the tawny-bellied cotton rat and yellow-nosed cotton rat contrast greatly with the distributions of the other two small mammals included in the Grassland Small Mammal Assemblage CE. Specifically, the tawny-bellied cotton rat and yellow-nosed cotton rat occur only in limited portions of the analysis extent in Arizona and New Mexico. The yellow-nosed cotton rat occurs only in grasslands and mixed grassland-shrubland in the westernmost portion of the analysis extent, bordering the Madrean Archipelago ecoregion to the west. The tawny-bellied cotton rat occurs only in grasslands and mixed grassland-shrubland from the Rio Grande valley westward. However, neither of these latter two mammals occurs in any area that is not also within the distributions of hispid cotton rat and Southern Plains woodrat. As a result, as shown in Figure 10-6, the combined distribution of the Grassland Small Mammal Assemblage CE covers almost all of the entire analysis extent in Arizona and New Mexico. Thus, although also selected for their strong association with grasslands in the ecoregion, the species in this assemblage are not limited to grasslands but also occur across shrublands and woodlands within the ecoregion, including riparian corridors. The inclusion of the two ubiquitous mammals in the assemblage masks the stronger grassland associations of the other two species.

The few areas not included in the overall distribution of the Grassland Small Mammal Assemblage CE include higher elevations, a few barren areas, and a large scatter of patches across the eastern side of the Pecos River Basin. This large scatter of patches occurs in an area with two types of grassland cover – Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe – that are not components of the Chihuahuan Desert Grasslands CE but nevertheless also are grasslands (see Chapter 2, above, and the Pre-Assessment report, Unnasch et al. 2017, Chapter 2). The avoidance of these latter grassland types suggests that, although the Grassland Small Mammal Assemblage CE occurs in both the Chihuahuan Desert Grassland and Chihuahuan Desert Scrub CEs, it does not occur in grassland types other than those that comprise the Chihuahuan Desert Grassland CE, particularly not in eastern grassland types that overlap the northeastern margins of the present analysis extent.

10.3 Conservation Element Current Conditions

The assessment evaluated the current condition of the two species assemblage CEs only qualitatively, through an examination of the spatial relationships between Change Agents and the two CEs. It was not possible to evaluate their current conditions quantitatively through analyses of any other indicators. A comparison of the Key Ecological Attributes for each of the two CEs, identified during the Pre-Assessment phase of the REA (Unnasch et al. 2017), and lists of potentially available data on these attributes, did not identify any systematic geospatial data suitable for use in an REA to assess the condition for these two species assemblage CEs.

Chapter 4, above, addresses in detail the ways in which climate change potentially will affect the present locations of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs, and potentially affect their future distributions. As discussed above, these three terrestrial ecological system CEs provide the majority of habitat for the four species that comprise the Grassland Bird Assemblage, which occurs across the entire analysis extent other than at the highest elevations and across a few barren areas. The information presented in Chapter 4, concerning the effects of climate change on the three terrestrial ecological system CEs therefore also provides a general picture of potential effects on habitat for the four species that comprise the Grassland Bird Assemblage. The forecasts of a significant contraction of the distribution of the Pinyon-Juniper Woodlands and CE and its replacement largely by Chihuahuan Desert Grasslands, and the even more significant contraction of the distribution of the Chihuahuan Desert Grasslands CE and its replacement by Chihuahuan Desert Scrub by 2050 and 2070 do not necessarily point to any significant loss of habitat for the Grassland Bird Assemblage CE. However, the forecasted changes in temperatures and moisture availability discussed in Chapter 4 presumably could affect organism health. Chapter 16 in the Pre-Assessment report (Unnasch et al. 2017) provides an extended discussion of the ways in which climate change potentially could affect the health and distribution of each of the five individual species that comprise the Grassland Bird Assemblage CE.

Similarly, as also discussed above, the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs provide the majority of habitat for the four species that comprise the Grassland Small Mammal Assemblage CE. The information presented in Chapter 4, concerning the effects of climate change on the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs, therefore also provides a general picture of potential effects on habitat for the four species that comprise the Grassland Small Mammal Assemblage CE. The forecasts of a significant contraction of the distribution of the Chihuahuan Desert Grasslands CE and its replacement largely by Chihuahuan Desert Scrub by 2050 and 2070 do not necessarily point to any significant loss of habitat for the Grassland Small Mammal Assemblage CE. However, the forecasted changes in temperatures and moisture availability discussed in Chapter 4 presumably could affect organism health. Chapter 17 in the Pre-Assessment report (Unnasch et al. 2017) provides an extended discussion of the ways in which climate change potentially could affect the health and distribution of each of the four individual species that comprise the Grassland Small Mammal Assemblage CE.

Chapter 5, above, discusses the present and forecasted future distribution of development within the analysis extent. Residential, commercial, industrial, and irrigated agricultural development, mostly concentrated along the large river valleys, has not substantially eliminated habitat for most of the five individual species that comprise the Grassland Bird Assemblage. However, the chestnut-collared longspur does use riparian habitat more than do the other four members of the assemblage. As a result, further development along the large river valleys does have the potential to reduce habitat for this particular species. Further, development does overlap with the distribution of this CE in numerous portions of the analysis extent, including the large area of oil and gas production across southeastern New Mexico and western Texas, simply because the overall distribution of the Grassland Bird Assemblage CE covers so much of the analysis extent. The ICLUS forecasts for development and the projections for oil and gas production indicate that development will expand in all of these areas of existing overlap, and expand into additional areas within the distribution of this CE as well.

The information presented in Chapter 5 on the present distribution of development within the analysis extent also indicates that has not substantially eliminated habitat for any of the four individual species that comprise the Grassland Small Mammal Assemblage CE. However, the overall distribution of the Grassland Small Mammal Assemblage CE covers much of the analysis extent in Arizona and New Mexico. As a result, as with the Grassland Bird Assemblage, development does overlap with the distribution of the Grassland Small Mammal Assemblage CE in numerous portions of the analysis extent, including the large area of oil and gas production across southeastern New Mexico and western Texas. As noted above, the ICLUS forecasts for development and the projections for oil and gas production indicate that development will expand in all of these areas of existing overlap, and expand into additional areas within the distribution of the Grassland Small Mammal Assemblage CE as well.

Chapter 5, above, also discusses the distribution of grazing allotments on U.S. Forest Service and BLM lands within the REA analysis extent in Arizona and New Mexico. These allotments include significant fractions of the distributions of the five individual species that comprise the Grassland Bird Assemblage and the four individual species that comprise the Grassland Small Mammal Assemblage CE, within the analysis extent. As noted in Chapter 5, however, the REA was not able to acquire any data on grazing intensity or impacts within the allotments or on the large expanses of private land used for livestock grazing in New Mexico and Texas. As a result, it is not possible in this REA to assess the potential direct impacts of grazing on either of the species assemblage CEs.

Chapter 6, above, discusses the distribution of invasive terrestrial plants across the REA analysis extent based on county-scale data. As discussed in Chapter 7, above, the data presented in Chapter 6 indicate that invasive terrestrial plants occur widely across the entire analysis extent. As a result, invasive terrestrial plants occur widely across the entire areas of distribution of the Grassland Bird Assemblage and Grassland Small Mammal Assemblage CEs. However, as noted in Chapters 6-9, above, the records assessed in Chapter 6 do not represent the results of systematic surveys to map the distributions of these invasive species. As a result, it is not possible to assess how well they represent actual conditions across the distributions of these two species assemblage CEs. Chapters 16-17 in the Pre-Assessment report (Unnasch et al. 2017) provide extended discussions of the ways in which invasive species potentially affect habitat quality and diet for each of the individual species that comprise the Grassland Bird and Grassland Small Mammal Assemblage CEs.

Chapter 6 also discusses possible changes in wildfire patterns across the analysis extent. Table 10-1 shows the distribution of LANDFIRE vegetation departure (VDEP) values (LANDFIRE 2016; see Chapter 6, above, Figure 6-14) by percentile, across the 30-m pixels identified as occurrences of the Grassland Bird Assemblage and Grassland Small Mammal Assemblage CEs. For the reasons explained earlier in this chapter, concerning the availability of data on the individual species that comprise these two assemblages, Table 10-1 addresses VDEP values only across the analysis extent in Arizona and New Mexico.

Table 10-1. Vegetation Departure (VDEP) percentile distributions by species assemblage CE.

CE➔ VDEP Percentile🡻	Grassland Bird Assemblage	Grassland Small Mammal Assemblage
0-10%	8.68%	5.63%
11-20%	7.15%	3.45%
21-30%	10.33%	10.80%
31-40%	4.11%	5.14%
41-50%	4.81%	4.40%
51-60%	13.00%	20.36%
61-70%	27.32%	16.83%
71-80%	13.26%	8.69%
81-90%	5.87%	12.56%
91-100%	5.47%	12.14%
Total	100.00%	100.00%

Table 10-1 indicates that, across the areas (30-m pixels) in which the Grassland Bird Assemblage CE occurs, nearly 65% has a VDEP value > 50%. Similarly, Table 10-1 indicates that, across the areas (30-m pixels) in which the Grassland Small Mammal Assemblage CE occurs, nearly 71% has a VDEP value > 50%. In both cases the modal VDEP value is in the range of 51-70%. Both CE distributions thus are moderately highly disturbed.

Finally, Chapter 6 also discusses the distribution of landscape restoration treatments across the analysis extent. The data presented in Chapter 6 do not indicate the vegetation type(s) that each restoration treatment sought to restore. Table 10-2 shows the percentage of each treatment type (by area; see BLM vegetation treatment data discussion and Figure 6-18 in Chapter 6) that took place across 30-m pixels identified as occurrences of the Grassland Bird Assemblage and Grassland Small Mammal Assemblage CEs. For the reasons explained earlier in this chapter, concerning the availability of data on the individual species that comprise these two assemblages, Table 10-2 addresses VDEP values only across the analysis extent in Arizona and New Mexico. The LANDFIRE Vegetation Disturbance (VDIST) data shown in Chapter 6, Figure 6-19, include both prescribed fires and wildfires, and therefore are not included in Table 10-2.

Table 10-2 shows that, among all land treatments, chemical treatments have been used more often across the areas (30-m pixels) in which both assemblage CEs occur. Secondarily, physical (mechanical) treatments have occurred more often on areas of occurrence of the Grassland Bird Assemblage than areas of occurrence of the Grassland Small Mammal Assemblage, while prescribed fire treatments have occurred more often on the latter than on the former.

Table 10-2. Distribution of landscape restoration treatment types by species assemblage CE.

CE➔ **Treatment type 🡻**	**Grassland Bird Assemblage**	**Grassland Small Mammal Assemblage**
Chemical Treatments	87.71%	86.88%
Prescribed Fire Treatments	1.30%	11.76%
Physical Treatments	10.99%	1.36%
Total, all treatments	100%	100%

10.4 Distribution of Faunal Species Diversity

MQ 5 asks where the areas of greatest faunal species biodiversity occur among the thirteen species that comprise the species and species-assemblage CEs taken together: Pronghorn, mule deer, banner-tailed kangaroo rat, black-tailed prairie dog, Arizona grasshopper sparrow, Baird's sparrow, Cassin's sparrow, Chestnut-collared longspur, scaled quail, hispid cotton rat, Southern Plains woodrat, tawny-bellied cotton rat, and yellow-nosed cotton rat. The assessment of MQ 5 was expanded during Phase II of the REA, at the request of the AMT, to include the four species that comprise the Chihuahuan Desert amphibian assemblage discussed in Chapters 2 and 8, above: Arizona toad, Chiricahua leopard frog, Northern leopard frog, and Yavapai leopard frog. Figure 10-7 presents the results.

Figure 10-7. Species richness among the four individual species, five grassland birds, four grassland small mammals, and four amphibians.

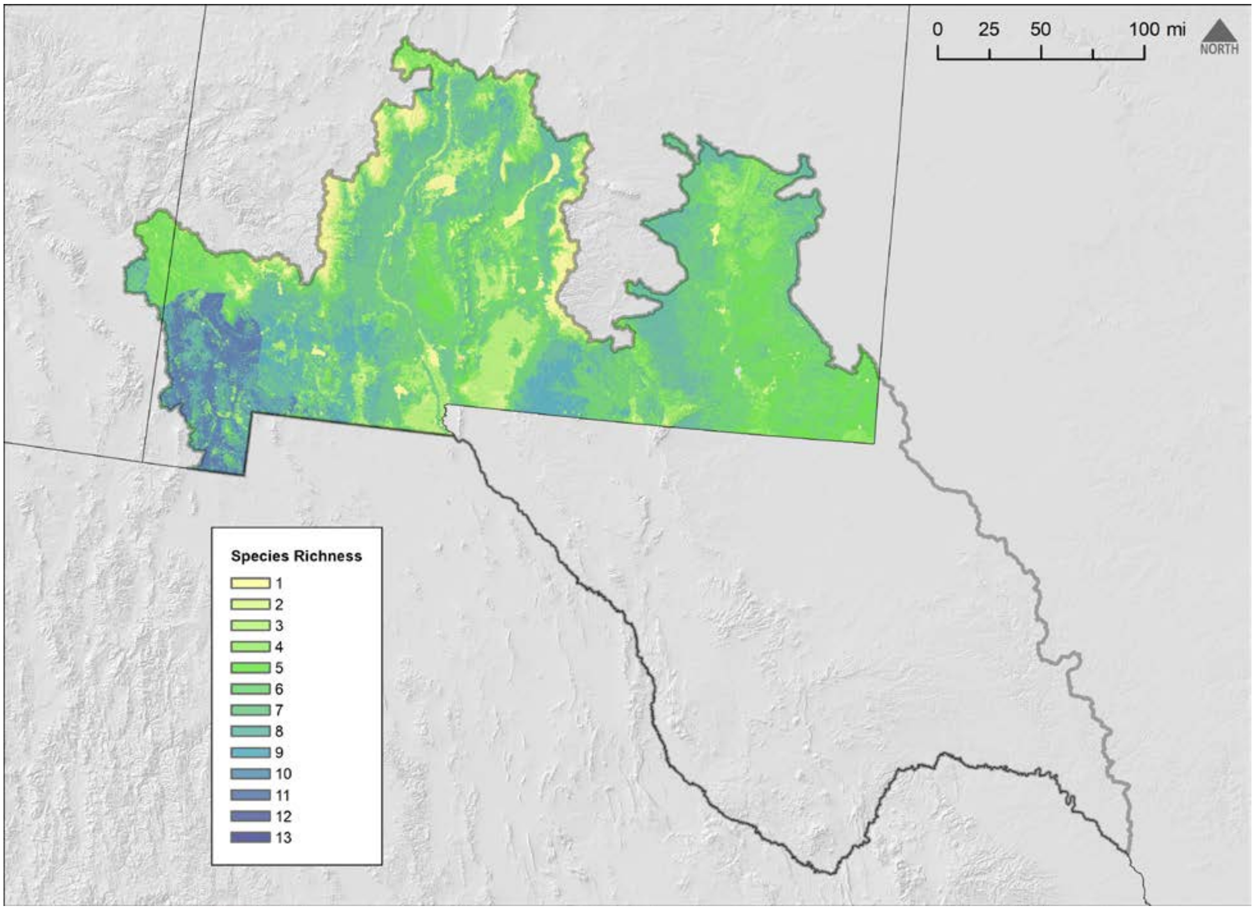


Figure 10-7 indicates, for each 30-m pixel within the analysis extent, the total number of species among these seventeen species with a current distribution that includes that pixel, based on the data used to map the distribution of that species for the present REA (see above and Chapter 9). Such a measure, based simply on the number of species, typically is termed a measure of species richness. No pixel registered more than thirteen of the seventeen possible species; as a result, species richness in this analysis ranges from a low of 0 to a high of 13. Figure 10-7 only addresses lands within Arizona and New Mexico, because the distributions of several species could not be mapped at a high level of resolution in Texas with existing data, as discussed above and in Chapter 9. The four amphibian species included in the Chihuahuan Desert amphibian assemblage have little or no presence in Texas. However, this appears to be a fact of their actual distributions rather than an artifact of data availability (see Chapter 8, above). Figure 10-7 indicates that species richness is highest in the far west of the analysis extent in Arizona and New Mexico, in an areas corresponding roughly to Hidalgo and western Grant County, New Mexico. Species richness in fact is high across most lands between Las Cruces, New Mexico and the Arizona border, although with several included patches of very low richness. An area of widespread, consistently high species richness occurs within the Fort Bliss Military Reservation in New Mexico, extending southward from the foothills of the Sacramento Mountains toward and presumably into Texas, as well.

In turn, Figure 10-7 indicates that species richness is lowest across all higher elevations and also in the vicinities of all the cities in New Mexico within the analysis extent. For example, areas of low species richness occur along the far eastern margins of the Tularosa Basin and along the far western margins of the Rio Grande valley. Other large patches of low species richness include non-playa barrens in the Tularosa Basin and in the Jornada del Muerto valley east of Socorro, New Mexico; and developed areas in the vicinities of Silver City, Deming, Las Cruces, Roswell, Artesia, and Carlsbad, New Mexico.

10.5 Distribution and Impacts of Gypsum in Soil and Water

Chapter 7 discusses the methods used in the present REA to estimate the distribution of watersheds with gypsic soils and/or surface exposures of gypsic and/or anhydric geologic formations. Chapter 7, Figure 7-8 shows the resulting estimated distribution, and Figure 7-10 compares that map to the distributions of the three terrestrial ecological system CEs. Comparison of the current distributions of the Grassland Bird Assemblage and Grassland Small Mammal Assemblage CEs (Figure 10-3(bottom) and Figure 10-6, above) with the results presented in Chapter 7 indicate that the distributions of the two species assemblages are spatially independent of the distribution of gypsic conditions, at least at the scale of the data assessed here. As noted in Chapter 7 and also discussed in Chapter 9, the evidence presented by Moore and Jansen (2007) indicates that soils with elevated soil gypsum levels that select for gypsophilous vegetation occur only in discrete patches ("islands" in their terminology) within larger areas of grasslands and scrub, although gypsovagous vegetation occurs more widely. The geologic and soils data appropriate for a rapid ecoregional assessment are not suitable for identifying locations of individual potential islands of local soils with elevated soil gypsum levels and gypsophilous vegetation. Similarly, as described earlier, National GAP species distribution data also are not suitable for analysis at a fine spatial scale. The present data therefore do not allow for a comparison of species distributions with the distribution of local soils with elevated soil gypsum levels and gypsophilous vegetation, to determine whether any of the two species assemblage CEs preferentially occur in or exclude such distinctive patches within the ecoregion.

11 Conclusions

This chapter summarizes the findings of Phase II (Assessment phase) of the Chihuahuan Desert Rapid Ecoregional Assessment (REA), prepared for the U.S. Department of the Interior, Bureau of Land Management. The present chapter first summarizes the findings for the four core Management Questions (MQs), concerning (A) the current geographic distributions of the individual Conservation Elements (CEs), (B) the current condition of each CE across its geographic distribution, (C) the current geographic distribution of the impacts of each Change Agent (CA), both in general and in relation to each CE, and (D) the forecasted geographic distributions of development and climate change impacts in relation to each CE. The present chapter then summarizes the findings for each of the thirteen MQs addressed by the REA. Finally, the chapter offers recommendations concerning weaknesses and gaps in the data available to address the core concerns and MQs identified for the REA.

11.1 Conservation Element Current Geographic Distributions

11.1.1 Terrestrial Ecological System CEs

The Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs together currently cover 84% of the land area in the U.S. portion of the ecoregion: Chihuahuan Desert Scrub, 59%, Chihuahuan Desert Grasslands, 22%, and Pinyon-Juniper Woodlands, 3%.

The current distributions of these three CEs largely reflect the interactions of climate and topography (see Chapters 2, 4, and 7). The Chihuahuan Desert Grasslands CE occurs on piedmonts, foothills, and lowlands mainly between 1,100 and 1,700 m in elevation. These topographic zones tend to experience slightly less precipitation and slightly cooler temperatures than do areas at lower elevations, which in turn are dominated by the Chihuahuan Desert Scrub CE. As a result, the Chihuahuan Desert Grasslands CE within the analysis extent is more common in New Mexico than in Texas, occurs within New Mexico mostly west of the Pecos River valley and especially west of the Rio Grande valley. Almost none of the Chihuahuan Desert Grasslands CE within the analysis extent occurs in Arizona. The Chihuahuan Desert Scrub CE has the opposite pattern. In turn, the Pinyon-Juniper Woodlands CE within the analysis extent occurs generally at elevations between 1,400 and 2,200 m in elevation. These elevations experience slightly greater precipitation and slightly cooler temperatures compared to areas dominated by the Chihuahuan Desert Grasslands CE. Pinyon-juniper woodlands in fact are often bordered by grasslands at their lower elevations.

11.1.2 Aquatic-Wetland Ecological System CEs

The locations of the twenty Montane-Headwater Perennial Streams, fifteen Lowland-Headwater Perennial Streams, and three Large River-Floodplain Systems follow their natural valleys. Many of the Lowland-Headwater Perennial Streams originate at discrete springs or spring complexes, the locations of which also determine the locations of the channels into which their discharge flows. Thirteen of the fifteen Montane-Headwater Perennial Streams occur in the northern third of the analysis extent, all in New Mexico, emerging from various mountain ranges to form tributaries to the Pecos River, Rio Grande, and Gila River. The other two Montane-Headwater Perennial Streams occur in Texas: the Delaware

River, flowing out of the Delaware Mountains, and Limpia Creek, flowing out of the Davis Mountains. In contrast, fourteen of the twenty Lowland-Headwater Perennial Streams occur in Texas, and four of the other six occur just in the Tularosa Basin in New Mexico. However, Montane-Headwater and Lowland-Headwater Perennial Streams differ only in the *relative* importance of surface runoff versus groundwater discharge in maintaining their perennial character, and it was not always clear how to categorize some streams. The mapped current distributions of the Montane-Headwater Perennial Streams, Lowland-Headwater Perennial Streams, and Large River-Floodplain Systems include their remaining riparian vegetation corridors.

The Springs-Emergent Wetlands CE occurs widely but extremely unevenly throughout the analysis extent. The locations of individual springs, spring complexes, and seeps depend on the locations of major bedrock fractures rather the locations of aquifers, as discussed further, below (see MQ 9). They are notably scarce east of the Pecos River, for example, and notably common in several areas including around the Davis and Del Norte Mountains, the Big Bend region, the southern San Andres Mountains, and the southern flanks of the Mogollon Mountains. Some are crucial sources of discharge for perennial streams, but most are not. The mapped locations of all Springs-Emergent Wetlands include their wetlands, when present.

Small occurrences of the Playas and Playa Lakes CE exist throughout the analysis extent, but large occurrences are limited to the larger closed basins, such as the Tularosa and Salt Basins, the Jornada del Muerto valley, and the Lordsburg and Playas valleys near the Arizona border. All of these larger occurrences are remnants of, or mark the former locations of, Pleistocene pluvial lakes. The mapped locations of all Playas and Playa Lakes include surrounding barrens and potentially hydrologically associated vegetation communities such as wetlands and patches of phreatophytic vegetation.

11.1.3 Individual Species CEs

Accurate estimates of the current distribution of Pronghorn within the analysis extent are limited to Arizona and New Mexico. The pronghorn estimated distribution in Arizona and New Mexico roughly resembles the distribution of the Chihuahuan Desert Grasslands CE, discussed above, but also includes areas with Pinyon-Juniper Woodlands cover. The pronghorn distribution includes areas along the northeastern edge of the analysis extent dominated Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe, ecological system types that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands.

The current distribution of Mule Deer within the analysis extent could be assessed only using highly generalized polygon data maintained by the Western Association of Fish and Wildlife Agencies (WAFWA Mule Deer Working Group 2005). These data include separate polygons for “year-round distribution,” “other important habitat,” and “limited range.” The “year-round distribution” encompasses all areas in the Pinyon-Juniper Woodlands CE and most areas of the Chihuahuan Desert Grasslands CE within the analysis extent, a few areas of Chihuahuan Desert Scrub, and areas along the northeastern edge of the analysis extent dominated Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands. The “limited range” polygons mostly cover areas of Chihuahuan Desert Scrub. The “other important habitat" mostly consists of riparian areas, most substantially along the Black River and along the Pecos River between Roswell and Carlsbad, New Mexico.

Accurate estimates of the current distribution of the Banner-tailed Kangaroo Rat within the analysis extent are limited to Arizona and New Mexico, where the species is estimated to occur across approximately the lower elevations of occurrence of the Chihuahuan Desert Grasslands CE and the higher elevations of occurrence of the Chihuahuan Desert Scrub CE, including areas in which these two terrestrial ecological system CEs intermix. As with the pronghorn and mule deer, the distribution of the banner-tailed kangaroo rat includes areas along the northeastern edge of the analysis extent dominated Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands.

Accurate estimates of the current distribution of the Black-Tailed Prairie Dog cover Arizona, New Mexico, and Texas, and indicate that the species occurs almost exclusively in areas extensively covered by the Chihuahuan Desert Grasslands CE without intermixtures of either the Chihuahuan Desert Scrub or Pinyon-Juniper Woodlands CE. As with the pronghorn, mule deer, and banner-tailed kangaroo rate, the black-tailed prairie dog distribution includes areas along the northeastern edge of the analysis extent dominated Western Great Plains Shortgrass Prairie and Western Great Plains Sandhill Steppe that are not components of the Chihuahuan Desert Grasslands CE but nevertheless are grasslands. However, unlike the other individual species CEs, the black-tailed prairie dog does not occur on any lands immediately along or west of the Rio Grande valley.

11.1.4 Species Assemblage CEs

Among the five individual species in the Grassland Bird Assemblage (see species list above), the available data indicate that Cassin's sparrow is widely distributed, occurring year-round across almost the entire analysis extent. The scaled quail also is widely distributed, including in areas such as the Tularosa Basin and the northernmost portion of the Pecos River valley within the analysis extent, but not the lower Pecos River valley. The other three species in the Grassland Bird Assemblage have more restricted distributions. However, none of these other three species occurs in any area that is not also within the distribution of Cassin's sparrow or the scaled quail. As a result, the combined distribution of the five species covers the entire analysis extent, including woodlands, grasslands, and scrub, except for the highest elevations and a few barren areas. The chestnut-collared longspur also occurs in riparian vegetation. Among the five species, the Arizona grasshopper sparrow and Baird's sparrow appear to have the closest associations with grassland habitat. Except for its occurrence along riparian corridors and at higher elevations, the chestnut-collared longspur also mostly occurs in grassland habitat. The inclusion of Cassin's sparrow and scaled quail in the assemblage masks the grassland associations of the other three species.

Among the five individual species in the Grassland Small Mammal Assemblage, accurate estimates were not located for the distribution of the Chihuahua deer mouse, and were obtained for the other four species only for Arizona and New Mexico. The Southern Plains woodrat is estimated to occur almost everywhere within the analysis extent in Arizona and New Mexico, except for riparian corridors, the extreme northeastern margin of the Pecos River valley, and some higher elevations. The hispid cotton rat also occurs almost everywhere within the analysis extent in Arizona and New Mexico, but avoids higher elevations to a greater extent than does Southern Plains woodrat and, unlike the Southern Plains woodrat, does occupy riparian corridors. In contrast, the tawny-bellied cotton rat is estimated to occur within the analysis extent in Arizona and New Mexico only in grasslands and mixed grassland-scrub from the Rio Grande valley westward, and the yellow-nosed cotton rat is estimated to occur only in the far westernmost portion of the analysis extent, near the Arizona-New Mexico border. However, neither of these latter two mammals occurs in any area that is not also within the joint distribution of the hispid cotton rat and Southern Plains woodrat. As a result, the combined distribution of the four species in the Grassland Small Mammal Assemblage CE covers almost all of the analysis extent in Arizona and New Mexico, including riparian corridors.

11.2 Conservation Element Current Conditions

11.2.1 Terrestrial Ecological System CEs

The REA assessed the current conditions of the three terrestrial ecological system CEs using information on: (1) the distribution of impacts from the Change Agents, (2) current conditions for which no reference values are available, and (3) current conditions for which information on estimated reference conditions is available for comparison. The summaries of the assessments of the six Change Agents, below, address the first of these three bodies of information.

Estimates of vegetation cover density (percent cover) and height provide information for which no historic reference information is available. Both tree and herbaceous cover percentages generally increase with elevation within their overall geographic distributions. However, two areas distinctly do not follow this broad pattern: (1) An area of very low herbaceous (mostly grassland) cover extending south from the Sacramento Mountains in New Mexico well into Texas; and (2) an area of moderately high shrub cover and high herbaceous cover across the northern Pecos River valley roughly from the vicinity of Roswell, northward. As discussed below, other data for the latter area also indicate a high degree of vegetation alteration and a high wildfire hazard potential. Estimated herbaceous vegetation height is generally less than 0.5 m, except in scattered locations mostly along the Pecos River in New Mexico and in the vicinity of the town of Pecos, Texas. Estimated shrub height is generally less than 3.0 m. The northern third of the analysis extent includes large areas with estimated average shrub heights less than 1.0 m and a few small, scattered patches with estimated average shrub heights greater than 3.0 m. Forest canopy height varies fairly consistently with elevation.

A comparison of current generalized vegetation cover types with estimated reference conditions prior to Euro-American settlement indicates significant differences: Among all 30-m pixels within the analysis extent estimated to have been dominated historically by either grassland, shrubland, or conifer woodland, more than 61% are estimated to have been dominated by grassland cover and nearly 37% by shrubland cover. In contrast, among all pixels within the analysis extent currently dominated by grassland, shrubland, or conifer woodland, only approximately 26% are dominated by grassland cover and more than 66% by shrubland cover. These values refer to generalized vegetation cover types rather than specifically to the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper

Woodlands CEs in particular, but the values for current conditions are very similar. In fact, only 29% of the area estimated to have had predominantly grassland cover under historic conditions remains grassland today, while nearly 65% of the area estimated to have had predominantly grassland cover under historic conditions has transitioned to shrubland today. In contrast, nearly 72% of the area estimated to have had predominantly shrubland cover under historic conditions remains shrubland today, while only 21% of the area of historic shrubland cover has transitioned to grassland.

An assessment of vegetation departures from natural disturbance regimes provides information on the degree to which vegetation cover composition, structural stage, and canopy closure within the analysis extent differ from estimated historic conditions prior to Euro-American settlement. The results show four areas of substantial departure: (1) along the lower elevations of the Rio Grande valley in New Mexico; (2) across the Jornada del Muerto and Jornada Draw closed valleys immediately to the east of the Rio Grande valley in New Mexico that mostly encompass areas of current Chihuahuan Desert Grassland; (3) along the lower elevations of the Pecos River valley roughly from the vicinity of Roswell, New Mexico, northward, that mostly encompass areas of current Chihuahuan Desert Scrub; and (4) a band extending westward from the Rio Grande valley to the Arizona border. Conversely, three large areas show little departure: (1) across the Tularosa and Salt Basin closed valleys, roughly within the large military reservations that encompass these areas; (2) across the Rio Grande valley through the Big Bend region, and across much of the southernmost Pecos River valley; and (3) across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range that comprise the northwestern boundary of the analysis extent. The first two of these three zones with minimal departure encompass areas dominated by the Chihuahuan Desert Scrub CE; the last of the three zones with minimal departure encompasses areas dominated by the Pinyon-Juniper Woodlands CE.

11.2.2 Aquatic-Wetland Ecological System CEs

The REA evaluated the current conditions of the five aquatic-wetland ecological system CEs qualitatively through an examination of the spatial relationships between Change Agents and the five CEs, and quantitatively through analyses of five indicators: (1) the current versus likely historic extent of riparian habitat, (2) the current extent of modification or conversion of natural river/stream channel to artificial hydrologic features, (3) the current extent of water quality impairment as defined under state water quality standards, (4) the current versus historic distribution of sensitive native fish species, and (5) the current distribution of the Chihuahuan Desert amphibian assemblage. Most of these quantitative indicators pertain only to the rivers and streams, not to springs-emergent wetlands or playas and playa lakes. The summaries of the assessments of the six Change Agents, below address the spatial relationships between Change Agents and the five aquatic-wetland ecological system CEs.

A comparison of current generalized riparian vegetation cover types with estimated conditions prior to Euro-American settlement, i.e., reference conditions, indicates that the area of riparian vegetation within the analysis extent has declined by approximately 54%. Riparian vegetation has disappeared in some locations as a result of land development and/or altered hydrology, and has appeared or expanded around reservoirs and in irrigated locations. In particular, the data indicate extensive losses of riparian vegetation along the former riparian corridor of the Rio Grande from the vicinity of El Paso, Texas, northward and along the Pecos River riparian corridor from the vicinity of Roswell, New Mexico, northward. Other areas of prominent loss include: (1) the northwest flanks of Las Uvas Mountains, northwest of Las Cruces, New Mexico, where irrigated agricultural development has replaced riparian cover, and (2) an area of river meanders in the extreme southeastern-most corner of the ecoregion, east of the Pecos River. These latter patches represent areas of former riparian vegetation along the lower Devil's River.

The REA analyzed data on the extent of conversion of perennial stream and river channels into artificial features, either through mechanical modification or through inundation beneath a reservoir. The results indicate that more than 90% by length of both the Pecos River and the Rio Grande and nearly 64% of the length of the Gila River within the analysis extent consist of converted flow segments. Lowland-headwater perennial streams have experienced less modification overall (average 9% by length), but the percentage affected varies widely among the individual streams, from 0% along Independence and Leon Creeks to nearly 43% along San Francisco Creek. Montane-headwater perennial streams are moderately altered overall (average approximately 26% by length) but the percentage again varies widely among the individual streams, from 2% along Limpia Creek to nearly 61% along the Mimbres River. Overall, 52% of all Large River-Floodplain System and Montane- and Lowland-Headwater Perennial Stream channels today are artificial.

The three States covering the analysis extent have identified water quality impairments along essentially all of the New Mexico portion of Pecos River and roughly half the Texas portion within the analysis extent; along the Rio Peñasco, a Pecos River tributary that enters the mainstem from the west roughly half-way between the cities of Roswell and Carlsbad, New Mexico; along all of the Texas portion of the Rio Grande; along the entire length of Elephant Butte Reservoir along the Rio Grande in New Mexico; along Las Animas Creek, a Rio Grande tributary that enters the mainstem from the west near the lower end of Elephant Butte Reservoir; along the upper Mimbres River; and along the entire length of the Gila River mainstem within the analysis extent. New Mexico has also identified impairments along sections of Mangas Creek, a tributary to the Gila River, and small sections of two small streams (Three Rivers and an unnamed creek) flowing into the Tularosa Basin from the east. The Rio Grande in New Mexico, between Elephant Butte Dam and the Texas border, also would be considered highly impaired but for the fact that it runs dry much of the time and only supports irrigation (Hogan 2013).

The REA assessed the current (2000-2016) extent of distribution of six biogeographic groups of native fishes relative to their historic distributions, with the latter determined from records in a regional database of fish survey findings going back over a century. Five of the six biogeographic groups consist of "sensitive" fishes native to the Gila River, Mimbres River, Rio Grande, Tularosa, and Pecos River basins. The sixth group consists of fishes native to the Rio Grande and Pecos River basins together. The analysis defined "sensitive" fishes as species identified as imperiled or critically imperiled by the individual States, or listed as a Species of Greatest Conservation Need in the New Mexico or Texas Comprehensive State Wildlife Action Plan. The results, tabulated by 5th-Level watershed, indicate that 49% of the watersheds that historically supported species in these six sensitive native fish assemblages currently no longer support any of these species, and only 17% support all of their of their historic complements of species. In the worst instances, none of the watersheds within the analysis extent in the

Mimbres River basin support any members of its sensitive native fish assemblage, and only one of four watersheds within the Tularosa Basin still supports the sole member of its sensitive native fish assemblage. These results represent only species presence versus absence, not relative abundance. The fact that many of the species in these six groups are State-listed as imperiled or critically imperiled indicates they currently have greatly reduced abundances as well as constricted spatial distributions.

The REA assessed the distribution of four native amphibians identified based on their conservation status, to serve collectively as an additional indicator of ecoregional condition to answer MQ 2. The assemblage consists of the Arizona toad (*Anaxyrus microscaphus*), Chiricahua leopard frog (*Lithobates (*aka *Rana) chircahuaensis*), northern leopard frog *(L. pipiens*), and Yavapai leopard frog (*L. yavapaiensis*). No reference data were found on the historic distributions of these four species. The combined distribution of the four species within the analysis extent includes the Rio Grande floodplain, roughly northward from the vicinity of El Paso, Texas; the watersheds that make up the northwestern margins of the Rio Grande Basin in New Mexico; the Gila River mainstem and its tributary watersheds; western-most, lower-elevation watersheds of the Mimbres River Basin; and scattered locations in and along the eastern side of the Tularosa Basin and areas to its south in New Mexico and far western Texas, including the southern end of the Guadalupe Mountains. Two of the four species (Chiricahua leopard frog, northern leopard frog) occur along the Rio Grande floodplain, where they are vulnerable to habitat loss to development. On the other hand, all four species – particularly the Arizona toad and Yavapai leopard frog – also occupy habitat in less developed areas, and protected areas along the Rio Grande floodplain also provide safe harbors for the Chiricahua leopard frog and northern leopard frog.

11.2.3 Individual Species CEs

The REA evaluated the current conditions of the four individual species CEs only qualitatively, through an examination of the spatial relationships between Change Agents and the four CEs. The summaries of the assessments of the six Change Agents, below, address the spatial relationships between Change Agents and these four individual species CEs.

The assessment of vegetation departures from natural disturbance regimes across lands within the analysis extent (see discussions above and below) included the lands estimated to be occupied by each of the four individual species CEs (see the summaries of the assessments of the six Change Agents, below). The assessment provides information on the degree to which vegetation cover composition, structural stage, and canopy closure differs from estimated historic conditions prior to Euro-American settlement on lands within the estimated distributions of the four individual species. The results show that, across the areas in which pronghorn are estimated to occur, nearly 70% currently is moderately to highly disturbed. This metric is lower for mule deer, at 66%, but higher, 73%, for the black-tailed kangaroo rat and even higher, 79%, for the black-tailed prairie dog. The vegetation cover across the distributions of all four individual species CEs thus is moderately highly disturbed.

11.2.4 Species Assemblage CEs

The REA evaluated the current condition of the two species assemblage CEs only qualitatively, through an examination of the spatial relationships between Change Agents and the two CEs. The summaries of the assessments of the six Change Agents, below, address the spatial relationships between Change Agents and the two species assemblage CEs.

The assessment of vegetation departures from natural disturbance regimes across lands within the analysis extent (see discussions above and below) included the lands estimated to be occupied by each of the two species assemblage CEs (see the summaries of the assessments of the six Change Agents, below). The assessment provides information on the degree to which vegetation cover composition, structural stage, and canopy closure differs from estimated historic conditions prior to Euro-American settlement on lands within the estimated distributions of the two species assemblages. The results show that approximately 65% of the area in which the Grassland Bird Assemblage CE occurs, and approximately 71% of the area in which the Grassland Small Mammal Assemblage CE occurs, is currently moderately to highly disturbed. That is, the vegetation cover in these areas exhibits moderate to severe departure from reference conditions.

11.3 Change Agent Geographic Distributions and Impacts

11.3.1 Climate Change

Current climate was assessed for six seasonal and annual climate variables: the mean temperatures of the warmest and coldest quarters, annual mean temperature and mean annual precipitation, and the mean precipitation of the wettest and driest quarters. Average and extreme temperatures generally are higher in the southeastern-most portion of the region, including the area around the Rio Grande on the border between Texas and Mexico and Big Bend Ranch State Park in west Texas. In turn, average and extreme temperatures generally are cooler in the north near Socorro, New Mexico, in the west near Silver City, New Mexico, and in multiple mountain regions including the Chinati, Chisos, Davis, and Eagle Mountains and Sierra Diablo in Texas and the Organ, Oscura, and San Andres Mountains in New Mexico. The higher elevations of the mountain ranges in Texas do not appear to be as cool relative to their surroundings during the coldest quarter as do the higher elevations of the mountains in New Mexico.

Annual precipitation and precipitation during the wettest quarter show fairly similar patterns, with areas of higher rainfall roughly corresponding to areas with cooler temperatures. However, there are some differences between areas of higher rainfall and the areas of relatively cooler temperatures. For example, the relatively cooler area around Socorro, New Mexico, alongside the Rio Grande at 1,400 m elevation does not receive the higher levels of rainfall that fall in the slightly warmer Magdalena Mountains, which rise to nearly 3,000 m immediately to the west. The region of higher precipitation in western Texas is larger than the area of cooler temperatures in the same portion of the ecoregion, and encompasses some additional mountain ranges, including the Del Norte and Glass Mountains, both east of the Davis Mountains. Zones of higher precipitation also occur northeast of the Guadalupe Mountains and along the Rio Grande valley in the Big Bend region, the southernmost extension of the analysis extent. The latter zone receives higher rainfall during the driest quarter but has higher temperatures and lower rainfall during the wettest quarter.

These six climate variables affect ecological conditions, as discussed in the Pre-Assessment report (Unnasch et al. 2017). For example, black-tailed prairie dogs may have lower survival in years with lower precipitation. Scaled quail abundance is higher in areas with higher annual precipitation across the southern portion of the analysis extent, and the scaled quail may not tolerate extremely high temperatures. More generally, the three terrestrial ecological system CEs have distributions strongly affected by climate and its interactions with topographic elevation across the ecoregion: The Chihuahuan Desert Grasslands CE occurs at elevations and in topographic settings that tend to experience slightly less precipitation and slightly cooler temperatures than do areas at lower elevations in the U.S. portion of the ecoregion, which in turn are dominated by the Chihuahuan Desert Scrub CE. In contrast, the Pinyon-Juniper Woodlands CE generally occurs at higher elevations that experience slightly greater precipitation and slightly cooler temperatures compared to areas dominated by the Chihuahuan Desert Grasslands CE. The separation of grasslands from woodlands in the ecoregion reflects the impacts of precipitation patterns and long-term climate variations on fundamental aspects of plant physiology: The success of C_4 perennial grasses at low elevations depends on summer precipitation (Havstad and Schlesinger 2006), while C_3 shrubs in grasslands and woody species at higher elevations rely more on winter precipitation (see Unnasch et al. 2017, Chapters 5-7).

11.3.2 Development

The REA mapped the current distribution of development using detailed (30-m or vector) data on six broad categories of development: (1) residential, commercial, industrial, other non-agricultural development; (2) military and other secured-area development; (3) agricultural development; (4) energy production and mining development; (5) transportation and utility development; and (6) water control development. The results show all major and minor features of development across the analysis extent, including all areas of high-, medium-, and low-density residential, commercial, and industrial development; all areas of irrigated agriculture, both along and away from the large-river floodplains; reservoirs; transportation corridors; oil and gas development; and water wells and tanks.

The analysis extent includes one particularly prominent area of dense residential, commercial, and industrial development, located in the Las Cruces-El Paso-Ciudad Juarez area, which itself lies within a roughly 75 mile long continuous belt of intensive agriculture along the Rio Grande valley. Other prominent features along the Rio Grande include the inundated areas of Caballo and Elephant Butte Reservoirs and a belt of farming and residential, commercial, and industrial development roughly centered on the city of Socorro. A discontinuous belt of dense irrigation farming, residential, commercial, and industrial development, and reservoirs also occurs along the Pecos River valley from the vicinity of Roswell, New Mexico, southward to Red Bluff Reservoir, just south of the New Mexico-Texas border.

Patches of less dense residential, commercial, and industrial development mark all the other cities and towns in within the analysis extent, including substantial clusters around Deming and Alamogordo in New Mexico and a large cluster in the Pecos River valley in Texas that includes the communities of Kermit, Monahans, Pecos, and Fort Stockton. These clusters include some irrigation farming, as well. Additional areas of intensive irrigation farming include the mainstem Gila River straddling the Arizona-New Mexico border, the northwest flanks of Las Uvas Mountains, northwest of Las Cruces, and the lands surrounding Dell City, Texas. Prominent transportation corridors include Interstate Highways 10, 20, and 25 and other U.S. highways in all three states.

The analysis extent also includes a widespread distribution of numerous small points of development. This peppering of small points of development is particularly dense within and east of the Pecos River valley in both New Mexico and Texas. Many of these latter small points mark oil and gas wells and the network of roads and service features associated with oil and gas production from Permian Basin oil and gas fields. A few oil and gas wells are also present in Otero County, New Mexico. The small points of development across the analysis extent also include numerous small roads and dirt tracks, and numerous groundwater wells and watering tanks.

There are few large areas of very low development. These include the higher elevations of all mountain ranges; parts of the Big Bend region in Texas; lands south of Interstate Highway 10 in New Mexico between El Paso, Texas, and Deming, New Mexico; lands within the White Sands Missile Range and Fort Bliss Military Reservation; and the western margins of the Rio Grande valley in New Mexico.

Most residential, commercial, industrial, and irrigated agricultural development within the analysis extent occurs within areas formerly dominated by scrub or on lands formerly dominated by vegetation cover types other than the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs (see next paragraph). Alamogorda, Deming, and Silver City, New Mexico, may be exceptions to this overall pattern, with their residential, commercial, and industrial development largely encompassing areas formerly dominated by grasslands. Oil and gas development, in turn is concentrated in a part of the ecoregion largely dominated by scrub vegetation and cover types other than the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs. The only substantial exception to this relationship for oil and gas development is a zone of greater grassland cover in Texas immediately adjacent to and extending roughly south-southeast from the southeastern corner of New Mexico. This latter zone lies in an area of already intense oil and gas development.

Residential, commercial, industrial, and irrigated agricultural development has eliminated natural wetland and floodplain habitat along a large fraction of the Gila River, Rio Grande, and Pecos River riparian corridors and elsewhere within the analysis extent. Water consumption and water management systems associated with residential, commercial, irrigated agricultural, and industrial development, including oil and gas production, have altered surface water hydrology and groundwater storage. These factors largely account for the losses of riparian habitat noted above.

Development has not substantially eliminated habitat for any of the four individual species CEs. However, development does overlap or conflict with species habitat in several areas. Development along the west slope of the Sacramento Mountains, along the east side of the Tularosa Basin, overlaps with the distributions of all four individual species CEs, as does the large area of oil and gas production across southeastern New Mexico and western Texas. Development along the Pecos River valley in New Mexico, from Roswell to the New Mexico-Texas state border, overlaps with the distributions of the pronghorn and banner-tailed kangaroo rat, and with the mule deer, including “other important habitat” for the latter species. Similarly, development has not substantially eliminated habitat for any of the four individual species that comprise the Grassland Small Mammal Assemblage CE. However, because the overall distribution of the Grassland Small Mammal Assemblage CE covers so much of the analysis extent in Arizona and New Mexico, development has eliminated habitat for this CE in numerous portions of the analysis extent, including the large area of oil and gas production across southeastern New Mexico and western Texas.

11.3.3 Excessive Domestic Grazing

Livestock ranching in the U.S. portion of the ecoregion focuses on cattle ranching, with some sheep and goat ranching. Most grazing in Arizona and New Mexico takes place on public lands administered by the U.S. Forest Service and BLM, which control the spatial distribution and intensity of grazing through permits and leases for grazing on specifically designated lands, termed “allotments.” The present analysis uses data on the locations and boundaries of these grazing allotments. Most lands within the analysis extent in Texas are privately owned. Unfortunately, no systematic data were available on grazing intensity by allotment in Arizona and New Mexico, nor on the spatial distribution or intensity of grazing on private lands in any of the three states. Consequently, the REA could not assess how grazing intensity varies across the analysis extent, or how grazing intensity may be affecting any of the CEs. Nevertheless, some general comments are possible.

U.S. Forest Service and BLM grazing allotments cover almost the entire analysis extent across Arizona and New Mexico. Notable exceptions include military reservations, publicly protected areas, developed lands, and reservoirs, and private lands. Grazing allotments generally do not exclude other compatible land uses, such as oil and gas production or wind and solar electrical generation. The allotments within the analysis extent in Arizona and New Mexico include nearly every area of occurrence of the Chihuahuan Desert Grasslands CE; nearly every occurrence of the Montane-Headwater Perennial Streams, Lowland-Headwater Perennial Streams, and Springs-Emergent Wetlands CEs, and many Playas and Playa Lakes; significant fractions of the distributions of all four individual species CEs; and significant fractions of the distributions of the species that comprise the Grassland Bird and Grassland Small Mammal Assemblage CEs.

11.3.4 Invasive Species

Invasive plants are common across terrestrial habitats within the analysis extent, and both invasive plants and invasive animals are common or spreading among its aquatic-wetland habitats. The REA examined the spatial distributions of fourteen invasive plants across terrestrial habitats, after first selecting species identified during the Pre-Assessment phase of the REA (Unnasch et al. 2017) or identified by the BLM in New Mexico as particularly problematic, and then narrowing the list to species for which spatial data were available. Unfortunately, distribution data were available only at the county scale for these fourteen species. The plant species involved are highly invasive, and their presence anywhere in a county can reasonably be taken as evidence of their widespread presence. However, distributions mapped by county likely over-represent the extent of species distribution.

The county distribution data indicate that non-native grasses, such as cheatgrass, Lehmann lovegrass, and buffelgrass, occur widely throughout the analysis extent. The overlapped distributions of the fourteen assessed species cover every county within and overlapping the analysis extent many times over. However, the data are too spatially coarse to support a quantitative assessment of the extent to which these numerous non-native species have altered the composition, structure, or function of the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs in different parts of the analysis extent. Even without such regional-scale data, however, invasive plants are widely documented as ubiquitous – and often as ecologically disruptive – in all three terrestrial ecological system CEs, as discussed in detail in the Pre-Assessment report (Unnasch et al. 2017, Chapters 5-7).

The county distribution data also indicate that invasive terrestrial plants in general – not just invasive grasses – occur widely across the entire analysis extent, and consequently occur widely across the entire areas of distribution of all four individual species CEs and all of the species that comprise the Grassland Bird and Grassland Small Mammal Assemblages. However, the county records do not represent the results of systematic surveys to map the distributions of invasive species. As a result, it is not possible to assess how well they represent actual conditions that affect any individual species. The Pre-Assessment report (Unnasch et al. 2017) provides extended discussions of the ways in which invasive species potentially affect habitat quality and diet for each of individual native species.

The REA also examined the spatial distributions of four invasive plants and four invasive animals across aquatic-wetland habitats, after first selecting species identified during the Pre-Assessment phase of the REA (Unnasch et al. 2017) or identified by the BLM in New Mexico as particularly problematic, and then narrowing the list to species for which spatial data were available. Unfortunately, distribution data were available only at the county scale for three of the four plant species, two of which also appear on the list of species assessed across terrestrial habitats. The plant species involved are highly invasive, and their presence anywhere in a county can reasonably be taken as evidence of their widespread presence. However, as noted above, distributions mapped by county likely over-represent the extent of species distribution.

Aquatic-wetland invasive plants, notably Russian olive and tamarisk (aka saltcedar) are present throughout the analysis extent. They are widely regarded as threats to native ecological communities and to the hydrology of the aquatic-wetland communities they invade (see Pre-Assessment report, Unnasch et al. 2017, Chapters 8-11). Other invasive species affecting the aquatic-wetland ecological system CEs have more limited distributions. However, neither the county data nor the point data on the other plant and four animal species represent the results of systematic surveys to map the distributions of these invasive species. As a result, it is not possible to assess how well they represent actual conditions.

11.3.5 Uncharacteristic Wildfire

Wildfire historically and today plays a significant role in shaping the land cover of the U.S. portion of the ecoregion. As discussed in detail in the Pre-Assessment report conceptual ecological models for the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, and Pinyon-Juniper Woodlands CEs (Unnasch et al. 2017), fire frequency and intensity strongly affect vegetational succession, seed vitality among fire-adapted plant species, and nutrient cycling in all three terrestrial ecological system CEs. Invasive plant species may affect and be affected by wildfire patterns differently than native plant species. Changes to wildfire regimes among the three terrestrial ecological system CEs therefore have the potential to bring about significant changes in ecological system composition and distribution. The REA examined wildfire patterns in the U.S. portion of the ecoregion using data on: (1) the distribution of individual fires since 1985, both overall and in relation to each of the three terrestrial ecological system CEs; (2) vegetation departure from conditions expected under a historic fire regime, both overall and in relation to the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs; and (3) wildfire hazard potential.

Numerous wildfires burned within the analysis extent between 1985 and 2016. A large proportion of the burns covered both grasslands and adjacent pinyon-juniper woodlands within the same perimeter. Overall, between 1985 and 2016, 3% of the area of the Chihuahuan Desert Scrub CE, 7% of the Chihuahuan Desert Grasslands, and 12% of the Pinyon-Juniper Woodlands CE experienced one or more fires. Although woodlands and grasslands proportionally experienced more wildfire, several large and small burns involved scrub areas alone, particularly in the upper Pecos River valley in New Mexico and across a wide belt in Texas extending from the Chinati Mountains eastward to the REA boundary.

An assessment of vegetation departures from natural disturbance regimes provided information on the degree to which vegetation cover composition, structural stage, and canopy closure within the analysis extent differs from estimated historic conditions prior to Euro-American settlement. An earlier section of the present chapter (see Conservation Element Current Conditions, Terrestrial Ecological Systems) qualitatively summarized the results of this assessment. Quantitatively, the index of vegetation departure shows high values, largely but not exclusively a consequence of altered fire patterns, across most of the current distribution of the Chihuahuan Desert Grasslands CE. Over half of the total area of the Chihuahuan Desert Grasslands CE exhibits index values between 51 and 70%, with more than 76% exhibiting index values above 50%. The current distribution of Chihuahuan Desert Scrub CE includes several very large areas with index values less than 50%, as well as several very large areas with index values between 61 and 80% as well. As a result, more than 61% of all Chihuahuan Desert Scrub pixels have index values greater than 50%. Index values are mostly below 40% across the distribution of the Pinyon-Juniper Woodlands CE, with a secondary concentration of index values between 51 and 60%. Barely half of all Pinyon-Juniper Woodlands pixels have index values greater than 50%. These results indicate that fire regimes are less altered across areas of pinyon-juniper woodlands than across areas of scrub, and that fire regimes are most altered across grasslands within the analysis extent.

Wildfire regime alteration across the terrestrial ecological systems also has implications for the four individual species and two species assemblage CEs. The index of vegetation departure shows mostly high values across the areas in which the four individual species CEs occur. Nearly 70% of the area of current distribution of the pronghorn has index values > 50%, as do 66% of the area of distribution of the mule deer, 73% of the area of distribution of the black-tailed kangaroo rat, and 79% the area of distribution of for the black-tailed prairie dog. Similarly, the index of vegetation departure shows mostly high values across the areas in which the two grassland species assemblages occur. Approximately 65% of the area of distribution of the Grassland Bird Assemblage CE and nearly 71% of the area of distribution of the Grassland Small Mammal Assemblage CE have index values > 50%.

Values for the index of vegetation departure also are high among 30-m pixels classified as parts of Spring-Emergent Wetlands CE occurrences, with more than 53% exhibiting index values > 50%; and even higher across the areas classified as parts of the Playas and Playa Lakes CE occurrences, with more than 57% exhibiting index values > 50%. In contrast, index values are mostly relatively low across the areas classified as parts of Montane-Headwater or Lowland-Headwater Perennial Stream CE occurrences, with nearly 75% exhibiting index values ≤ 50%. Index values are only slightly higher across the areas classified as parts of Large River-Floodplain CE occurrences, with more than 60% exhibiting index values ≤ 50%. The discussion of MQ 3, below, summarizes additional information on the potential impacts of wildfire on aquatic-wetland ecological systems.

The REA used the "Wildfire Hazard Potential" (WHP) metric developed by the U.S. Department of Agriculture, Forest Service, Fire Modeling Institute (Dillon 2015, Dillon et al. 2015, USDA FS 2015) to assess "the relative potential for wildfire that would be difficult for suppression resources to contain." The WHP data indicate three areas within the analysis extent with high to very high potential: (1) across the Mogollon, San Mateo, and Magdalena Mountains and the Black Range foothills; (2) across a large portion of the upper Pecos River valley roughly from the vicinity of Roswell, New Mexico, northward; and (3) along the east side of the entire Tularosa Basin. Areas with moderate potential include the northwest flanks of the Davis Mountains in Texas, the crest of the Guadalupe Mountains in Texas and New Mexico, and scattered low mountain ranges in far southwestern New Mexico. The portion of the upper Pecos River valley with high values for the WHP metric also exhibits high values for the index of vegetation departure discussed above, but did not experience a significant number of wildfires between 1985 and 2016, particularly none with large perimeters. The WHP data thus show high to very high hazard potential almost exclusively across the higher elevations currently dominated by the Pinyon-Juniper Woodlands CE. The only exception to this pattern is the large area of high potential in the upper Pecos River valley, which is currently dominated by the Chihuahuan Desert Scrub CE. The assessment of MQ 3, summarized below, used the WHP data additionally to examine the potential impacts of wildfire on aquatic-wetland ecological systems.

Finally, the assessment of wildfire patterns sought to consider how invasive species and wildfire patterns may interact. Unfortunately, the invasive terrestrial plant spatial data available to this REA proved too coarse for such a quantitative comparison.

11.3.6 Landscape Restoration

The REA assessment of landscape restoration focused on data identifying the locations and types of restoration work carried out in Arizona and New Mexico. Comparable data were not available for Texas. The data for Arizona and New Mexico unfortunately do not provide systematic information on the effectiveness of restoration efforts. The REA assessment of the landscape restoration data for Arizona and New Mexico focused on the distribution of the three broad categories of chemical, prescribed fire, and physical (e.g., mechanical) treatments.

The land treatment data indicate that, among the three terrestrial ecological system CEs, chemical and physical (mechanical) treatments have been applied more often to the Chihuahuan Desert Scrub CE than to the other two terrestrial ecological systems CEs. Prescribed fire treatments have been applied roughly equally to the Chihuahuan Desert Grasslands and Chihuahuan Desert Scrub CEs. Areas dominated by the Pinyon-Juniper Woodlands CE receive the least attention, across all three treatment types. Among the five aquatic-wetland ecological system CEs, chemical and prescribed fire treatments have been applied heavily to Playas and Playa Lake CE occurrences, while prescribed fire and, especially, physical (mechanical) treatments have been applied heavily to the riparian corridors of large river-floodplain systems.

11.4 Climate Change and Development Forecasts

11.4.1 Climate Change Forecast

The REA carried out two quantitative assessments of the potential impacts of climate change on the CEs:

(4) A quantitative assessment of potential impacts of climate change on six climate variables across the current distributions of the three terrestrial ecological system CEs, the Black-Tailed Prairie Dog, all five species in the Grassland Bird Assemblage, and two members of the Grassland Small Mammal Assemblage (tawny-bellied cotton rat and yellow-nosed cotton rat). The six climate variables are: annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month, annual precipitation, precipitation of the wettest month, and precipitation of the driest month. This assessment compared historic conditions, 1950-2000, to forecasted conditions in two future bi-decadal periods, 2041-2060 (period mean, 2050), and 2061-2080 (period mean, 2070).

(5) Quantitative modeling to address two specialized questions: Where will climate change result in transitions in land cover from grass to shrub dominance, grass to woodland dominance, or vice-versa? Where will climate change result in shifts in grassland distribution (e.g., expand, contract, shift)? This assessment also compared historic conditions, 1950-2000, to forecasted conditions for 2061-2080 (period mean, 2070) only.

Additionally, the conceptual ecological models in the Pre-Assessment report (Unnasch et al. 20017) explicitly addressed the potential impacts of climate change on all CEs. The assessment of climate change in the present report includes a summary of the findings from the Pre-Assessment report conceptual models, concerning the potential impacts of climate change on the aquatic-wetland ecological system CEs.

The current areas of occurrence of all three terrestrial ecological system CEs, the Black-Tailed Prairie Dog, all five species in the Grassland Bird Assemblage, and the two assessed members of the Grassland Small Mammal Assemblage are all forecasted to experience increases in annual mean temperature, the maximum temperature of the warmest month, and the minimum temperature of the coldest month by 2050, with additional increases by 2070. Concurrently, the present areas of occurrence of all three terrestrial ecological system CEs, the Black-Tailed Prairie Dog, all five species in the Grassland Bird Assemblage, and the two assessed members of the Grassland Small Mammal Assemblage are all forecasted to experience decreases in annual precipitation, precipitation of the wettest month, and precipitation of the driest month by 2050, with additional decreases by 2070. The forecasted increases in the three temperature variables are all in the range of 2-3 °C by 2050, with an additional approximately 1 °C by 2070.

The forecasted decreases in annual precipitation are all in the range of approximately 16-20 mm by 2050, with further decreases by 2070 ranging from approximately 2 mm across the current distribution of the Chihuahuan Desert Scrub CE up to approximately 19 mm across the current distribution of the yellow-nosed cotton rat. The forecasted decreases in precipitation during the historically wettest month range from approximately 0.8 mm across the current distribution of the black-tailed prairie dog to approximately 5 mm across the current distribution of the yellow-nosed cotton rat by 2050. The forecast for precipitation during the historically wettest month range for 2070 indicates a slight amelioration in conditions across the ranges of the Chihuahuan Desert Scrub CE and the black-tailed prairie dog, with decreases of only approximately 0.6 to 0.7 mm relative to historic conditions. On the other hand, the forecast for precipitation during the historically wettest month for 2070 indicates a significant worsening of conditions for other CEs, with an additional 3 mm decrease across the current distribution of the yellow-nosed cotton rat. The forecasted decreases in precipitation during the historically driest month range from approximately 0.4 mm across the current distribution of the chestnut-collared longspur to approximately 1 mm across the current distribution of the yellow-nosed cotton rat by 2050. Conditions consistently worsen further by 2070 for precipitation during the historically driest month, with additional decreases of 0.1 mm across the current distribution of Baird's sparrow up to 0.5 mm across the range of the Pinyon-Juniper Woodlands CE.

The quantitative modeling of the impacts of climate change by 2070 on the distributions of grasslands, scrub, and woodlands forecasts that large areas of current grassland will transition to scrub cover, as will small areas of current pinyon-juniper woodlands. Other areas of pinyon-juniper woodlands will transition to grassland, with a resulting significant loss of pinyon-juniper woodlands throughout the U.S. portion of the ecoregion. However, the transitioning of some areas of pinyon-juniper woodlands to grassland will not result in large increases in the spatial extent of grasslands. As a result, grasslands are forecast to experience a large net decrease throughout the U.S. portion of the ecoregion as well. These forecasted changes in vegetation cover reflect the increases in temperature and decreases in precipitation, with the increased temperatures necessarily resulting in increased rates of evapotranspiration loss, further increasing moisture stress.

The conceptual ecological models developed for the Pre-Assessment report (Unnasch et al. 2017) indicate that the forecasted changes in temperatures, precipitation, and evapotranspiration would be expected to have significant effects on all five aquatic-wetland ecological system CEs. The forecasted changes in temperatures, precipitation, and evapotranspiration within the ecoregion – and across the watersheds of the Gila River, Rio Grande, and Pecos River outside the ecoregion – would be expected to result in reduced surface runoff, reduced groundwater recharge, the disappearance of snowfall and snowmelt as components of the water budget resulting in further changes in both the magnitude and timing of mountain runoff and recharge, a greater rates of evapotranspiration losses of water across water bodies and their associated aquatic-wetland and floodplain vegetation. These changes in turn would be expected to result in altered runoff and baseflow magnitudes, more rapid seasonal declines in water tables, and reduced wetted surface areas, with attendant significant impacts on aquatic and wetland habitat quality. However, the magnitudes of these impacts on the aquatic-wetland CEs are difficult to forecast, because the same changes in regional temperatures and precipitation will also affect people and their patterns of water management and use. Increases in water use and changes in water management will have their own, additional impacts on the aquatic-wetland CEs.

11.4.2 Development Forecast

The REA carried out a quantitative assessment of the potential impacts of future development on the CEs using data from the U.S. Environmental Protection Agency, Integrated Climate and Land Use Scenarios (ICLUS) project, Version 2 (USEPA 2009, 2016). The ICLUS methodology focuses on nine types of "developed" land cover, including parks and golf courses, low-density exurban land use, high-density exurban land use, suburban land use, low-density urban land use, high-density urban land use, commercial land use, industrial land use, and transportation infrastructure.

The ICLUS methodology includes modeling of the potential effects of climate change on future development. This modeling takes into account a range of climate forecasts and demographic and socioeconomic scenarios, along with information on the ways in which differences in climate – specifically differences in average monthly humidity-adjusted temperature and average seasonal precipitation for both summer and winter – affect migration between counties across the U.S.

The ICLUS results, across all climate forecasts and demographic and socioeconomic scenarios forecast substantial expansions of developed land between 2010 and 2050, with moderate further expansions between 2050 and 2070. Areas of greatest extent of expansion are forecasted to include areas in New Mexico around Silver City and Deming, around Las Cruces, around and along a corridor connecting Alamogorda and Carrizozo, and around Roswell; around El Paso and Del Rio, Texas; and along and close to the Interstate Highway 10 and Interstate Highway 20 corridors in Texas from their intersection at Kermit, Texas, eastward, including the area around Pecos, Texas.

Development along the Rio Grande, particularly in the region that includes both El Paso and Las Cruces, will take place in part through the conversion of irrigated agricultural lands to one of the aforementioned nine types of developed land use. Elsewhere, development largely is forecasted to expand into lands currently largely dominated by the Chihuahuan Desert Scrub CE. However, the areas of forecasted development in far western New Mexico around Deming and Silver City, and along the U.S. Highway 54 corridor from Alamogorda north to Carrizozo along the east side of the Tularosa Basin, also in New Mexico, are exceptions. In these latter areas, residential, commercial, and industrial development is forecasted to substantially encroach on existing areas of the Chihuahuan Desert Grassland CE. These expansions of development into terrestrial ecological system habitats will encroach on habitat for all four individual species CEs and both species assemblage CEs, but the areas involved will be small relative to the total areas of current distribution of these CEs.

The REA did not include a quantitative, geospatial forecast of oil and gas development. However, the amounts of oil and gas predicted to be available within the Permian Basin under existing and emerging technologies, changes in oil and gas field development technologies, and continuing demand for both oil and natural gas, all strongly predict that oil and gas production will continue to expand spatially within the analysis extent. This development currently is concentrated in a part of the ecoregion largely dominated by scrub vegetation and cover types other than the Chihuahuan Desert Grasslands, Chihuahuan Desert Scrub, or Pinyon-Juniper Woodlands CEs. The only substantial exception to this relationship is a zone of already intense oil and gas development in an area dominated by grassland cover in Texas immediately adjacent to and extending roughly south-southeast from the southeastern corner of New Mexico. The geology of the Permian Basin will confine future development of oil and gas resources roughly within the outer perimeter of the present overall geographic extent of such development. However, some areas of oil and gas production within the analysis extent lie outside the boundaries of the Permian Basin

11.5 Management Questions

MQ 1: Where have restoration treatments been applied to dry-system CEs, and what is the status (e.g., success rate) of those treatments?

The REA sought to address MQ 1 through the analysis of landscape restoration data, as discussed above (see Change Agent Geographic Distributions and Impacts, Landscape Restoration, this chapter). However, as also noted above, the available data supported an assessment of where different types of treatments have been applied but not any analysis of the effectiveness of these different treatments.

MQ 2: What is the geographic distribution of the Chihuahuan desert amphibian assemblage?

The REA examined the geographic distribution of sensitive Chihuahuan desert amphibians as part of its assessment of indicators of the condition of aquatic-wetland ecological systems, presented above (see Conservation Element Current Condition, Aquatic-Wetland Ecological System CEs, this chapter).

MQ 3: Where would uncharacteristic wildfire likely increase sedimentation and loss of habitat among the wet systems?

The REA addressed MQ 3 in four steps. First, the REA identified soils that potentially would be highly erodible following intense wildfire, based on the U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey (USDA NRCS 2017a) data on “Erosion factor K.” This variable provides an index of the susceptibility of soils to sheet and rill erosion based primarily on percentage of silt, sand, and organic matter and on soil structure, slope, and saturated hydraulic conductivity. The REA focused specifically on a sub-type of Erosion factor K, designated Erosion factor “Kw,” that addresses susceptibility for the entire soil profile, including rock fragments.

Second, as discussed above (see Change Agent Geographic Distributions and Impacts, Uncharacteristic Wildfire, this chapter), the REA tabulated data for the analysis extent for the “Wildfire Hazard Potential” (WHP) metric developed by the U.S. Department of Agriculture, Forest Service, Fire Modeling Institute (Dillon 2015, Dillon et al. 2015, USDA FS 2015). These data provide a means for identifying areas with a high relative potential for wildfire that would be difficult to suppress or contain.

Third, the REA identified 5th-Level watersheds that meet two criteria: (1) Kw > 0.24 (roughly the median Kw value for the analysis extent) over > 10% of the watershed area, and (2) WHP = Moderate, High, or Very High over > 10% of the watershed area. Based on the definitions of Kw and WHP, the REA proposed these watersheds as catchments with high risks of severe wildfire, across which the elimination of ground cover by such severe wildfires could result in significant soil erosion during subsequent runoff events. The resulting erosion could then potentially result in sedimentation and loss of habitat among aquatic-wetland ecological system occurrences into which the runoff flows.

Finally, the REA identified those 5th-Level watersheds that met the above two criteria, that also contain occurrences of any of the aquatic-wetland ecological system CEs. This step identified several occurrences of the Montane- and Lowland-Headwater Perennial Stream and Playa-Playa Lake CEs that lie within the watersheds that meet the two aforementioned criteria, including: Blue Creek, flowing into the Gila River from the north; catchments affecting the Lordsburg and Playas Lake playa complexes in far western New Mexico; the upper Mimbres River; Alamosa, Cuchillo Negro, Palomas, Seco, and Percha Creeks, flowing into the Rio Grande from west, from the Black Range; the headwaters of Three Rivers, Tularosa Creek, and Lost River, flowing westward out of the Sacramento Mountains in the Tularosa Basin toward the basin's large playa-playa lake complex; Arroyo del Macho, Salt Creek, and Rio Hondo, flowing eastward out of the Sacramento Mountains into the Pecos River; and Limpia Creek, flowing westward out of the Davis Mountains.

MQ 4: What areas of potential black-tailed prairie dog habitat would support restoration?

The REA addressed MQ 4 by identifying locations (30-m pixels) within the analysis extent that meet four criteria: (1) The current ground cover at the location consists of grassland, including not only the Chihuahuan Desert Grassland CE but other types of grassland such as Western Plains grasslands, which the black-tailed prairie dog may inhabit as well; (2) the location falls within the species range but (3) does not fall within the current distribution of the species, indicating unoccupied habitat; and (4) the location is not developed. That is, the assessment defined "areas of potential black-tailed prairie dog habitat potentially could support restoration" as locations within the species range with grassland as the dominant cover type that are not already occupied and are not developed.

The results indicate a substantial concentration of areas with restoration potential in the far west of the analysis extent, from the western margins of the Rio Grande valley westward to the far edge of the analysis extent in New Mexico but not significantly into Arizona. An arc of substantial areas potentially suitable for restoration extends eastward from the foothills of the Davis Mountains to the eastern edge of the analysis extent in Texas. Other areas of potential interest exist east and southeast of the vicinity of Kermit, Texas, and southeast to southwest of Carlsbad, New Mexico. Resource managers presumably would apply additional criteria to narrow down the resulting pool of locations, possibly including factors such as distance from local threats, accessibility for restoration and protection, available contiguous area, and others.

MQ 5: Where are the areas of greatest faunal species biodiversity among the species and species-assemblage CEs taken together?

The REA addressed MQ 5 by tabulating the combined distribution of the thirteen species that comprise all of the individual species and species assemblage CEs taken together: pronghorn, mule deer, banner-tailed kangaroo rat, black-tailed prairie dog, Arizona grasshopper sparrow, Baird's sparrow, Cassin's sparrow, Chestnut-collared longspur, scaled quail, hispid cotton rat, Southern Plains woodrat, tawny-bellied cotton rat, and yellow-nosed cotton rat. At the request of the AMT, the REA also included in the assessment of MQ 5 the four species that comprise the Chihuahuan Desert amphibian assemblage discussed above (see Conservation Element Current Condition, Aquatic-Wetland Ecological System CEs, this chapter): Arizona toad, Chiricahua leopard frog, Northern leopard frog, and Yavapai leopard frog.

The REA tabulated the total number of species among these seventeen species with a current distribution within the analysis extent that includes each 30-m pixel, based on the data used to map the distributions of these species for the present REA. Such a tabulation measures species richness. Species richness in this analysis ranges from a low of 0 to a high of 13. The results indicate that species richness is highest in the far west of the analysis extent in Arizona and New Mexico, in an areas corresponding roughly to Hidalgo and western Grant County, New Mexico. Species richness in fact is high across most lands between Las Cruces, New Mexico and the Arizona border, although with several included patches of very low richness. An area of widespread, consistently high species richness occurs within the Fort Bliss Military Reservation in New Mexico, extending southward from the foothills of the Sacramento Mountains toward and presumably into Texas, as well. In turn, species richness is lowest across all higher elevations, in the vicinities of all heavily developed areas in New Mexico within the analysis extent, and across barrens in the Tularosa Basin and the Jornada del Muerto valley east of Socorro, New Mexico.

MQ 6: Where will urban and industrial growth impact intact grasslands or impede their recovery?

The REA addressed MQ 6 as part of its assessment of the ICLUS forecasts of development and the spatial relationships of areas of forecast development with the current distribution of the Chihuahuan Desert Grasslands CE, discussed above (see Climate Change and Development Forecasts, this chapter).

MQ 7: How do the current and historic geographic distributions of the dry-system CEs differ?

The REA addressed MQ 7 as part of its assessment of the current conditions of the three terrestrial ecological system CEs, discussed above (see Conservation Element Current Condition, Terrestrial Ecological System CEs, this chapter).

MQ 8: How will urban and industrial growth alter the geographic distribution of the grassland bird assemblage?

The REA addressed MQ 8 as part of its assessment of the ICLUS forecasts of development and the spatial relationships of areas of forecast development with the current distribution of the Grassland Bird Assemblage CE, discussed above (see Climate Change and Development Forecasts, this chapter).

MQ 9: What and where are the aquifers and their recharge zones that support the wet systems?

Systematic data were not located on the specific aquifers that have been shown to supply the groundwater to the perennial streams, large rivers, springs, or playa lakes within the U.S. portion of the ecoregion. Hydrogeological studies have identified the aquifers that support particular aquatic-wetland resources, but only on a case-by-case basis. Such studies also often show that surface geology and topography do not consistently provide reliable clues to the locations of the aquifers or recharge zones for individual groundwater flow paths. These flow paths often appear to depend on the presence and orientation of bedrock fault and fracture systems that act as either barriers or conduits to groundwater movement. The resulting patchwork of local studies does not lend itself to the kind of geospatial analysis appropriate for an REA. At most, such studies identify the aquifers and groundwater flow paths that support only a handful of the river or stream reaches or springs and emergent wetlands in the ecoregion. As a result, the REA could not directly address MQ 9.

However, groundwater recharge occurs in a generally well understood geographic pattern in the region. Mapping this pattern provides guidance on where recharge may be vulnerable to the effects of change agents. Specifically, groundwater recharge in the Southwest takes place in two general settings. First, recharge takes place across mountain ranges and their foothills because these are zones of greater precipitation and lower rates of evapotranspiration, often with coarser soils that allow for greater rates of infiltration. Recharge rates in these settings vary with the amount of precipitation received, whether the precipitation occurs as rain or snow (melting snow recharges more effectively than does rainfall), and air temperature through its effect on evapotranspiration. Second, recharge also takes place at lower elevations, focused along stream and river courses and across their floodplains, and along permeable irrigation ditches, whenever the water table lies lower than the elevation of the surface water along these flow paths, i.e., during runoff and flood events and during irrigation delivery and return flows. Recharge rates in these latter settings vary with the amount of water present (e.g., from runoff) and air temperature through its effect on evapotranspiration.

The REA mapped these two general settings for recharge in the U.S. portion of the ecoregion based on the types of vegetation associated with these geophysical settings. The REA mapped areas of mountain recharge based on the distribution of conditions suitable for montane conifer and hardwood woodlands, which also require the greater magnitudes of precipitation and cooler temperatures that occur in these orographic settings. The REA mapped areas where focused, lower-elevation recharge may occur based on the distribution of conditions suitable for riparian vegetation. The data sources for these distributions consisted of models for the distributions of conifer and hardwood woodlands and riparian vegetation in the ecoregion prior to Euro-American settlement, based on their geophysical requirements.

The results identify multiple recharge areas within the analysis extent. These include the Sacramento Mountains, recharge across which is estimated to support groundwater flows to the Tularosa Basin, the Salt Basin immediately west of the Guadalupe Mountains (Huff and Chace 2006, Szynkiewicz et al. 2012, Sigstedt et al. 2016), and Bitter Lake National Wildlife Refuge (Land and Huff 2010, Partey et al. 2011). The results also include the Guadalupe and Davis Mountains, recharge from which is estimated to support groundwater flows to numerous springs in west Texas (Sharp et al. 2003), including the San Solomon Spring complex in the Toyah Creek watershed (Chowdhury et al. 2004); and the mountains in the extreme west of the U.S. portion of the ecoregion in both New Mexico and Arizona, recharge from which supports the groundwater systems of the Animas and Lordsburg Basins and their associated playas (Johnson and Rappuhn 2002). The results also correctly identify the Rio Grande along the Mesilla Valley as a large area of focused recharge for both river and irrigation water that also receives some groundwater from surrounding bedrock aquifers recharged in the adjacent mountain ranges (Hogan 2013; see also Szynkiewicz et al. 2015a, 2015b).

MQ 10: How do the current and historic geographic distributions of the Pecos River and Gila River fish assemblages differ?

The REA addressed MQ 10 as part of its assessment of the current conditions of the perennial stream and large river-floodplain system CEs, discussed above (see Conservation Element Current Condition, Aquatic-Wetland Ecological System CEs, this chapter).

MQ 11: Where are the breeding, winter, and year-around habitats for pronghorn and mule deer?

The REA sought to address MQ 11 by seeking systematic geospatial data with which to differentiate breeding, winter, and year-round habitats for these two species. Unfortunately, the REA could not locate appropriate datasets for this purpose.

MQ 12: Are there areas where invasive plants are being killed on a broad scale (e.g., by the tamarisk leaf-eating beetle) where managers need to focus on restoration or controlling succession?

The REA focused this MQ specifically on the distribution of tamarisk beetles (*Diorhabda* spp.) across the analysis extent and its impact on their target plant, the tamarisk or salt cedar. Data maintained and provided by the Tamarisk Coalition (2016; http://www.tamariskcoalition.org/) indicate that first observations of tamarisk beetles within the analysis extent date to 2010 along the Rio Grande in the Big Bend region. The beetle population then expanded along the Rio Grande and Pecos River and some of their tributaries as well as into the Tularosa Basin in 2012-2014; and expanded again in 2016 within the Tularosa Basin, along the Rio Grande, and westward toward the Arizona border. The data maintained by the Tamarisk Coalition for each year indicate locations where beetles previously had occurred but were no longer present in that year. The data provided by the coalition are current through 2016, and therefore include all locations where the beetle was absent in 2016 after having been observed in those locations in 2015. The “absence” locations in the 2016 data fall within the Tularosa Basin and along the Rio Grande and Pecos River potentially. Such locations indicate sites where the beetles have at least temporarily exhausted the supply of salt cedar on which they feed and thereby defoliate. The beetles potentially could also soon exhaust the supply of salt cedar in adjacent locations where they have fed for multiple years. Managers could target such sites of completed or imminent defoliation as areas potentially warranting restoration or efforts to control succession. However, the beetles can return quickly to locations where the salt cedar has recovered following prior defoliation by the beetles.

Consequently, the data on absences in 2016 may no longer provide the best guidance on areas of particularly severe defoliation in 2017.

MQ 13: What is the current geographic distribution of the impacts of gypsum in the soil and water, in general and in relation to each CE and CA?

The REA did not locate any single systematic geospatial database on the distribution of gypsic soil and water conditions across the U.S. portion of the ecoregion. Instead, the REA compiled and qualitatively tested a spatial model of this distribution. The model builds on a substantial body of reports documenting a strong relationship between the bedrock geology of the ecoregion and the distribution of gypsic geologic, geochemical, soil, and watershed conditions across the U.S. portion of the ecoregion. This relationship, together with the availability of data on the distributions of gypsum- and anhydrite-bearing geologic formations and gypsic soils across the U.S. portion of the ecoregion, makes it possible to assess the geographic distribution of localities where gypsic geochemical, soil, and watershed conditions may affect ecological conditions and resources.

The REA identified all geologic formations included in state geology map databases for New Mexico and Texas, for which the published information indicated the presence of gypsum and/or anhydrite. The analysis extent in Arizona does not include any such formations. The REA also tabulated the mineralogy data in the U.S. Department of Agriculture, Natural Resources Conservation Service, STATSGO2 soils database (Soil Survey Staff 2016, USGS NRCS 2017B), for all soil types that occur within the analysis extent. The database classifies soils based on their percent of gypsum by dry weight, but does not distinguish soils based on the presence or concentration of anhydrite. The REA then also copied a map prepared by Moore and Jansen (2007) showing the distribution of gypsophilous plant species across a broad region that encompasses the U.S. portion of the Chihuahuan desert ecoregion, and transformed the scale and projection of this map so that it could be compared directly with the distribution of potentially gypsic ground and water conditions across the analysis extent. The REA found that the distribution of 5th-Level watersheds containing soils with percent gypsum > 1% and/or surface exposures of any gypsic or anhydric geological formations closely matched the distribution of gypsophilous plants identified by Moore and Jansen (2007). The distributions of all CEs were then compared to the resulting map of watersheds, to visually assess the spatial relationships – if any – between these two distributions.

Watersheds with percent soil gypsum > 1% and/or with surface exposures of gypsic and/or anhydric geologic formations span most of the New Mexico portion of the Pecos River basin and much of the Texas portion, including almost all watersheds originating in the Guadalupe, San Andres, Oscura, Davis, Glass, Chinati, and Chisos Mountains. The only substantial portions of the analysis extent not included in these watersheds are the plains east of the Pecos River in Texas, the plains east of the Pecos River in extreme southeastern New Mexico, and most of the ecoregion west of the Rio Grande. Current ground cover across these watersheds largely consists of the Chihuahuan Desert Scrub and Chihuahuan Desert Grasslands CEs, although some gypsic watersheds reach into higher elevations dominated by the Pinyon-Juniper Woodlands CE. Grasslands are more common in affected watersheds to the north, but grasslands are more common across the northern portions of the analysis extent in general. It should be noted that, as Moore and Jansen (2007) discuss, gypsophilous plants in the region tend to occur only in discrete patches with locally elevated soil gypsum levels within larger areas of grasslands and shrublands. The geologic and soils data appropriate for a rapid ecoregional assessment are not suitable for identifying such local soil patches. The data developed for the present REA provide the basis only for identifying watersheds within which such patches are likely to occur.

11.6 Recommendations on Data Gaps and Weaknesses

The individual chapters of this report, and their findings summarized above, this chapter, identify several gaps and weaknesses in the data available for the present REA. Eliminating or reducing these gaps and weaknesses would enhance the abilities of resource management agencies to manage the ecological resources of the ecoregion.

11.6.1 Conservation Elements

The data available on the distributions of the aquatic-wetland ecological system CEs did not include information with which to categorize spring types based on their hydrology or geochemistry, including the aquifers that supply each spring. Management concerns for individual springs may vary with such factors. The data available on the distributions of the aquatic-wetland ecological system CEs did not include or distinguish sinkholes or cenotes as a groundwater-fed ecological resource type. Such features exist across the northeastern quadrant of the analysis extent because of its distinctive karst geology, and ecological studies indicate they can harbor diverse aquatic and wetland communities.

Systematic geospatial data on the distributions of most individual species CEs and the species that comprise the Grassland Small Mammal Assemblage CE were not available for Texas, limiting some analyses in this REA to the analysis extent within only Arizona and New Mexico. The National Gap Analysis Program (USGS-GAP 2005, 2011, Gergely and McKerrow 2013) are preparing species data for Texas. Systematic geospatial data are also lacking on seasonal occurrences of both pronghorn and mule deer. More generally, as discussed in Chapters 9 and 10 of the present report, the mapped distributions of individual species used in this REA are not based on systematic ground-level observations of these species in each individual grid unit included in these maps. Instead, these mapped distributions are models of *"… the spatial arrangement of environments suitable for occupation by a species. In other words, a species distribution is created using a deductive model to predict areas suitable for occupation within a species range…. It should be noted that all our range and distribution models are predictions about the occurrence of a species within the U.S. GAP ranges and distribution models are intended for use at the landscape scale (i.e., areas the size of square kilometers). They are not intended to be precise predictions of species occurrence/absence at local scales (areas the size of square meters). It is important for GAP data users to evaluate the suitability of the data for their intended purpose…"* Validation and/or refinement of the available distribution data would require systematic surveys on the ground.

The conceptual ecological models developed for the Pre-Assessment report (Unnasch et al. 2017) identified several key ecological attributes for each CE, systematic geospatial data on which would provide a basis for assessing the condition of each CE. The REA was not able to locate systematic geospatial data on indicators for the vast majority of these key ecological attributes, particularly for the terrestrial ecological system CEs and the species CEs and species assemblage CEs within them. As a result, the present REA mostly focuses on indirect information on CE condition, specifically information on the distributions of the CAs relative to the CEs.

11.6.2 Change Agents

A spatially explicit forecast of oil and gas development covering the entire analysis extent for the present REA would benefit ecological resource managers. The available forecast for southeast corner of New Mexico (Engler et al. 2012, Engler and Cather 2012) provides a comprehensive template for such a larger-scale forecast. Assessment of the impacts of livestock grazing would be enhanced by the systematic availability of data on actual grazing intensities.

The availability of only county-level data on the distributions of invasive plants limited the ability of the REA to assess the impacts of these species on the native ecological resources of the ecoregion. County-level data are spatially too coarse to be of much use for management, and depend on voluntary reporting, the completeness of which cannot be evaluated. The point data used to examine the distributions of invasive species in aquatic-wetland settings also have clear weaknesses. The data also depend on voluntary reporting, the completeness or accuracy of which cannot be evaluated. Closing such gaps in knowledge would require systematic ground surveys, with the results fed into a digital database. The database on landscape restoration treatments assessed in the present REA for Arizona and New Mexico did not include information on the purposes or effects of individual treatments, or any data on treatments in Texas. The costs of developing and maintaining these kinds of information in a digital database could be substantial.

11.6.3 Models of Recharge Zones and Gypsic Conditions

The REA developed data models to represent two types of areas, for which there were no existing datasets: a model of the distribution of recharge zones for groundwater in the ecoregion, and a model of the distribution of gypsic soil and surface water conditions. Both models would benefit from field studies to help fine-tune and validate their designs.

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13 Glossary

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.

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 an ecological community or system relative to its known, or predicted historical range of variability.

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.

Analysis Extent: Every REA addresses an area slightly larger than its Level-III ecoregion(s), termed the "analysis extent," that includes all watersheds that overlap the Level-III boundaries. The analysis extent for the Chihuahuan Desert REA overlaps with the analysis extents for the Madrean Archipelago and Southern Great Plains REAs.

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 (LANDFIRE 2016).

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, Grid Unit: 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.

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 5^{th} and 6^{th} levels. (Seaber et al. 1987).

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 invasive (modified from BLM Handbook 1740-2, Integrated Vegetation Handbook. (BLM 2008)

Key Ecological Attribute: Key ecological attributes include defining physical, biological, and ecological characteristics of a Conservation Element, along with its abundance and/or spatial distribution. When one or more key ecological attributes of a CE become stressed in a specific setting, i.e., are altered so that they depart significantly from long-term historic conditions, the entire Conservation Element in that setting is degraded or, in extreme circumstances, will disappear. A well-constructed conceptual model for a Conservation Element necessarily identifies a *limited* set of key ecological attributes to represent the overall condition of the CE. Ecosystem complexity, the limits of scientific knowledge, and the constraints of budgets prevent evaluation of all possible characteristics and processes of any single resource. The key ecological attributes identified in the conceptual ecological models for the fourteen Conservation Elements for the Chihuahuan Desert REA served as crucial guides for identifying datasets for analysis during the Assessment phase of the REA.

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.

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 2001).

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

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.)

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, Grid Unit*).

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).

Status: Formally, the Global or State conservation status of a species (e.g., “extinct,” “vulnerable,” “threatened,” etc.). Informally, the presence/absence, abundance, or other measure of the condition of an ecological resource relative to some reference condition.

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.

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 (see Hydrologic Unit).

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 (LANDFIRE 2016).

14 Acronyms

AFMSS	Automated Fluid Mineral Support System
AMT	Assessment Management Team
ASR	Antenna Structure Registration
AUC	Area Under the ROC (Receiver Operating Characteristic)
AUC_{Test}	Area Under the Curve for Test Data
BLM	Bureau of Land Management
CA	Change Agent
CDIMN	Chihuahuan Desert Inventory and Monitoring Network
CE	Conservation Element
CMIP5	Coupled Model Inter-comparison Project
COG	Council of Governments
EDDMapS	Early Detection and Distribution Mapping System
EPA	Environmental Protection Agency
ESM	Earth System Model
EVC	Existing Vegetation Cover
EVH	Existing Vegetation Height
EVT	Existing Vegetation Type
FIA	Forest Inventory Analysis
FPA	Fire Program Analysis
FSim	Large Fire Simulator
GAP	Gap Analysis Program
GCM	Global Climate Models
GIS	Geographic Information Systems
GISS	Goddard Institute for Space Studies
GNIS	Geographic Names Information System
gSSURGO	Gridded Soil Survey Geographic Database
GTLF	Ground Transportation Linear Features
HadGEM2-ES	Hadley Centre Global Environment Model version 2 Model ES
HGL	Hydrocarbon Gas Liquids
HUC	Hydrologic Unit Code
IBWC	International Boundary Waters Commission
ICLUS	Integrated Climate and Land Use Scenarios
IUCN	International Union for Conservation of Nature
Kw	Whole-soil K factor
LCC	Landscape Conservation Cooperative
LHP	Lowland-Headwater Perennial
MAF	Master Address File
MESS	Multivariate Environmental Similarity Surface

MHP	Montane-Headwater Perennial
MPI	Max Planck Institute for Meteorology
MQ	Management Question
MRDS	Mineral Resources Data System
MRLC	Multi-Resolution Land Characteristics
MTBS	Monitoring Trends in Burn Severity
MTFCC	MAF/TIGER Feature Class Code
MVEDA	Mesilla Valley Economic Development Alliance
NAS	Nonindigenous Aquatic Species
NASS	National Agriculture Statistics Service
NCLD	National Land Cover Database
NECI	National Centers for Environmental Information
NED	National Elevation Dataset
NESDIS	National Environmental Satellite Data and Information Service
NGP	National Geospatial Program
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NMAWSA	New Mexico-Arizona Water Settlement Act
NMDGF	New Mexico Department of Game and Fish
NMEMNRD	New Mexico Energy, Minerals and Natural Resources Department
NMOGA	New Mexico Oil and Gas Association
NMOSE	New Mexico Office of the State Engineer
NPS	National Park Service
NRCS	Natural Resource Conservation Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCP	Representative Concentration Pathways
REA	Rapid Ecoregional Assessment
RFD	Reasonable Forseeable Development
ROW	Rights-Of-Way
RUSLE	Revised Soil Loss Equation
SAHM	Software for Assisted Habitat Modeling
SENM	Southeast New Mexico
SENMEDD	Southeast New Mexico Economic Development District
SGCN	Species of Greatest Conservation Need
SSI	Springs Stewardship Institute
SSP	Shared Socioeconomic Pathways
STATSGO	State Soil Geographic Database
TIGER	Topologically Integrated Geographic Encoding and Referencing
TM	Thematic Mapper
TNRIS	Texas Natural Resources Information System

TSS	True Skills Statistics
TWDB	Texas Water Development Board
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USEIA	U.S. Energy Information Administration
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
USFWS	U.S. Fish and Wildlife Service
VDEP	Vegetation Departure Data
VDIST	Vegetation Disturbance (LANDFIRE 2016)
WAFWA	Western Association of Fish & Wildlife Agencies
WHP	Wildfire Hazard Potential
WIPP	Waste Isolation Pilot Plant
WRCC	Western Regional Climate Center

U.S. Department of the Interior
Bureau of Land Management

Data Request Method

Rapid Ecoregional Assessments (REAs)—National Operations Center, CO

Individual REA data layers and some other products are still available but are no longer being published.

If you would like to obtain more information, including data and model zip files* (containing Esri ModelBuilder files for ArcGIS 10.x and relevant Python scripts), please email **BLM_OC_REA_Data_Portal_Feedback_Team@blm.gov**.
*Note that a few models require software that BLM does not provide such as R, Maxent, and TauDEM.

Models associated with individual REAs may require data links to be updated to function properly. REA reports, technical appendices, and model overviews (for some REAs) contain detailed information to determine what products are available and what datasets are necessary to run a certain model.

Please include the report name and any specific data information that you can provide with your request.

Other BLM data can be found on the Geospatial Business Platform Hub (https://gbp-blm-egis.hub.arcgis.com).