Managing Changing Landscapes in the Southwestern United States

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Managing Changing Landscapes in the Southwestern United States

A Report by
The Southwest Climate Change Initiative
of The Nature Conservancy

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In collaboration with

CLIMAS
Climate Assessment for the Southwest

WILDLIFE CONSERVATION SOCIETY

FOREST SERVICE
US
DEPARTMENT OF AGRICULTURE

UNIVERSITY OF WASHINGTON

The Southwest Climate Change Initiative

The Nature Conservancy established the Southwest Climate Change Initiative in 2008 to assess the impacts of climate change on natural resources in the Southwest. The goal of the Initiative is to provide information and tools to natural resource managers and conservation practitioners for climate adaptation in vulnerable landscapes in Arizona, Colorado, New Mexico and Utah.

For more information, please see www.nmconservation.org.

Acknowledgments

The authors would like to thank Evan Girvetz, formerly with the University of Washington and now with The Nature Conservancy, for conducting the climate change analyses in this report and for providing technical expertise and practical insights. We thank Dan Majka of The Nature Conservancy for developing the report layout and formatting. We thank Jason McNees and Patrick Comer of NatureServe for providing habitat and species data used in this report. Patrick McCarthy, Laura McCarthy, Dave Gori, Terry Sullivan, Betsy Neely, Tim Sullivan, Joel Tuhy, Ann Wallach Thomas, Gregg Garfin, Rob Marshall, Gita Bodner and Ed Smith provided critical review of this report.

Executive Summary

Natural landscapes in the Southwestern United States are changing. In recent decades, rising temperatures and drought have led to drier conditions, contributed to large-scale ecological impacts, and affected many plant and animal species across the region. The current and future trajectory of climate change underscores the need for managers and conservation professionals to understand the impacts of these patterns on natural resources. In this regional assessment of the Southwest Climate Change Initiative, we evaluate changes in annual average temperatures from 1951–2006 across major habitats and large watersheds and compare these changes to the number of species of conservation concern that are found within these places.

We found that *90% of habitats in the Southwest have warmed significantly in the past 55 years.* Along with other factors, warming very likely contributed to ecological changes in 40% of Southwestern habitats, including changes in the timing of species events, increases in wildfire activity, widespread insect infestations and forest tree mortality. Those habitats with the highest temperature change and the most species of conservation concern include subalpine forests, piñon-juniper woodlands, sage shrublands, and Colorado Plateau canyonlands and grasslands. At least 119 plant and animal species within these habitats have been affected by climate change.

Resource managers and conservation professionals now possess sufficient knowledge to begin adapting to climate change

Additionally, we found that *70% of the watersheds in the Southwest have warmed significantly.* Hydrological changes associated with recent warming, including reductions in snowpack and earlier peak stream flows, have already been observed in 50% of these watersheds. Warming has been most pronounced within the watersheds that comprise the Colorado River Basin, a regional center for native fish diversity that hosts a number of world-renowned national parks and tourist destinations and supplies water for four major cities in the Southwest.

Given that contemporary scientific studies confirm and global climate models project that our environment is becoming drier and warmer, resource managers and conservation professionals now possess sufficient knowledge to begin adapting to climate change. Management tools already used to restore natural systems, such as mechanical thinning and prescribed fire, not only reduce fire risk but also build ecosystem resilience to drier conditions. Current planning approaches, including multi-year management plans and adaptive management, are well suited to anticipate and adjust to a changing environment. Therefore, the most prudent approach is to build upon, reevaluate, and learn from the current set of tools used to maintain and restore forests, grasslands, rivers and wetlands.

In response to the results of our regional assessment, the Southwest Climate Change Initiative convened scientists and managers within four case-study landscape sites. Together, we evaluated how current resource plans, objectives and monitoring protocols could be adjusted to bolster the health and resilience of natural systems given what is currently known about the effects of climate change. Three actionable recommendations emerged from these workshops and this regional assessment:

Modify and expand the use of current management tools to moderate the effects of climate change on rivers, wetlands, and water supply. Examples include strategically-located mechanical thinning and controlled burns to boost snowpack retention and water infiltration in forests; and restoration of vegetation and natural water flow patterns in riparian areas and wetlands such that base flows and groundwater recharge are sustained.

Develop climate-smart adaptive management and monitoring protocols. Adjust adaptive management and monitoring protocols to

evaluate the effectiveness of management activities designed to address climate change. Reevaluate historical monitoring data sets to understand whether temperature-driven changes to species and ecological process are already occurring within the management area.

Coordinate management of shared resources. Given the regional pattern of recent temperature change—some areas have warmed more rapidly than others—natural resource managers will benefit by coordinating their activities with others that are managing common resources. Piñon-juniper woodlands for example span the 4-corner region and have experienced a range of temperature change in the last half-century from −1°F to +3°F. Regional and coordinated management of this shared habitat may be the only way to ensure that portions of the habitat can be maintained in a resilient state, while at the same time, other portions are allowed to transition to another state.

Taking action on these recommendations will be critical for achieving conservation and management goals in the face of a changing climate.

Introduction

Natural landscapes in the Southwestern United States are changing. In recent years, periodic droughts coupled with warmer temperatures have led to drier conditions on the ground. Droughts are natural phenomena in this region, whereas rising temperatures are linked to human activities that increase concentrations of greenhouse gases in the atmosphere.[1] The combination of drought and warming has tipped the ecological balance across many habitats and waterways across the Southwest, leading to severe and sometimes dramatic impacts.[2,3] Although global climate models cannot tell us precisely where or when these extreme events will take place in the future, they do project that they will become more frequent and severe as temperatures in the Southwest continue to rise.[4] We can expect, therefore, increasingly severe impacts to our natural systems as more "tipping points" are surpassed.

The current and future trajectories of climate change in our region underscores the need for natural resource and conservation professionals to understand the impacts of climate change on the resources they manage. This report describes the impacts of recent climate change on management priorities common to most natural resource professionals—habitats, watersheds, and species of conservation concern. We focus on recent temperature change because warming trends in the last 50 years have been linked to ecological and hydrological impacts across the West.[2,3,5-10] We explore the following questions:

We focus on recent temperature change because warming trends in the last 50 years have been linked to ecological and hydrological impacts across the West

What is the pattern of temperature change over the past 55 years across habitats and watersheds and in relation to the number of species of conservation concern?

Which habitats and watersheds have already experienced ecological and hydrological changes that are consistent with warming?

Where and when should we consider adjusting our conservation and management approaches to help species and natural systems adapt to a changing climate?

Our report reveals several unique dimensions of the future of natural resource management in light of climate change. Climate change has already affected resources in the Southwest. Resource managers and conservation professionals now possess sufficient knowledge about these effects to begin adapting their conservation and management activities. The current set of tools used to maintain the health of our natural systems are well-suited to address climate change, but they will need to be reevaluated in light of our emerging understanding of the effects of a changing climate. Accelerated changes to our landscapes will require balancing complex trade-offs between conventional objectives, such as maintaining the current composition of habitats, and emerging objectives, such as optimizing hydrological processes or facilitating the transition of resources from one state to another. Changing landscapes will require regional coordination across agencies and boundaries because management objectives may not be attainable at the unit level.

Climate is Changing in the Southwest

Temperatures in the Southwest have risen by 1.5 °F in the last 55 years, and are projected to increase 2–5 °F by 2030 and 4–10 °F by 2090. This warming acts alone or in concert with natural disturbances to affect natural resources.

Recent Climate Patterns (1951–2006)

Average annual temperatures in the Southwest have already risen by 1.5 °F (Figure 1). While most locations experienced warming, temperatures rose faster in some places. For example, temperatures increased almost 2°F across Arizona and Utah, while they only rose about 1°F across Colorado and New Mexico. Examination of the paleo-climate record in the Southwest suggests that the pace of temperature change during the past half century is unprecedented. In the last 400 years, no other period has experienced more rapid temperature change than 1950–2000.[11]

Average annual precipitation increased 17% across the region during the past half century (Figure 1). However, these patterns were variable in geography and through time. Whereas most of New Mexico was wetter, portions of Arizona, western Colorado, and central Utah were drier (Figure 1). This past half century captured 3 precipitation episodes: a dry period in the 1950s, a wet period (1970s through early 1990s) and another dry period from the late 1990s to the early 2000s.[12,13]

Future Climate Patterns (2030 and 2090)

Global climate models in the Climate Wizard project that temperatures will continue to rise in the Southwest.[14] By 2030, average temperatures in the region could be 2–5 °F higher than the 1950s (Figure 2). By 2090, regional average temperatures could be 4–10 °F higher. Unfortunately, the spatial resolution of the output from models is not fine enough to project which states or habitats might experience greater temperatures increases (See Supporting Information S2 for maps of future climate change data displayed in Figure 2).

Scientists are less certain about future precipitation patterns. Near the end of this century, the models we evaluated project that average precipitation could decline by 2–10% in New Mexico, slightly decline in portions of Arizona and Colorado, and remain the same or slightly increase in most of Utah. This result is generally consistent with other analyses of future precipitation for this region,[12,17,18] but there is less agreement between models. Though we know year-to-year and decade-to-decade fluctuations in precipitation are driving factors in ecosystem function,[19] global climate models cannot yet accurately or consistently project future precipitation at this temporal scale.

Warming Effects on Natural Resources

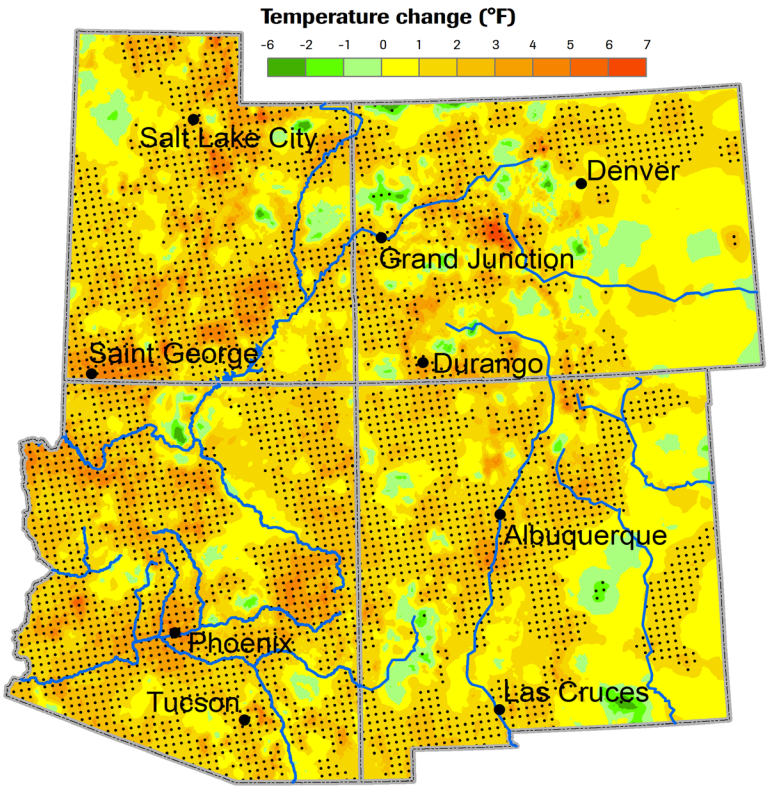
Native plants and animals of the Southwest have adaptations to cope with and survive the harsh and variable climate conditions that are characteristic of this region. Droughts, for example, have always occurred in the Southwest, and only those plants and animals that can tolerate or recover from these periodic events have survived. *What is different now is that rising temperatures associated with human activities[1] amplify the magnitude and severity of natural disturbances.*[2,3] Researchers have already demonstrated that a 'global warming footprint'—changes in species ranges and the timing of seasonal events (*phenology*)that are coincident with rising temperatures—is evident for many species across the globe.[20] In the Southwest, recent warming has affected native species and natural systems either directly or through an amplification of natural disturbances.

In this section

In this section, we use a publicly available climate change toolbox, called Climate Wizard,[15] to describe changes in temperature and precipitation across the Four Corner states of the Southwest in the last half century (1951–2006) and two future periods, 2030 and 2090.[16] We highlight temperature changes in the past half century for two reasons: (1) several independent studies have shown that ecological and hydrological events linked to warming have occurred in the last 50 years;[2,3,5-10] (2) a longer historic period reduces the possibility that temporal trends are due to natural variability or chance. We also describe the ways in which warming affects species and natural systems.

For more information on the climate change data used in this report, see Supporting Information S1.

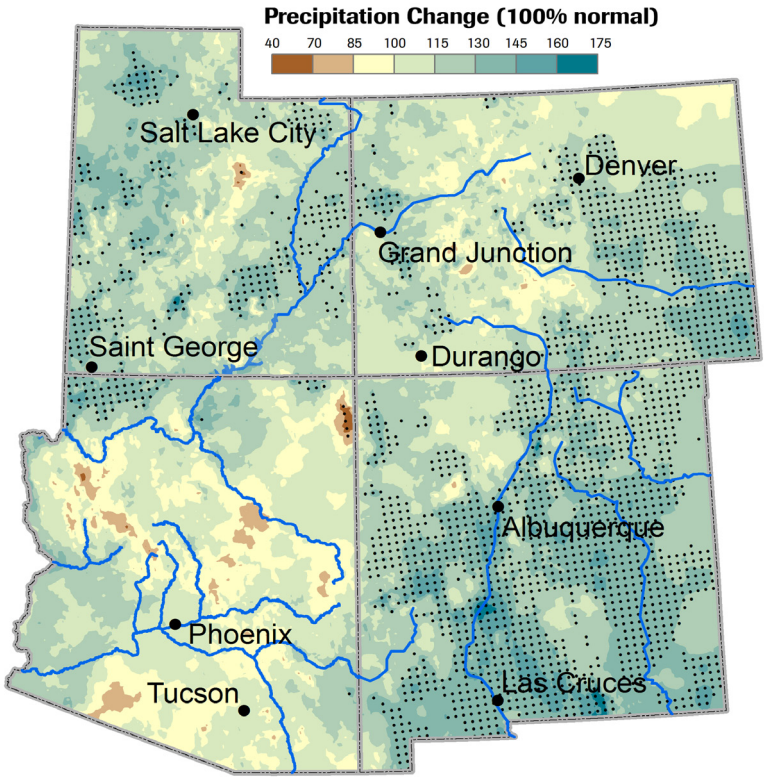
Figure 1: Climate Change in the Southwest, 1951–2006



4-Corner States	+1.5
Arizona	+1.9
Colorado	+1.1
New Mexico	+1.2
Utah	+1.8

Table shows changes in mean annual temperature by state. Map shows temperature changes across all locations.[15,21] Dots on map indicate where the trend is significant ($p < .05$).[22] Locations with values near 0 experienced little change in temperature on average from 1951–2006. Locations with positive values experienced warming. Locations with negative values experienced cooling.

See Supporting Information S1 for more detailed description of climate data.



4-Corner States	117%
Arizona	105%
Colorado	115%
New Mexico	128%
Utah	120%

Table shows changes in mean annual precipitation by state.[15,21] Map shows precipitation changes across all locations in the Southwest. Dots on map indicate where the trend is significant ($p < 0.05$).[22] The average of mean annual precipitation at each location from 1951-2006 was set to 100%. Locations with values near 100% have experienced no trend in precipitation in the last half century. Locations with values less than 100% have become drier. Locations with values greater than 100% have become wetter.

See Supporting Information S1 for more detailed description of climate data.

Direct Warming Effects

Many natural events are cued to changes in temperatures. The onset of spring—from the emergence of hibernating mammals to the migration of birds to spring flowers—is often triggered by changes in temperatures. As temperatures have risen in recent years, so has the timing of these species events. For example, yellow-bellied marmots in subalpine forests in Colorado are emerging earlier from hibernation as a consequence of warmer spring temperatures (Figure 3).[23] Earlier emergence has led to a lengthening of the growing season, an increase in body mass, survival, and ultimately population size of these mammals.[24] Warmer spring temperatures are also associated with earlier breeding dates for Mexican Jays in southeastern Arizona[25] and earlier migration from low to high elevations of the American Robin in Colorado (Figure 3).[23]

Warming Amplifies Ecosystem Change

Additionally, warming in recent decades has amplified the impact of disturbances on natural resources, primarily by altering the water balance. Warmer temperatures, for example, have driven changes in hydrology and wildfire activity in the western United States. In recent decades, peak streamflows are now occurring 1–4 weeks earlier,[7] snowpack levels have declined at low to mid elevations within mountain ranges,[6,26] and a greater fraction of precipitation is falling as rain.[27] While variability in precipitation has played a role in these trends in hydrology, another significant portion can be attributed directly to rising temperatures, especially in the winter and spring.[6-10,28] These changes in climate and hydrology, in turn, have are now been observed to affect forest disturbances. Specifically, rising temperatures and earlier spring snowmelt are strongly associated with a recent increase in wildfire activity in the last 20 years (Figure 3).[3]

In a similar fashion, warming amplifies the effects of drought on natural systems. Plant mortality events are often associated with droughts, where for example, mortality of ponderosa trees occurred at a northern New Mexico site during the 1950s drought.[29] However, the scale and severity of these events has increased due to the warmer conditions experienced in recent years. A recent piñon tree mortality event was much larger than a similar die-off event that occurred during the 1950s.[2] While the recent drought in the 2000s occurred under wetter conditions than the 1950s drought, it was also warmer.[30] Recent studies suggest that higher temperatures increased evaporative demand and water stress experienced by plants, and ultimately, damage sustained from pine beetle outbreaks.[31]

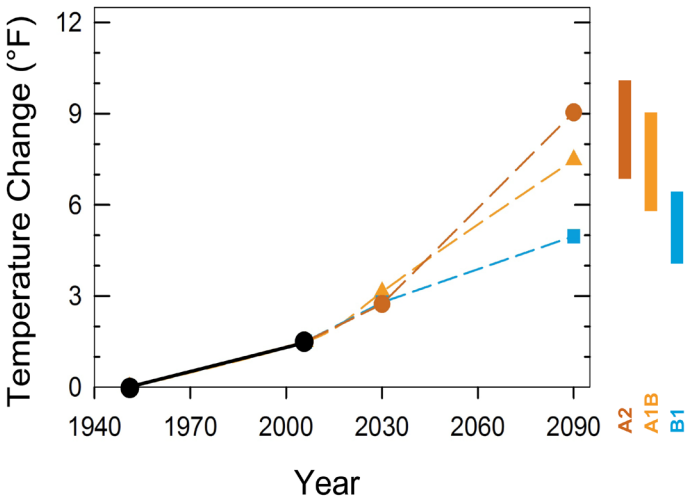


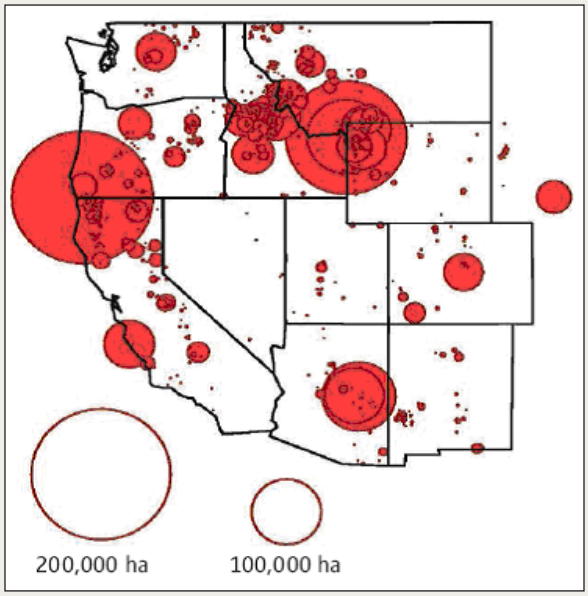
Figure 2: Temperature Change Projections in the Southwest, 2030 & 2090

Estimates of historic and future temperature change in the Southwest. Black dots represents temperature change from 1951–2006.[15,21] Colored symbols represent ensemble averages of future temperatures in 2030 and 2090 from 16 global climate models.[15,16,18] Vertical colored bars represent ranges of temperature change that are predicted by the models for 2090 (between the 20th and 80th percentiles, temperature ranges for 2030 are also available but not shown here).

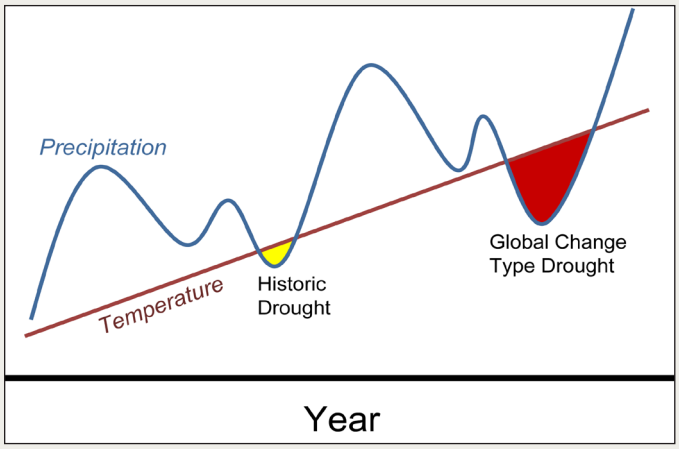
See Supporting Information S1 for more detailed description of climate data and S2 for a depiction of these data as regional maps.

Figure 3: Warming effects on natural resources

In recent years, warmer temperatures in spring months contributed to changes in the timing of events for the yellow-bellied marmot *(Marmota flaviventris)*, American robin *(Turdus migratorius)*, and Mexican Jay *(Aphelocoma ultramarina)*.[23-25]



Large wildfires became more prevalent in the western United States, starting in the mid-1980s. This change in wildfire activity was strongly associated with increased spring and summer temperatures and an earlier spring snowmelt (from Running 2006; data from Westerling et al. 2006; reprinted with permission from AAAS).[32]



The severity of droughts under rising temperatures, so-called Global Change-Type Droughts, is greater than droughts that occurred historically because higher temperatures lead to greater water loss and stress.[2]

Southwestern Natural Landscapes are Changing

90% of the habitats and 70% of the watersheds in the Southwest have warmed in the last 55 years. This warming has contributed to changing ecological processes within 40% of these habitats and modifying hydrology in 50% of these watersheds, affecting at least 119 species.

Assessments of the effects of climate change on natural resources and biodiversity have been conducted at the global scale[20] or at a scale limited to the boundary of a single state.[33,34] To our knowledge, no such assessment has been conducted at the broader regional scale for the Southwest. Yet, assessing vulnerability[35] at this level makes biological sense given that the distributions of many native species are bounded by bio-geographic areas that only occur in the region, such as the Colorado Plateau, the Sonoran Desert and the Chihuahuan Desert to name a few. As a first approximation of climate change impacts on a suite of species in the Southwest, we compare the number of species of conservation concern found within habitats and watersheds (Figure 4) to recent temperature change (1951–2006) across these habitats and watersheds.

To help interpret our results, we grouped habitats and watersheds into four vulnerability classes.[36] Classes were delineated by values above (high) and below (low) the 50th percentile for temperature change and the number of species, respectively (Figure 5). These classes can be interpreted as a preliminary assessment of the relative vulnerability[37] of management priorities. In turn, this can facilitate prioritization or scheduling of management actions. For example, natural resource planning in places with lower temperature change could focus on maintaining the resilience of natural resources. Conversely, investments in places with higher temperature change could more carefully consider options for managing ecological change.[38,39]

These categories can be considered a snapshot in time, a snapshot that captures the current status of a dynamic process. For such an approach to be truly valuable, evaluating changes in temperature and precipitation, and the effects of such changes on species and ecological processes, would need to be incorporated into monitoring protocols. To begin this process, we present the results of a literature review that describes species, habitats and watersheds in the Southwest that have been affected by recent temperature change. As climate patterns or ecological effects change through time, these groupings could be updated to represent more contemporary knowledge.

For more information on climate change vulnerability assessments, see Supporting Information S3.

In this section

In this section, we use Climate Wizard[15] and spatial information on natural resources to evaluate the exposure of habitats and watersheds in the Southwest to one key aspect of recent climate change, changes in annual mean temperatures from 1951–2006. We compare temperature change across habitats and watersheds to the number of species of conservation concern found within them. In total, we evaluated 25 major habitats, 52 large watersheds, and over 3,000 species. Additionally, we present the results of a literature review, where we found that 10 habitats (40%), 26 watersheds (50%), and 119 species in the Southwest have already observed to be affected by recent temperature change.

Habitats are Vulnerable to Climate Change

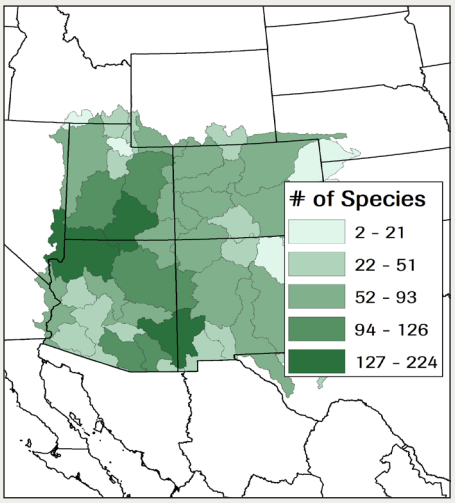
Ninety percent of the habitats in the Southwest have warmed over the last 55 years; some have warmed twice as fast as others. Habitats experiencing more rapid temperature change (1.6–2.1 °F in the 'most vulnerable' and 'vulnerable' categories) span geographies and elevations (Figure 6). Those habitats with the highest temperature change and the most species of conservation concern include subalpine forests, piñon-juniper woodlands, sage shrublands, and Colorado Plateau canyonlands and grasslands. Those habitats with less rapid temperature change (0.8–1.5 °F in the 'somewhat vulnerable' and 'least vulnerable' categories) were concentrated within the shortgrass prairie and Chihuahuan desert regions of eastern Colorado, eastern New Mexico, and southeastern Arizona.

Figure 4: Watersheds, Habitats, and Species of Conservation Concern: a description of the natural resources information used in the report

Watersheds are large drainage basins that are governed by topography and not subject to shifting ecological boundaries. We used standard mid-scale watershed units (6-digit HUC).[40]

Habitats are groups of plant communities (called MacroGroups) with a common set of dominant plants, regional climate, and disturbance regimes.[41]

For detailed information on habitat data, see Supporting Information S4.



Species of Conservation Concern are those species, sub-species, or varieties listed under the U.S. Endangered Species Act (including candidate or proposed) or those species that have a global conservation status of critically imperiled (G1/T1), imperiled (G2/T2), or vulnerable (G3/T3).[42]

Scientists have observed warming effects across 40% of the habitats in the Southwest, affecting at least 119 species.[43] The majority of these species effects pertain to changes in phenology—the timing of events—such as breeding or emergence from hibernation. Tracking warmer spring temperatures, at least 6 bird species—hermit thrush, orange-crowned warbler, red-faced warbler, Virginia's warbler, gray-headed junco, and Mexican jay—are breeding earlier,[25,44] while yellow-bellied marmots are emerging earlier from hibernation.[23] The ultimate consequence of these changes in terms of species populations or survival has not yet played out, but it is likely that each species will respond differently. Due to differences in life history, for example, the average body size of yellow-bellied marmots has increased with warmer temperatures, while the average body size of white-throated woodrats has declined.[24,45] Evidence of the effects of warming on species and the uncertain outcome of these effects heightens the importance that monitoring programs for these species are designed to capture fluctuations in key species and climate parameters.

Changes in ecological processes such as fire and insect outbreaks may ultimately lead to a greater impact on species simply because these disturbances occur over such large areas. The recent piñon pine mortality event, for instance, oc-

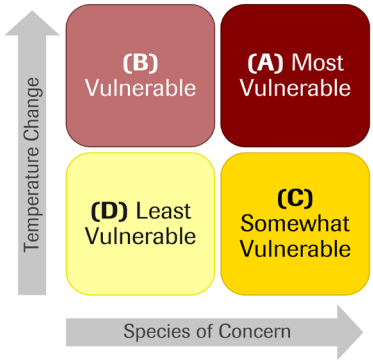


Figure 5: Place-based Vulnerability to Climate Change

One way to evaluate the climate change vulnerability of a place is to categorize it according to the relative degree of temperature change it has been exposed to and the number of species of conservation concern that are found within it. We adopted a method used for conservation planning[36] to evaluate the vulnerability of habitats and watersheds.

(A) Most Vulnerable: Higher Temperature Change, More Species

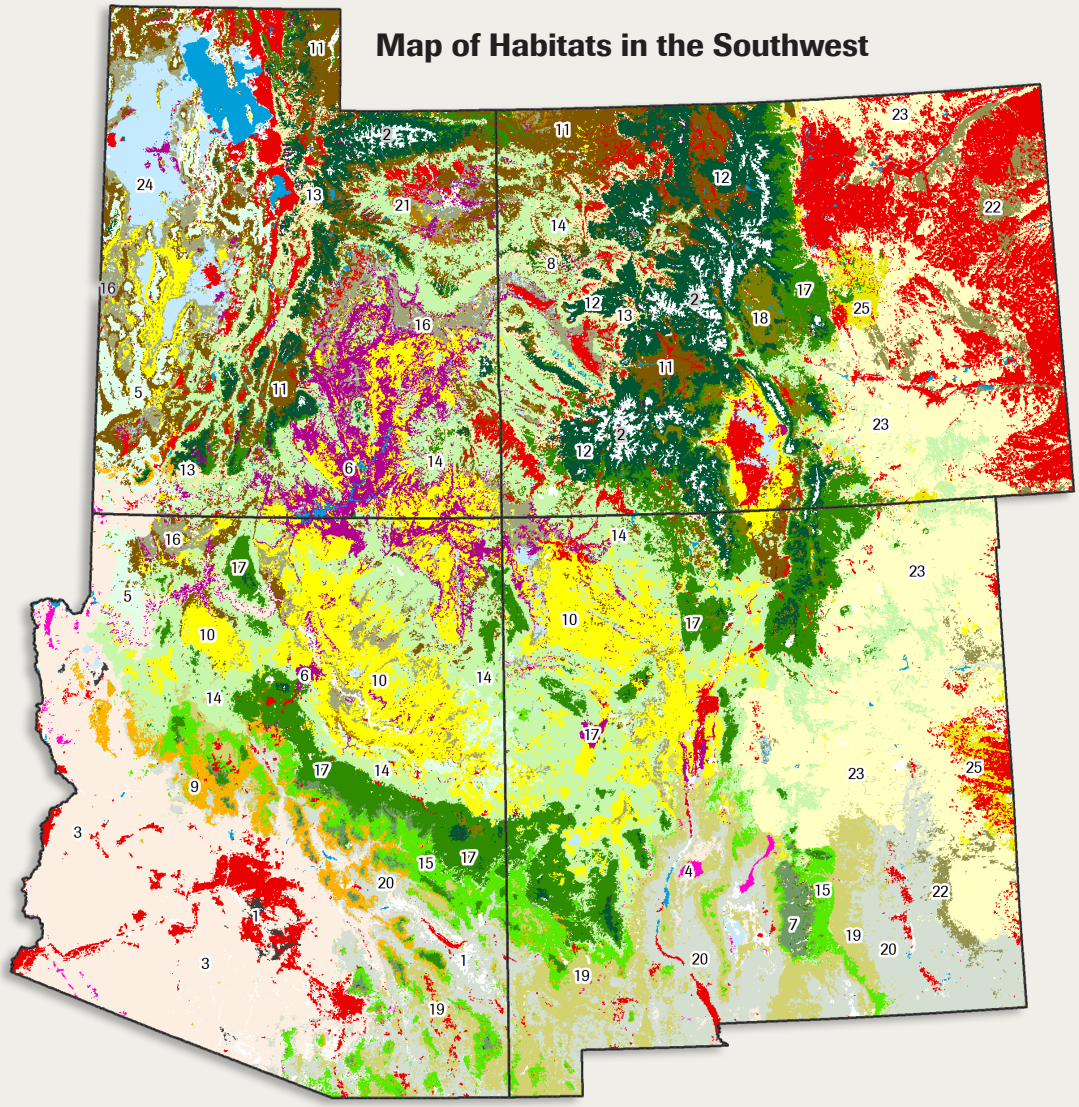
(B) Vulnerable: Higher Temperature Change, Fewer Species

(C) Somewhat Vulnerable: Lower Temperature Change, More Species

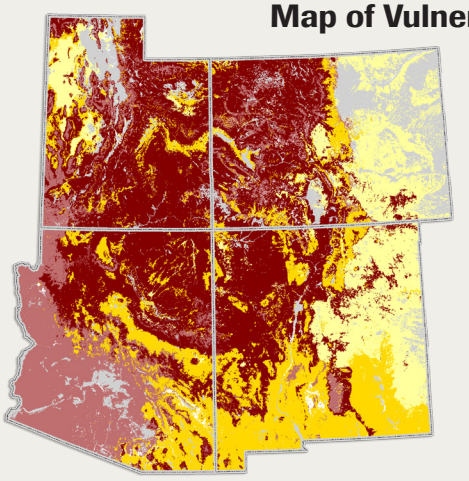
(D) Least Vulnerable: Lower Temperature Change, Fewer Species

Figure 6: Habitats that are Vulnerable to Climate Change

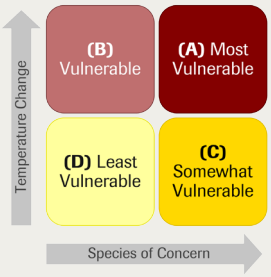
Map of Habitats in the Southwest



Map of Vulnerable Habitats



Habitats are grouped into relative vulnerability classes based on temperature change and the number of species of conservation concern found within them. High values are above the 50th percentile. Low values are below the 50th percentile. Areas in gray are areas that have been developed: urban, disturbed, agriculture.



Map Legend and Table of Habitats by Climate Change Vulnerability Class

Habitats are grouped by relative vulnerability to climate change along with information about their location, area, temperature change (°F 1951-2006), # species of conservation concern,[46] and observed impacts. Tables sorted by temperature change and # species. Label # and color refer to habitat locations on map (left). Temperature change and species are evaluated across the range of the habitat in the 4-corner states. Asterisk symbol '*' indicates that average temperatures within that habitat type have changed significantly ($p < 0.05$)[22] over 55-year period.

Observed ecological impacts associated with climate change:

- animal species population shift, change or decline
- plant species population shift, change or decline
- change in the timing of species events
- uncharacteristic fire

For detailed information about observed ecological impacts, see Supporting Information S5.

(A) Most Vulnerable: Higher Temperature Change, More Species

Map			*Climate & Ecology*		
Label	Habitat Name	Area (sq. mi.)	T Change (°F)	# Species	Impact
6	Inter-Mountain Canyonland & Rock	12,403	1.9*	357	
10	Inter-Mountain Grassland	33,173	1.7*	332	
14	Two-needle Piñon-Juniper Woodland	57,111	1.6*	525	
15	Madrean Piñon-Juniper Encinal Woodland	10,421	1.6*	441	
11	Tall Sage Shrubland	26,227	1.6*	435	
12	Subalpine Conifer Forest	24,230	1.6*	301	

(B) Vulnerable: Higher Temperature Change, Fewer Species

Map			*Climate & Ecology*		
Label	Habitat Name	Area (sq. mi.)	T Change (°F)	# Species	Impact
1	Desert Salt Flat	1,551	2.1*	3	
3	Mojave-Sonoran Desert	36,360	2.1*	219	
5	Singleleaf Piñon-Juniper Woodland	8,126	2.0*	165	
4	Desert Canyonland & Rock	697	2.0*	148	
2	Alpine	2,781	2.0*	101	
7	Madrean Pine & Oak Woodland	2,295	1.9*	188	
8	Rocky Mountain Canyonland & Rock	632	1.8*	165	
9	Chaparral	5,110	1.7*	236	
13	Montane Shrubland	8,410	1.6*	252	

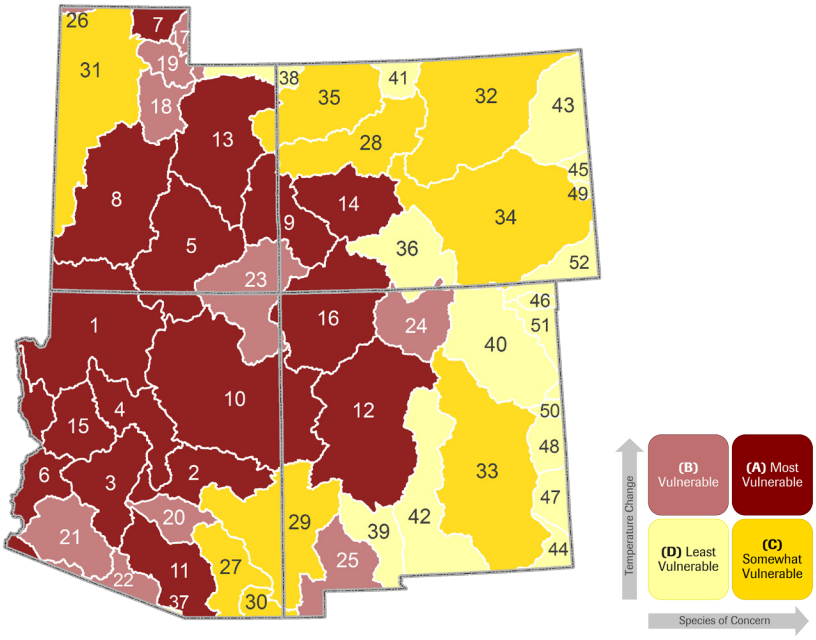
(C) Somewhat Vulnerable: Lower Temperature Change, More Species

Map			*Climate & Ecology*		
Label	Habitat Name	Area (sq. mi.)	T Change (°F)	# Species	Impact
16	Saltbrush Desert	12,411	1.5*	270	
17	Montane Forest	25,898	1.4*	428	
19	Semi-Desert Grassland	17,259	1.3*	261	
20	Chihuahuan	28,065	1.1*	262	

(D) Least Vulnerable: Lower Temperature Change, Fewer Species

Map			*Climate & Ecology*		
Label	Habitat Name	Area (sq. mi.)	T Change (°F)	# Species	Impact
18	Montane Grassland	3,452	1.4*	126	
21	Dwarf Sage Shrubland	962	1.2*	69	
22	Sand Grassland	4,499	0.9	25	
24	Inter-Mountain Salt Flat	8,515	0.8	181	
23	Shortgrass Prairie	44,736	0.8	81	
25	Mixedgrass Prairie	2,965	0.8	60	

Figure 7: Watersheds that are Vulnerable to Climate Change



Watersheds are grouped by relative vulnerability to climate change. Groups are based on the relative amount of temperature change and freshwater species of concern within each watershed. High values are above the 50th percentile. Low values are below the 50th percentile.

Description of tables (right). Watersheds are grouped by relative vulnerability along with information about temperature change (°F 1951-2006), # freshwater species of concern,[46] and observed impacts. Tables sorted by temperature change and # species. Temperature change and species are evaluated across the entire watershed, except for those watersheds that border Mexico. Asterisk symbol '*' indicates that average temperatures within that habitat type have changed significantly ($p < 0.05$)[22] over 55-year period.

Observed hydrological impacts associated with climate change:

= snowpack reductions documented[6]

= early streamflow documented[7]

Temperature change in Colorado River Basin watersheds

Warming in the Southwest has been pronounced within the Colorado River Basin.

Temp Change (ºF), 1951–2006

Upper Colorado	+1.6
Lower Colorado	+1.9
Rest of Southwest	+1.2

(A) Most Vulnerable: Higher Temperature Change, More Species

Label	Watershed	T Change (°F)	# Freshwater Species	Impacts
1	Lower Colorado-Lake Mead	2.4*	29	
2	Salt	2.3*	29	
3	Lower Gila-Agua Fria	2.2*	19	
4	Verde	2.1*	27	
5	Upper Colorado-Dirty Devil	2.0*	12	
6	Lower Colorado	1.9*	14	
7	Lower Bear	1.9*	11	
8	Escalante Desert-Sevier Lake	1.8*	16	
9	Upper Colorado-Dolores	1.8*	12	
10	Little Colorado	1.7*	25	
11	Santa Cruz	1.7*	25	
12	Rio Grande-Elephant Butte	1.6*	20	
13	Lower Green	1.6*	15	
14	Gunnison	1.5*	16	
15	Bill Williams	1.5*	16	
16	Upper San Juan	1.5*	14	

(B) Vulnerable: Higher Temperature Change, Fewer Species

Label	Watershed	T Change (°F)	# Freshwater Species	Impacts
17	Upper Bear	2.7*	5	
18	Jordan	2.4*	8	
19	Weber	2.4*	3	
20	Middle Gila	2.2*	10	
21	Lower Gila	2.1*	5	
22	Rio Sonoyta	1.9*	4	
23	Lower San Juan	1.7*	9	
24	Upper Rio Grande	1.6*	8	
25	Mimbres	1.5*	10	
26	Upper Snake	1.5*	4	

(C) Somewhat Vulnerable: Lower Temperature Change, More Species

Label	Watershed	T Change (°F)	# Freshwater Species	Impacts
27	San Pedro-Willcox	1.4*	31	
28	Colorado headwaters	1.4*	18	
29	Upper Gila	1.3*	37	
30	Rio De Bavispe	1.3*	13	
31	Great Salt Lake	1.2*	21	
32	South Platte	1.2	20	
33	Upper Pecos	0.8	19	
34	Upper Arkansas	0.7	12	
35	White - Yampa	0.6	12	

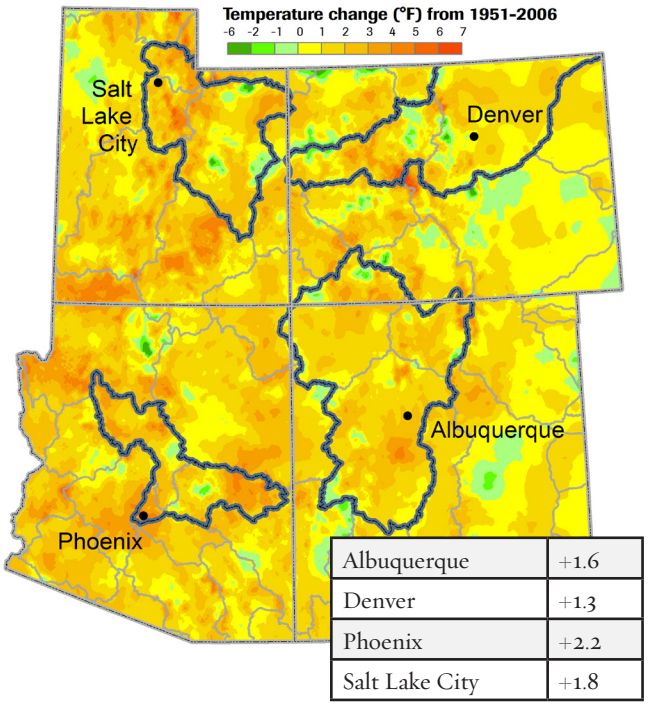
(D) Least Vulerable: Lower Temperature Change, Fewer Species

Label	Watershed	T Change (°F)	# Freshwater Species	Impacts
36	Rio Grande headwaters	1.3	10	
37	Rio De La Concepcion	1.3*	9	
38	Upper Green	1.2*	10	
39	Rio Grande-Caballo	1.2*	8	
40	Upper Canadian	1.0	7	
41	North Platte	0.9	10	
42	Rio Grande closed basins	0.9*	6	
43	Republican	0.8	1	
44	Lower Pecos	0.6	4	
45	Smoky Hill	0.6	0	
46	Upper Beaver	0.4	1	
47	Upper Colorado	0.4	0	
48	Brazos headwaters	0.1	0	
49	Middle Arkansas	0.0	0	
50	Prairie Dog Town Fork Red	0.0	0	
51	Middle Canadian	-0.1	1	
52	Upper Cimarron	-0.2	0	

curred over 3 million acres, an area that is about 2.5 times larger than Grand Canyon National Park.[2] Our report found that there are 525 species of conservation concern associated with these woodlands; others report that as many as 1,000 species may inhabit them.[47] Similarly, wildfires in the last several years have burned over areas as large as one-half million acres, potentially affecting many species found within montane forests (428 species of conservation concern) and Madrean pine and oak forests (188 species of conservation concern).

Watersheds are Vulnerable to Climate Change

Seventy percent of watersheds in the Southwest have warmed in the last 55 years. While watersheds in each of the four-corner states have experienced rising temperatures, warming has been most pronounced in watersheds within the Colorado River basin (Figure 7). Management of resources within these watersheds is very important for people and nature. The Colorado River basin, for example, is a center for endemism for fish species.[48] We found that this basin hosts 70% of the vulnerable aquatic and riparian species that are found in the four corner states. Additionally, several high profile National Parks—Grand Canyon, Zion and Canyonlands—that are enjoyed by thousands of visitors every year are within watersheds that have the highest levels of temperature change and freshwater species. Two other watersheds with rapid temperature change and a high number of freshwater species—the Salt and Verde—are a major supply of water for Phoenix (Figure 8). Watersheds with less rapid temperature change are found in eastern Colorado and New Mexico, southeastern Arizona, and northwestern Utah.



Albuquerque	+1.6
Denver	+1.3
Phoenix	+2.2
Salt Lake City	+1.8

Figure 8: Watersheds that Supply Major Cities and Temperature Change

Temperature change from 1951–2006 across watersheds that supply water to 4 major cities in the Southwest.

Practical Actions to Manage Changing Landscapes

The conservation and natural resource management community has sufficient information to begin taking action to reduce the impacts of climate change. The most prudent approach will include reevaluating the effectiveness of current restoration tools, modifying resource objectives, collaborating and sharing information across boundaries and learning from climate-smart adaptive management and monitoring.

The conservation and natural resource management community has sufficient information to begin taking action to reduce the impacts of climate change. As we have demonstrated in this report, warming is already occurring across many habitats and watersheds in the Southwest, and species and ecological effects associated with this warming are already apparent. The temperature-mediated effects that we see today will be amplified tomorrow. All global climate models project that temperatures will continue to increase.[12] Models also project that the frequency and severity of extreme precipitation events, both droughts and flooding, will increase.[49] Therefore, we can be certain that these two forces—rising temperatures and severe drought—will occur simultaneously in the future.

Natural resource management activities are designed to maintain the health and resilience of natural systems in a highly variable, arid climate. Some combination of these very same tools—prescribed fires and thinning to maintain forests; restoring hydrology of rivers and riparian areas—are likely to be beneficial in the future where conditions are expected to be drier and hotter.[38,39,50,51] To be clear, the application of these management tools without any adjustments will not likely be sufficient. Rather, information about the current and projected effects of climate change on natural resources in this report and others can be reviewed to critically evaluate the effectiveness of each of these activities under a changing environment. Under such a review, the pace, scale, sequencing, location and prioritization of management actions to maintain system health may change.

The temperature-mediated effects that we see today will be amplified tomorrow

Current planning approaches are also well suited to adapt to climate change. Natural resource managers develop multi-year management plans to implement large-scale treatments across their management units. Adaptive management protocols are established to monitor whether these treatments result in the desired outcomes, and to adjust accordingly. These very same tools, planning and adaptive management, will become even more essential under a changing climate.[39,50] Therefore, a prudent question to ask is: *How can we adjust our plans, resource objectives and monitoring protocols to bolster the health and resilience of natural systems given what we know and expect to be the effects of climate change?*

As part of the Southwest Climate Change Initiative, we convened a series of climate change adaptation workshops to explore this question with local managers from four priority landscapes across the Southwest: the Jemez Mountains in New Mexico, the Gunnison Basin in Colorado, Four National Forests in Arizona, and the Bear River Basin in Utah (Figure 9).[52] Here, we summarize three actionable recommendations that emerged from these case-study workshops and this regional assessment.

Sustaining Hydrology under a Changing Climate

Current forest management activities could be adapted to moderate the effects of climate change on forests and water supply. Forest managers use thinning and prescribed fires treatments to reduce the risk of catastrophic fires and to maintain wildlife habitat. These very same tools could potentially sustain water conditions of forests and woodlands

in a warmer and drier environment. For example, managing forests with moderate canopy densities improves snowpack retention, which may, in turn, enhance or at least sustain water yields in the face of climate change.[53] Workshop participants also cited the potential use of artificial or live-vegetation snow-fences to increase snowpack retention and infiltration.[54]

An expansion of watershed management approaches could also improve hydrologic conditions within headwater and riparian areas. Participants of the Gunnison Basin workshop in Colorado envisioned an expansion of existing approaches—including, seasonal return of water to the environment from reservoirs and agriculture; and construction of wetland complexes—could help maintain base flows, groundwater recharge, and timing of peak flows in headwater areas.[55] In a similar fashion, participants in the New Mexico and Arizona workshops discussed the potential of using riparian management techniques, such as reducing grazing along riparian areas and using beavers to improve stream management, as strategies that could help sustain flows and moderate the effects of warming air and stream temperatures.[56,57]

Climate-Smart Research & Monitoring

A clear information need identified in all four workshops is to determine the degree to which current forest and watershed management techniques can be modified to abate temperature-mediated changes in hydrology. Although there is some research on this topic,[58] many more questions need to be addressed. For example, to what extent are hydrology-based management objectives consistent with conventional natural resource objectives, such as the maintenance of habitat for species or reduction in fire risk? To answer these questions, we suggest establishing hydrology-based objectives within an adaptive management framework and monitoring the effectiveness of different treatment protocols against key hydrological indicators. A key challenge will be to establish specific hypotheses that describe how changes in temperature or precipitation, or ecological surrogates, such as soil moisture, are expected to drive species or ecological responses.[39]

Additionally, historical climate and monitoring datasets could be evaluated to confirm whether any of the warming effects reviewed in this report have occurred within their management units. In our review, we found a few cases where there was a plausible linkage between temperature change and an observed ecological response, but these relationships

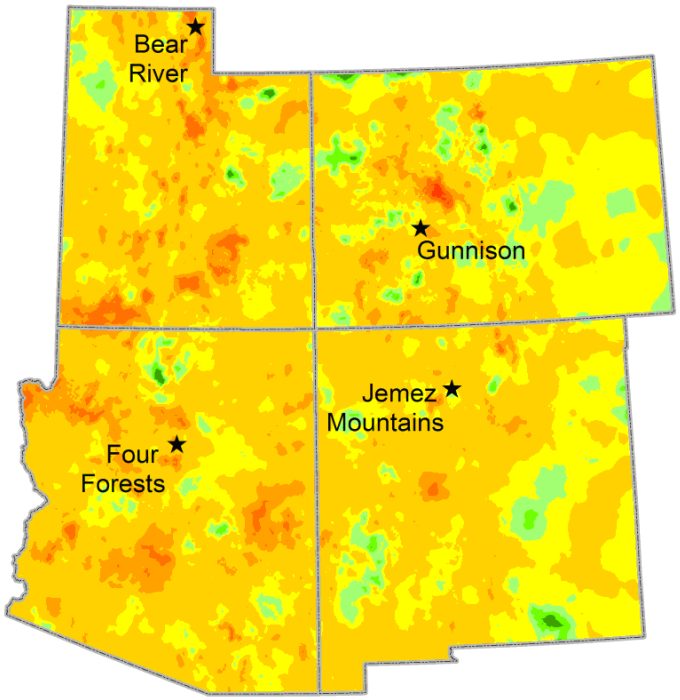


Figure 9. Planning for climate change across 4 landscape sites in the Southwest

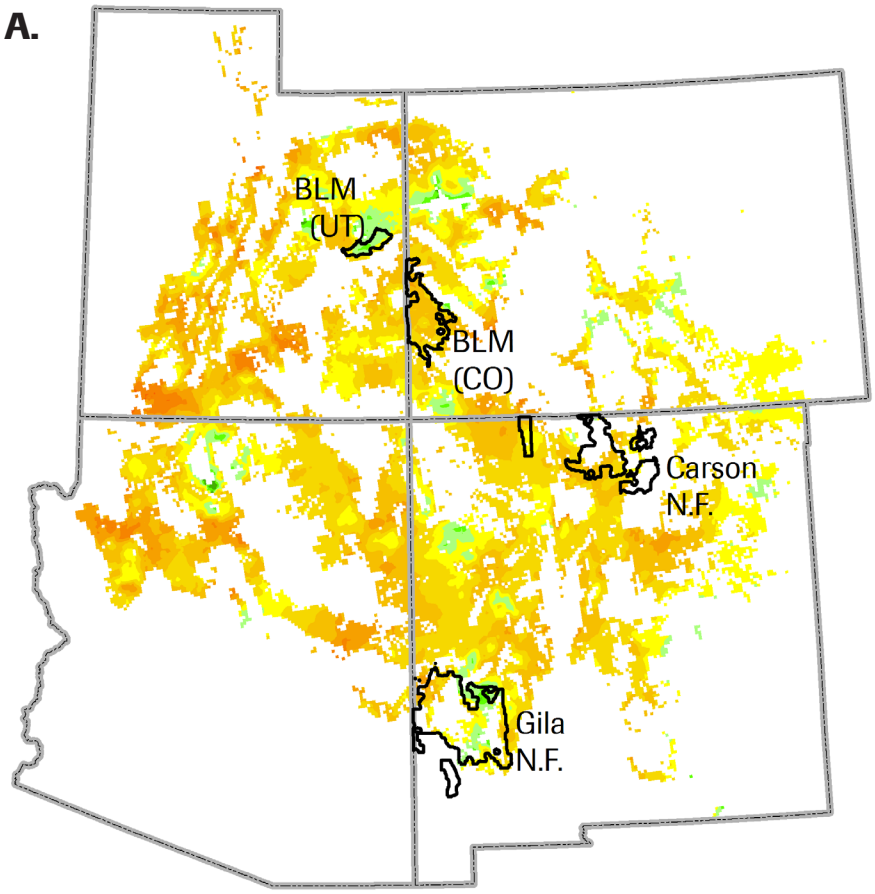
The Southwest Climate Change Initiative hosted workshops in four landscape sites—the Jemez mountains in New Mexico, the Gunnison Basin in Colorado, the Four Forest Restoration Initiative area in northern Arizona, and the Bear River Basin in northern Utah. The goal of the workshops was to provide information about current and forecasted impacts of climate change on important natural resources within the site so that managers and scientists could begin adapting their planning and management activities to address climate change.

Scientists and managers followed a straightforward and transparent process:[52]

1. Develop management objectives for commonly managed natural resources
2. Build a common understanding of the current and projected impacts of climate change on these resources
3. Evaluate and prioritize management intervention activities that would ameliorate these effects
4. Discuss the planning and monitoring that would be required to manage and monitor resources using this shared knowledge

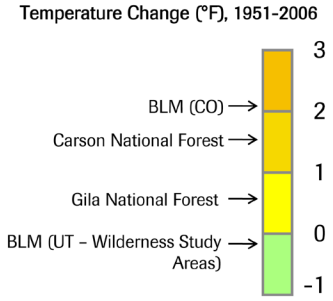
For more information about these workshops, visit nmconservation.org.

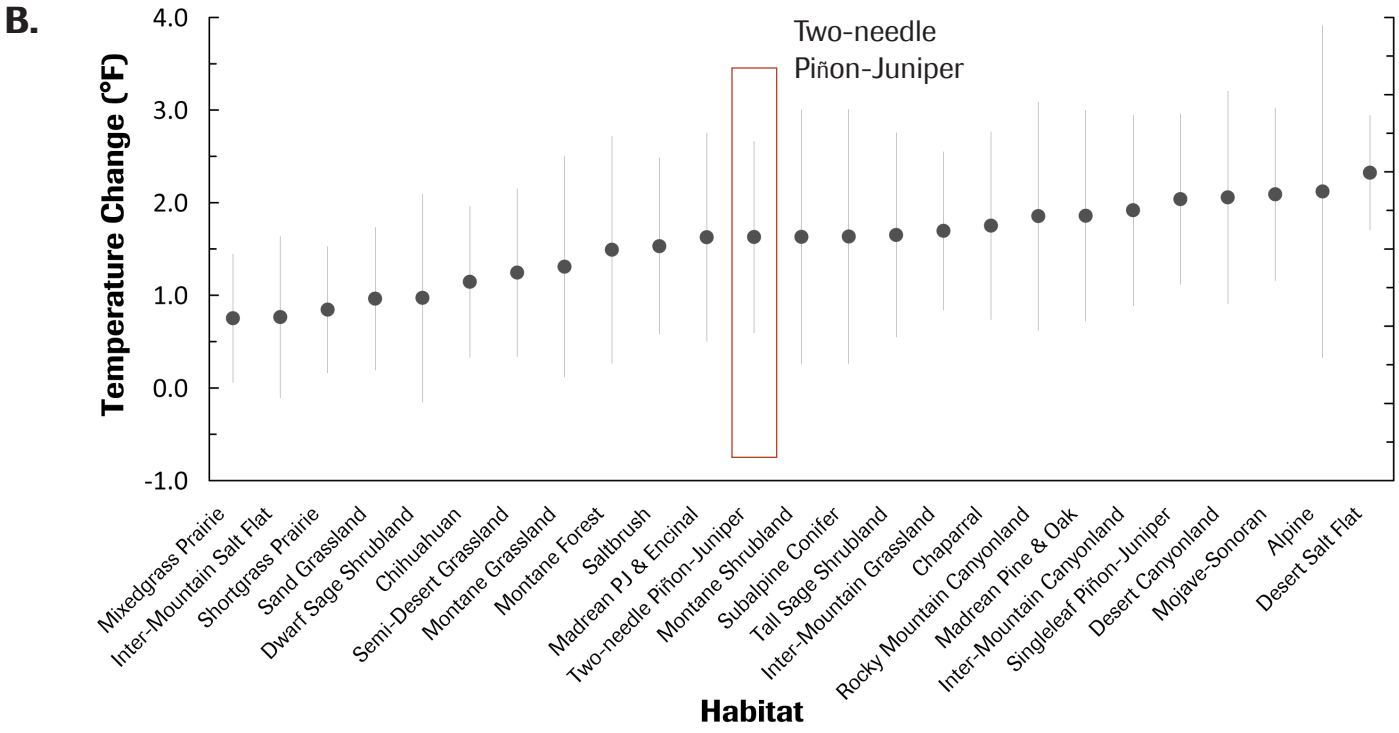
Figure 10: The Rationale for Coordinated Management



(a) Map showing how four representative management units fall into different "temperature-change zones" within the range of two-needle piñon-juniper habitat in the Southwest. Colors represent recent temperature change (1951–2006) across the range of two-needle piñon-juniper habitat.

(b) Note wide variability in temperature change across habitats. Managers would benefit from knowing the degree of temperature change that their habitats have experienced in relation to other areas.





have not been attributed to temperature change. In a long-term desert research site in southern Arizona, for example, mortality of some desert shrub species was 2–5 times higher during the recent drought when compared to the 1950s drought.[59] The author attributed this pattern to differences in precipitation across the two periods, but could higher temperatures also have contributed, as has been shown for piñon-juniper woodlands? Even though they may have not been designed as such, long-term monitoring datasets (e.g. species mortality or recruitment, species phenology or species cover) could be compared to temperature and precipitation records from local weather stations to corroborate the findings of this regional report. Such analyses would contribute to our understanding of how climate variability and climate change are already driving the systems we manage.

Coordinated Management of Shared Resources

The variability of warming across the range of a given habitat suggests that managers and conservationists would benefit from working together to meet habitat resource objectives. For example, recent temperature change varied considerably across two-needle piñon-juniper woodlands, from a slight cooling trend of −1°F in some places to warming up to 3°F in others (Figure 10). Individual management units fall into this matrix of temperature change. Management objectives may be more attainable within the Gila National Forest in southern New Mexico and BLM lands in central Utah because long-term temperature change has been moderate. In contrast, piñon-juniper management objectives may be harder to reach where temperature change has been more rapid, as has been the case for some BLM lands in southwestern Colorado and in the Carson National Forest in northern New Mexico. Regional and coordinated management of a shared habitat may be the only way to ensure that portions of the habitat can be maintained while other portions are allowed to transition to another state or managed to meet alternative objectives.

Conclusions

Average temperatures in 90% of the habitats and 70% of the watersheds in the Southwest increased from 1951–2006. These changes are significant because warming, acting alone or in concert with natural disturbances, alters the ecological balance of our landscapes and waterways, ultimately leading to adverse impacts on our natural resources. Our literature review indicates that warming has already contributed to changes in ecological and hydrological processes within 40% of the habitats and 50% of the watersheds in the Southwest, affecting at least 119 species.

Embedded within each of these observations are hypotheses of change that can be further evaluated at local scales. Can rising temperatures explain recent patterns in mortality or recruitment that are recorded within existing monitoring data sets? Are recent changes in phenology consistent with seasonal warming? Which management practices are effective at moderating the drying effects caused by rising temperatures? Answers to these questions may suggest ways that existing resource objectives could be adjusted to capture what is known about our changing landscapes. Modifying current adaptive management and monitoring protocols to evaluate ecological responses to climate variability may reveal species tolerances to temperature change.

Managers could also convene climate change adaptation workshops like those hosted by the Southwest Climate Change Initiative (Figure 9) to evaluate how a changing climate might affect management goals and monitoring protocols of shared natural resources. As we illustrated with piñon-juniper woodlands (Figure 10), managers who work in woodlands that have experienced more warming may have to use a different set of management objectives and approaches than those who are managing woodlands with less warming. At the very least, we should continue to work across boundaries and across the region to ensure that collectively resource management goals can be achieved. Fortunately, new federal programs and initiatives, such as the Landscape Conservation Cooperatives of the Department

of Interior and the U.S. Forest Service National Roadmap for Responding to Climate Change,[60,61] echo many of the findings of this report and may provide additional resources to manage resource cooperatively and to share information.

Although we have focused on aspects of climate change upon which we can act on, there are still important uncertainties that will need to be considered. For example, we do not know whether the recent spatial patterns in temperature change in the Southwest will continue in the near-future or even long-term future. That is, we do not know whether the habitats and watersheds that have warmed the most in the last 50 years will be the same places that will warm the most in the next 50. Nor do we know precisely when or where high temperatures and drought will collide in the future, or how important seasonal precipitation events, like the monsoon, may change. Technological advances in climate modeling, including regional climate models that are nested within global models and can simulate regional-scale factors and processes, such as topography, will hopefully provide more precise information in the near future.

Perhaps the greatest uncertainty of all is how people will respond to climate change. In the Southwest, climate change is often manifested as changes in the timing and amount of water available for people and nature. Coupled with the growth and development of our urban centers, competition for water will only increase. People and governments may place an increasing emphasis on the management of our natural resources in ways that sustain our water supply, which will require a balancing of watershed health objectives with more conventional natural resource objectives. Implementing management actions such as those recommended in this report will be critical to reevaluate and achieve management objectives in the face of a changing climate.

Endnotes

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Macrogroups are a coarse-scale classification unit within the U.S. National Vegetation Standard. In figure 6 of this report, we changed the original names of the macrogroups in the National Vegetation Classification Standard to the simpler and more common names (see Supporting Information S4 for a detailed list of the original classification and names of macrogroups). We evaluated only natural terrestrial habitats. We did not evaluate aquatic or riparian habitats because we determined that the accuracy and location of these habitats in the dataset was not sufficient. We also did not evaluate areas that have been disturbed by humans (e.g agriculture, urban, disturbed areas), or habitats that have a limited distribution in the Southwest.

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