Managing Changing Landscapes in the Southwestern United States

Supporting Information

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

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Contents

SI 1: Climate change data

Historic Data

Until recently, trends in a state or region's climate typically were derived from compiling data across broadly defined climate divisions (for example, there are eight divisions for the entire state of New Mexico). This is not a very realistic approach to mapping the region's varying temperature and precipitation patterns. Alternatively, there are methods to map climate across regions using fine resolution gridded data. Using an approach called statistical interpolation, researchers use mathematical models to "fill in" disconnected data points from the existing network of meteorological stations to generate digital maps with complete coverage of a geographical area of interest. Unfortunately, most of these interpolation methods do not adequately capture the complex variations in temperature that occur in mountainous regions[1]—and many of these data sets are not freely available.

To overcome these shortcomings, the publicly- available Parameter-elevation Regressions on Independent Slopes Model (PRISM) estimates monthly temperature and precipitation using a combination of climate station data, a digital elevation model and expert-based knowledge of complex climatic processes, such as rain shadows and temperature inversions, at a grid cell resolution of 4 square kilometers(http://www.prism.oregonstate.edu).[2] The point data estimates of monthly temperature and precipitation used in this dataset originate from a number of well-established meteorological station data sources, such as the National Weather Service Cooperative (COOP stations), Natural Resources Conservation Service (SNOTEL sites), and other local networks. Additionally, to help ensure more complete station data sets, the National Center for Atmospheric Research (NCAR) statistically in-filled missing monthly data. Maps of the spatial locations of the meteorological stations used in producing the interpolated datasets are available at the PRISM website.

As with any modeled data set, such as PRISM, there are inherent uncertainties associated with data that is further away from points with actual station data. These in-between areas should always be interpreted with caution, in addition to avoiding focus on the value of a single data cell. In the case of PRISM, data biases can still occur despite efforts to improve results in mountainous areas.[3] Furthermore, problems with the original station data can exist, as some of these may have shorter periods of record or may have been physically moved during the course of data collection.

In this report, we use PRISM data sets in our historical trend analyses (1951–2006) of Southwest climate because these data are currently the best available[4] and have been used in a number of peer-reviewed studies of climate.[5–8] In fact, PRISM are currently the USDA's official climatological data source. We specifically used the Climate Wizard climate analysis tool to perform our analyses of PRISM climate data sets[9] (www.climatewizard.org).

Future Data

For future climate projections, we also used the Climate Wizard tool to analyze an ensemble of 16 IPCC Fourth Assessment Report (AR4) global circulation models (GCM) statistically downscaled to 12 square kilometers.[10] These global circulation models are coupled atmospheric-ocean general circulation models that project the response of global climate system parameters to perturbations (e.g. changes in solar radiation, chemical composition of the atmosphere) to the climate system. We focused our analyses on the ensemble of GCM outputs under three different greenhouse gas (GHG) emission scenarios: B1, A1B, and A2.[11] The data set provide departures of temperature and precipitation from a historic reference period, in this case 1961–1990. It is critical to note that these models do not provide accurate predictions of future climate for any given location or specific time period.[9] Furthermore, the emissions scenarios used are based on plausible storylines of how human society could develop in the future relative to energy use, population growth, and technology generation. Although the mechanics behind climate and the influence of GHGs are quite well understood by the scientific community, there is currently no way to be certain about which way, or how closely, society will follow these potential development pathways.

Figure 2

Figure 2 is a compilation of historic[4] and future temperature[10] data across the Southwest that was constructed to allow the reader to compare historic temperature change to future projections in temperature change. Here we note assumptions that we made in order to create this figure. We placed historic temperature change from the PRISM data set on the same graph with future temperature change from the ensemble of 16 GCMs. The future data represents the ensemble average departure of temperature from 16 GCMs from a reference period, 1961–1990. Note that this timeframe of this reference period is slightly different than our historical data set (1961–1990 vs. 1951–2006), and also note that the PRISM data set was not used in order to calculate these departures. Given that GCM output provide a range of predicted temperatures, we think that these assumptions are acceptable.

S1 Footnotes/References

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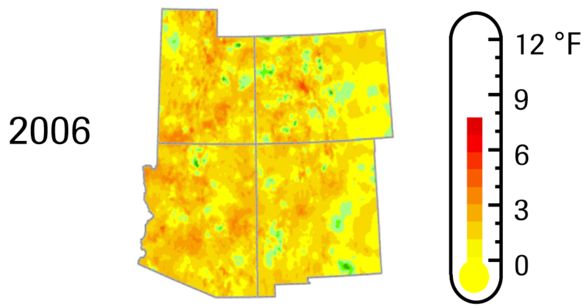
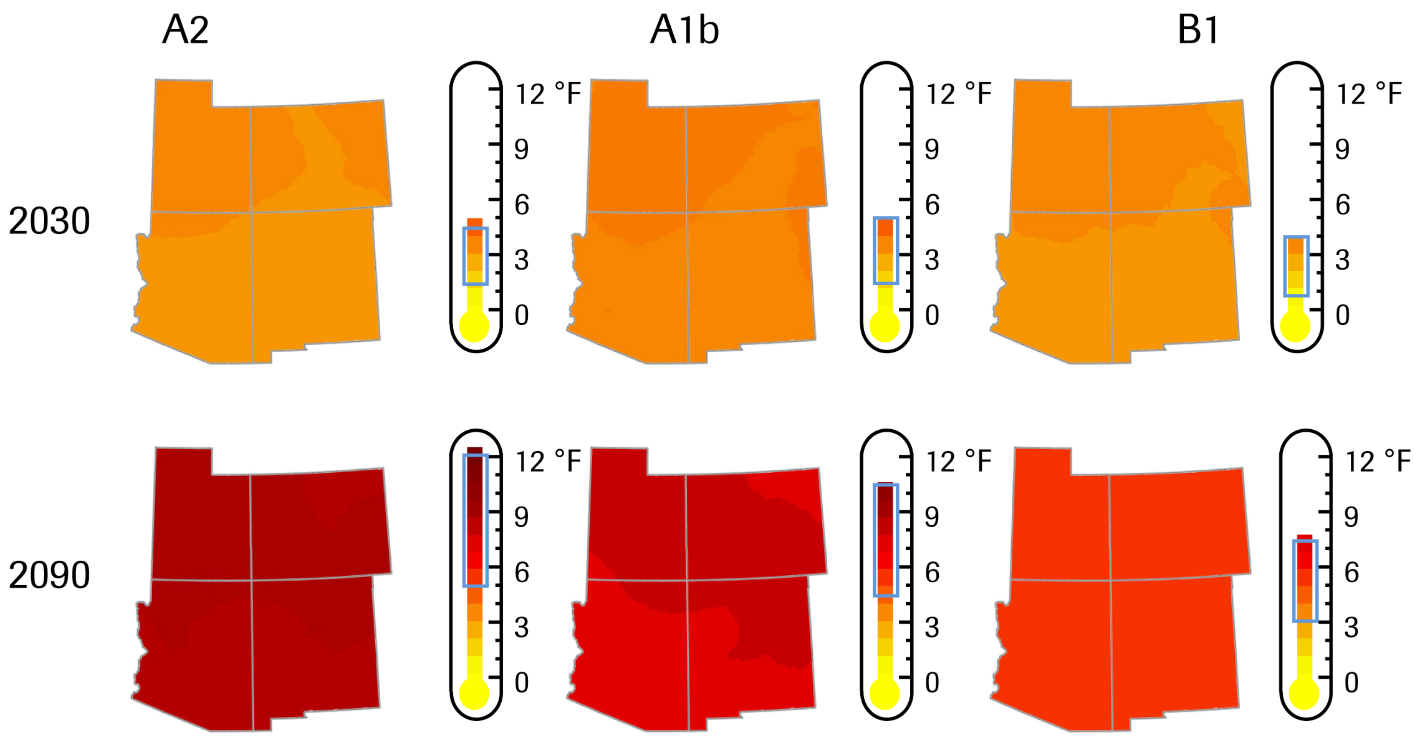
SI 2: Maps of climate change in the Southwest



Visual display of data shown in Figures 1 and 2. First map (2006) shows temperature change from 1951-2006.[1] Next 6 maps show projected changes in temperature under 3 climate change scenarios (A2, A1b, B1) in 2030 and 2090 respectively.[2] 2030 numbers represents the average from 2020 to 2040. 2090 numbers represents the average from 2080 to 2100. Colors displayed in maps represent the median value output from 16 Global Circulation Models from the IPCC 4th assessment while the blue boxes displayed within each thermometer show the range (between 20th and 80th percentiles) of temperature projections for that time period and scenario.



S2 Footnotes/References

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SI 3: Climate change vulnerability and vulnerability assessments

Vulnerability

Climate change vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes.[1] Broken down, vulnerability (V) is comprised of these components:

V = (exposure + sensitivity) − adaptive capacity

Here, exposure refers to the general degree, duration, and/or extent in which a system is in contact with a climate-related disturbance. The term is also commonly used in other contexts, such as human and occupational health, where there is a high of confidence that long-term, chronic exposure to certain chemicals can increase a person's chance of contracting disease. For example, people that smoke tobacco for long periods increasingly run the risk of developing lung cancer. Although medical professionals cannot be 100% certain a smoker will contract cancer, they still advise smokers to quit to reduce the risk of a very negative outcome. In the natural world, when habitats, plants and animals are exposed to long-term temperature or precipitation levels that are beyond what a system or habitat can tolerate, scientists are confident that the optimal functioning (or "health") of these species and systems will be compromised.

There are other factors, too, that may pre-dispose some species or habitats to have greater or less climate sensitivity (the degree to which a system or species is affected directly or indirectly and either adversely or beneficially by climate variability or change). Adaptive capacity refers to the ability of a system to adjust to climate change to minimize potential damages, to take advantage of opportunities, or to cope with consequences. This can refer directly to an organism's inherent genetic ability to adapt to change over the long-term (across generations via evolution) or its capacity to adjust to new environmental circumstances in the short-term (within one generation via phenotypic plasticity). In other words, adaptive capacity may actually offset some effects associated with exposure and sensitivity, thus reducing vulnerability.

Vulnerability Assessments

Assessments of vulnerability are a key tool for climate change adaptation planning, where adaptation refers to preparing for and responding to the negative impacts of climate change. Vulnerability assessments are often used as a first step in this planning process. They are not necessarily a prerequisite to identifying adaptation strategies (management actions that may help build species or habitat resilience), yet they can improve identification if applied strategically.[2] Furthermore, vulnerability assessments can allow scarce resources for biodiversity conservation to be allocated more effectively. Additional rationale for conducting vulnerability assessments at the regional scale include:[3]

- To support decisions about the selection of conservation priorities and investment in them.
- To understand regional implications for priorities with high conservation importance (value).
- To raise public awareness of climate change threats to biodiversity and ecosystem services.

A number of vulnerability assessment methodologies exist.[4–8] Similar to classic risk-hazards assessment, a top-down approach is often used when first evaluating past and future climate exposure on a broad scale, followed by assessing a focal unit's (such as a species or habitat) sensitivity to this exposure. Ideally, this would be followed by analysis of the focal unit's adaptive capacity. However, this can be the most challenging component of vulnerability to measure. Bottom-up approaches typically are the reverse of top-down approaches.

Place-based Vulnerability Assessment used in this Report

In this report, we wanted to provide managers and planners with information regarding the potential impacts of recent climate change on the resources that they manage—habitats, watersheds and species of concern—that could provide some preliminary guidance on how they could adjust or adapt their management and planning activities. Due to the fact that we wanted to conduct a coarse regional-scale assessment and given several data constraints, we were not able to conduct a vulnerability assessment of these resources in the strict sense, but instead attempted to synthesize information that was readily available. Standardized information on the sensitivity and adaptive capacity of natural resources (habitats, watersheds, species) in the Southwest is simply not available in a comprehensive or scientifically-credible fashion.

Instead, we adopted a top-down approach by primarily focusing on exposure, or more specifically, temperature change across the region from 1951-2006 (we chose recent temperature change for reasons that are fully described in the report). Then, we developed a crude index of "place-based" sensitivity by evaluating the number of species of concern (see definition in report) that fall with habitats and watersheds in the Southwest. Our hope was to capture the collection of species, organized by the habitats and watersheds that host them, that are a priority for many federal and state agencies. We see this assessment as one tool that can be managers can use to evaluate options at the regional scale. It can be viewed as complementary to assessments that are conducted at finer scales for a smaller set of species, habitats, or watersheds.

To be sure, many of the species we selected are likely to be sensitive to climate change. Many of these rare species have characteristics that can make them vulnerable to climate change, including isolated populations, limited distributions, restriction to specific physical habitats (edaphic, geology, snow, water), and limited ability to disperse or migrate.[9] The freshwater species that we evaluated for watersheds are certainly vulnerable to climate change given that many of the temperature-mediated changes in the southwest are manifested as changes in hydrology.

We recognize that it is a top priority for scientists and managers to conduct research that provides a better understanding of species-climate threshold relationships. As this information emerges, additional vulnerability assessments could be completed that compare exposure and sensitivity in a more concise fashion.

S3 Footnotes/References

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SI 4: Habitat Data

Description of Macrogroups

The dataset was based on a nationwide map and dataset of ecological systems.[1] NatureServe staff assisted in the aggregation of this dataset to the macrogroup classification level. We then changed the technical names of the macrogroups to simpler descriptive names and in a few cases, aggregated macrogroups. The table below shows the original macrogroup and ecological system names. Label and name attributes show the information that is displayed in Figure 6 of the main report. Macrogroup and ecological system show the original names from the National Vegetation Classification Standard.[1]

Label	Name	MACROGROUP	Ecological System	Notes
1	Desert Salt Flat	Cool Semi-Desert Alkali-Saline Wetland	Inter-Mountain Basins Playa	
1	Desert Salt Flat	Cool Semi-Desert Alkali-Saline Wetland	Inter-Mountain Basins Greasewood Flat	
2	Alpine	Rocky Mountain Alpine Scrub, Forb Meadow & Grassland	Rocky Mountain Alpine Dwarf-Shrubland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Rocky Mountain Alpine Scrub, Forb Meadow & Grassland; Rocky Mountain Alpine Cliff, Scree & Rock Vegetation)
2	Alpine	Rocky Mountain Alpine Scrub, Forb Meadow & Grassland	Rocky Mountain Alpine Fell-Field	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Rocky Mountain Alpine Scrub, Forb Meadow & Grassland; Rocky Mountain Alpine Cliff, Scree & Rock Vegetation)
2	Alpine	Rocky Mountain Alpine Scrub, Forb Meadow & Grassland	Rocky Mountain Alpine Turf	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Rocky Mountain Alpine Scrub, Forb Meadow & Grassland; Rocky Mountain Alpine Cliff, Scree & Rock Vegetation)

Label	Name	MACROGROUP	Ecological System	Notes
2	Alpine	Rocky Mountain Alpine Cliff, Scree & Rock Vegetation	Rocky Mountain Alpine Bedrock and Scree	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Rocky Mountain Alpine Scrub, Forb Meadow & Grassland; Rocky Mountain Alpine Cliff, Scree & Rock Vegetation)
3	Mojave-Sonoran Desert	Mojave-Sonoran Semi-Desert Scrub	North American Warm Desert Active and Stabilized Dune	
3	Mojave-Sonoran Desert	Mojave-Sonoran Semi-Desert Scrub	Mojave Mid-Elevation Mixed Desert Scrub	
3	Mojave-Sonoran Desert	Mojave-Sonoran Semi-Desert Scrub	Sonora-Mojave Creosotebush-White Bursage Desert Scrub	
3	Mojave-Sonoran Desert	Mojave-Sonoran Semi-Desert Scrub	Sonoran Mid-Elevation Desert Scrub	
3	Mojave-Sonoran Desert	Mojave-Sonoran Semi-Desert Scrub	Sonoran Paloverde-Mixed Cacti Desert Scrub	
4	Desert Canyonland & Rock	North American Warm Semi-Desert Cliff, Scree & Rock Vegetation	North American Warm Desert Bedrock Cliff and Outcrop	
4	Desert Canyonland & Rock	North American Warm Semi-Desert Cliff, Scree & Rock Vegetation	North American Warm Desert Badland	
4	Desert Canyonland & Rock	North American Warm Semi-Desert Cliff, Scree & Rock Vegetation	North American Warm Desert Pavement	
4	Desert Canyonland & Rock	North American Warm Semi-Desert Cliff, Scree & Rock Vegetation	North American Warm Desert Volcanic Rockland	
5	Singleleaf Piñon-Juniper Woodland	Intermountain Singleleaf Pinyon-Western Juniper Woodland	Great Basin Pinyon-Juniper Woodland	
5	Singleleaf Piñon-Juniper Woodland	Intermountain Singleleaf Pinyon-Western Juniper Woodland	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	
5	Singleleaf Piñon-Juniper Woodland	Intermountain Singleleaf Pinyon-Western Juniper Woodland	Inter-Mountain Basins Juniper Savanna	
6	Inter-Mountain Canyonland & Rock	Inter-Mountain Basin Cliff, Scree & Rock Vegetation	Inter-Mountain Basins Volcanic Rock and Cinder Land	
6	Inter-Mountain Canyonland & Rock	Inter-Mountain Basin Cliff, Scree & Rock Vegetation	Inter-Mountain Basins Shale Badland	

Label	Name	MACROGROUP	Ecological System	Notes
6	Inter-Mountain Canyonland & Rock	Inter-Mountain Basin Cliff, Scree & Rock Vegetation	Inter-Mountain Basins Active and Stabilized Dune	
6	Inter-Mountain Canyonland & Rock	Inter-Mountain Basin Cliff, Scree & Rock Vegetation	Inter-Mountain Basins Cliff and Canyon	
6	Inter-Mountain Canyonland & Rock	Inter-Mountain Basin Cliff, Scree & Rock Vegetation	Colorado Plateau Mixed Bedrock Canyon and Tableland	
7	Madrean Pine & Oak Woodland	Madrean Warm Montane Forest & Woodland	Madrean Lower Montane Pine-Oak Forest and Woodland	
7	Madrean Pine & Oak Woodland	Madrean Warm Montane Forest & Woodland	Madrean Upper Montane Conifer-Oak Forest and Woodland	
8	Rocky Mountain Canyonland & Rock	Rocky Mountain Cliff, Scree & Rock Vegetation	Rocky Mountain Cliff, Canyon and Massive Bedrock	
9	Chaparral	Warm Interior Chaparral	Madrean Oriental Chaparral	
9	Chaparral	Warm Interior Chaparral	Mogollon Chaparral	
9	Chaparral	Warm Interior Chaparral	Sonora-Mojave Semi-Desert Chaparral	
10	Inter-Mountain Grassland	Intermountain Dry Shrubland & Grassland	Colorado Plateau Blackbrush-Mormon-tea Shrubland	
10	Inter-Mountain Grassland	Intermountain Dry Shrubland & Grassland	Southern Colorado Plateau Sand Shrubland	
10	Inter-Mountain Grassland	Intermountain Dry Shrubland & Grassland	Inter-Mountain Basins Semi-Desert Shrub-Steppe	
10	Inter-Mountain Grassland	Intermountain Dry Shrubland & Grassland	Inter-Mountain Basins Semi-Desert Grassland	
11	Tall Sage Shrubland	Western North America Tall Sage Shrubland & Steppe	Great Basin Xeric Mixed Sagebrush Shrubland	
11	Tall Sage Shrubland	Western North America Tall Sage Shrubland & Steppe	Inter-Mountain Basins Big Sagebrush Shrubland	
11	Tall Sage Shrubland	Western North America Tall Sage Shrubland & Steppe	Inter-Mountain Basins Big Sagebrush Steppe	
11	Tall Sage Shrubland	Western North America Tall Sage Shrubland & Steppe	Inter-Mountain Basins Montane Sagebrush Steppe	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Rocky Mountain Aspen Forest and Woodland	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Rocky Mountain Lodgepole Pine Forest	

Label	Name	MACROGROUP	Ecological System	Notes
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	
12	Subalpine Conifer Forest	Rocky Mountain Subalpine & High Montane Conifer Forest	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	
13	Montane Shrubland	Southern Rocky Mountain Montane Shrubland	Rocky Mountain Lower Montane-Foothill Shrubland	
13	Montane Shrubland	Southern Rocky Mountain Montane Shrubland	Rocky Mountain Gambel Oak-Mixed Montane Shrubland	
14	Two-needle Piñon-Juniper Woodland	Rocky Mountain Two-needle Pinyon-Juniper Woodland	Colorado Plateau Pinyon-Juniper Woodland	
14	Two-needle Piñon-Juniper Woodland	Rocky Mountain Two-needle Pinyon-Juniper Woodland	Southern Rocky Mountain Pinyon-Juniper Woodland	
14	Two-needle Piñon-Juniper Woodland	Rocky Mountain Two-needle Pinyon-Juniper Woodland	Colorado Plateau Pinyon-Juniper Shrubland	
14	Two-needle Piñon-Juniper Woodland	Rocky Mountain Two-needle Pinyon-Juniper Woodland	Southern Rocky Mountain Juniper Woodland and Savanna	
15	Madrean Piñon-Juniper Encinal Woodland	Madrean Warm Lowland Evergreen Woodland	Madrean Encinal	
15	Madrean Piñon-Juniper Encinal Woodland	Madrean Warm Lowland Evergreen Woodland	Madrean Pinyon-Juniper Woodland	
16	Saltbrush Desert	Cool Semi-Desert Saltbrush Scrub	Inter-Mountain Basins Mat Saltbush Shrubland	
16	Saltbrush Desert	Cool Semi-Desert Saltbrush Scrub	Inter-Mountain Basins Mixed Salt Desert Scrub	
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Recently Logged Areas	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)

Label	Name	MACROGROUP	Ecological System	Notes
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Rocky Mountain Bigtooth Maple Ravine Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
17	Montane Forest	Northern Rocky Mountain Lower Montane & Foothill Forest	Rocky Mountain Foothill Limber Pine-Juniper Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)

Label	Name	MACROGROUP	Ecological System	Notes
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Southern Rocky Mountain Ponderosa Pine Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
17	Montane Forest	Northern Rocky Mountain Lower Montane & Foothill Forest	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
17	Montane Forest	Southern Rocky Mountain Lower Montane Forest	Southern Rocky Mountain Ponderosa Pine Savanna	Grouped 2 macrogroups for mapping and climate change analysis shown in in Figure 6 (Southern Rocky Mountain Lower Montane Forest; Northern Rocky Mountain Lower Montane & Foothill Forest)
18	Montane Grassland	Rocky Mountain-Vancouverian Montane Dry Grassland	Northern Rocky Mountain Subalpine-Upper Montane Grassland	
18	Montane Grassland	Rocky Mountain-Vancouverian Montane Dry Grassland	Southern Rocky Mountain Montane-Subalpine Grassland	
19	Semi-Desert Grassland	Chihuahuan Semi-Desert Grassland	Madrean Juniper Savanna	
19	Semi-Desert Grassland	Chihuahuan Semi-Desert Grassland	Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	
19	Semi-Desert Grassland	Chihuahuan Semi-Desert Grassland	Chihuahuan Gypsophilous Grassland and Steppe	
19	Semi-Desert Grassland	Chihuahuan Semi-Desert Grassland	Chihuahuan Sandy Plains Semi-Desert Grassland	
19	Semi-Desert Grassland	Chihuahuan Semi-Desert Grassland	Chihuahuan Loamy Plains Desert Grassland	
20	Chihuahuan	Chihuahuan Desert Scrub	Chihuahuan Creosotebush Desert Scrub	
20	Chihuahuan	Chihuahuan Desert Scrub	Chihuahuan Stabilized Coppice Dune and Sand Flat Scrub	

Label	Name	MACROGROUP	Ecological System	Notes
20	Chihuahuan	Chihuahuan Desert Scrub	Chihuahuan Succulent Desert Scrub	
20	Chihuahuan	Chihuahuan Desert Scrub	Apacherian-Chihuahuan Mesquite Upland Scrub	
20	Chihuahuan	Chihuahuan Desert Scrub	Chihuahuan Mixed Desert and Thorn Scrub	
21	Dwarf Sage Shrubland	Western North America Dwarf Sage Shrubland & Steppe	Colorado Plateau Mixed Low Sagebrush Shrubland	
21	Dwarf Sage Shrubland	Western North America Dwarf Sage Shrubland & Steppe	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	
22	Sand Grassland	Great Plains Sand Grassland & Shrubland	Western Great Plains Sandhill Steppe	
22	Sand Grassland	Great Plains Sand Grassland & Shrubland	Western Great Plains Sand Prairie	
23	Shortgrass Prairie	Great Plains Shortgrass Prairie & Shrubland	Western Great Plains Mesquite Woodland and Shrubland	
23	Shortgrass Prairie	Great Plains Shortgrass Prairie & Shrubland	Western Great Plains Shortgrass Prairie	
24	Inter-Mountain Salt Flat	Warm Alkaline-Saline Semi-Desert Scrub	Chihuahuan Mixed Salt Desert Scrub	
24	Inter-Mountain Salt Flat	Warm Alkaline-Saline Semi-Desert Scrub	Sonora-Mojave Mixed Salt Desert Scrub	
25	Mixedgrass Prairie	Great Plains Mixedgrass Prairie & Shrubland	Central Mixedgrass Prairie	
25	Mixedgrass Prairie	Great Plains Mixedgrass Prairie & Shrubland	Northwestern Great Plains Mixedgrass Prairie	
25	Mixedgrass Prairie	Great Plains Mixedgrass Prairie & Shrubland	Western Great Plains Foothill and Piedmont Grassland	
	MAPPED, NOT LABELED OR ANALYZED		Agriculture - General	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Agriculture - Pasture/Hay	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.

Label	Name	MACROGROUP	Ecological System	Notes
	MAPPED, NOT LABELED OR ANALYZED		Agriculture - Cultivated Crops and Irrigated Agriculture	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Developed-Open Space	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Developed-Low Intensity	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Developed-Medium Intensity	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Developed-High Intensity	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Non-Specific Disturbed	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Recently Burned	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Introduced Upland Vegetation - Annual and Biennial Forbland	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.

Label	Name	MACROGROUP	Ecological System	Notes
	MAPPED, NOT LABELED OR ANALYZED		Introduced Upland Vegetation - Annual Grassland	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Introduced Upland Vegetation - Perennial Grassland and Forbland	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Introduced Riparian Vegetation	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED		Introduced Wetland Vegetation	Human disturbed systems not classified in macrogroup classification; shown in Figure 6 in gray but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED	Water/Ice	Open Water	Water systems shown in Figure 6 in dark blue but not labeled. Temperature change, species, not evalated.
	MAPPED, NOT LABELED OR ANALYZED	Water/Ice	North American Glacier and Ice Field	Water systems shown in Figure 6 in blue but not labeled. Temperature change, species, not evalated.
	NOT MAPPED OR ANALYZED	Northern Rocky Mountain Lower Montane & Foothill Forest	Northwestern Great Plains - Black Hills Ponderosa Pine Woodland and Savanna	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Northern Rocky Mountain Lower Montane & Foothill Forest	Northern Rocky Mountain Foothill Conifer Wooded Steppe	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Badlands Vegetation	Western Great Plains Badlands	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.

Label	Name	MACROGROUP	Ecological System	Notes
	NOT MAPPED OR ANALYZED	Great Plains Cliff, Scree & Rock Vegetation	Western Great Plains Cliff and Outcrop	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Cool Semi-Desert Xero-Riparian	Inter-Mountain Basins Wash	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Semi-Desert & Mediterranean Alkaline-Saline Wetland	North American Warm Desert Playa	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Cliff, Scree & Rock Vegetation	Southwestern Great Plains Canyon	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Cool Interior Chaparral	Great Basin Semi-Desert Chaparral	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Northern Rocky Mountain Lowland Grassland & Shrubland	Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain-Vancouverian Mesic Grass & Forb Meadow	Rocky Mountain Subalpine-Montane Mesic Meadow	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Tallgrass Prairie & Shrubland	Western Great Plains Tallgrass Prairie	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm-Desert Xero-Riparian	North American Warm Desert Wash	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.

Label	Name	MACROGROUP	Ecological System	Notes
	NOT MAPPED OR ANALYZED	Great Plains Flooded & Swamp Forest	Western Great Plains Floodplain	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain and Great Basin Flooded & Swamp Forest	Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain and Great Basin Flooded & Swamp Forest	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain and Great Basin Flooded & Swamp Forest	Rocky Mountain Subalpine-Montane Riparian Woodland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Desert Riparian, Flooded & Swamp Forest	North American Warm Desert Lower Montane Riparian Woodland and Shrubland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Desert Freshwater Shrubland, Meadow & Marsh	North American Warm Desert Riparian Mesquite Bosque	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Desert Riparian, Flooded & Swamp Forest	North American Warm Desert Riparian Woodland and Shrubland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain and Great Basin Flooded & Swamp Forest	Rocky Mountain Subalpine-Montane Riparian Shrubland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Freshwater Marsh	Western Great Plains Depressional Wetland Systems	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.

Label	Name	MACROGROUP	Ecological System	Notes
	NOT MAPPED OR ANALYZED	Western North American Wet Meadow & Low Shrub Carr	Rocky Mountain Alpine-Montane Wet Meadow	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Freshwater Marsh	Western Great Plains Open Freshwater Depression Wetland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Desert Freshwater Shrubland, Meadow & Marsh	North American Arid West Emergent Marsh	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Rocky Mountain Subalpine & Montane Fen	Rocky Mountain Subalpine-Montane Fen	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Brackish Marsh & Saline Wet Meadow	Western Great Plains Saline Depression Wetland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Flooded & Swamp Forest	Northwestern Great Plains Riparian	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Great Plains Flooded & Swamp Forest	Western Great Plains Riparian	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Warm Desert Freshwater Shrubland, Meadow & Marsh	Chihuahuan-Sonoran Desert Bottomland and Swale Grassland	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.
	NOT MAPPED OR ANALYZED	Western North America Dwarf Sage Shrubland & Steppe	Columbia Plateau Low Sagebrush Steppe	Limited distribution in Southwest. Source data may not accurately map extent (e.g. freshwater system). Did not map or analyze.

S4 Endnotes

[1]NatureServe. 2009. US National Vegetation Classification (US NVC) Macrogroup level map. Boulder, CO: NatureServe.

SI 5. Evidence of climate change impacts on species and habitats in the Southwest

The following table contains information regarding ecological changes that have been linked to temperature change in the Southwest. Four types of ecological change were identified: animal species population shifts, changes, or declines; plant species population shifts, changes, or declines; changes in the timing of life-history events; and, uncharacteristic large wildfires. We only cite peer-reviewed articles where the author(s) provide evidence that recent temperature change contributed to an ecological change.

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
2	Alpine	Animal species population shift, decline or change	Species	1	~30% of Pika populations known from 20th century in the Great Basin have been extirpated. Extirpated populations occurred in northwestern Nevada and southern Oregon. One of the contributing factors to this trend is warmer temperatures: "...warmer temperatures seem likely to be contributing to the apparent losses that have occurred at a pace significantly more rapid than that suggested by paleoecological records." Temperatures at extirpated sites were 7-10% higher than extant sites.	Beever et al. 2003
3	Mojave-Sonoran Desert	Phenological Change	Species	93 species across 2 habitats: mojave-sonoran desert; madrean pine-oak	20-year observation dataset along a Sky Island Mountain trail in Tucson (AZ) shows changes in the elevation at which plant species flower from an earlier period (1884-1993) to a latter period (1994-2003). Phenological change occured across three habitats in this study: Mojave-Sonoran Desert; Madrean Pine & Oak Forest; and Montane Forest. Phenological change is consistent with and associated with statistically significant higher summer temperatures (~2F) in the latter period.	Crimmins et al. 2009

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
7	Madrean Pine & Oak Woodland	Phenological Change	Species	93 species across 2 habitats: mojave-sonoran desert; madrean pine-oak	20-year observation dataset along a Sky Island Mountain trail in Tucson (AZ) shows changes in the elevation at which plant species flower from an earlier period (1884-1993) to a latter period (1994-2003). Phenological change occured across three habitats in this study: Mojave-Sonoran Desert; Madrean Pine & Oak Forest; and Montane Forest. Phenological change is consistent with and associated with statistically significant higher summer temperatures (~2F) in the latter period.	Crimmins et al. 2009
7	Madrean Pine & Oak Woodland	Uncharteristic Fire	Landscape	2	Recent changes in fire regimes from low-intensity, frequent fires to high-intensity, stand-replacing crown fires have led to changes in community composition in these forests. The abundance and basal area of oaks after recent fires has increased, wherease, pines have declined. Affected pines are: Chihuahuan Pine (Pinus leiophylla var. chihuahuana) and Apache Pine (Pinus engelmannii). The key ecological difference seems to be that oaks species sprout prolifically after these fires, whereas pines are unable to do so. The change in the fire regime in these forests is associated with fire suppression (Barton 2002), but regional climate change has probably also played a role (Westerling et al. 2006).	Barton 2002 Westerling et al. 2006
7	Madrean Pine & Oak Woodland	Phenological Change	Species	1	Mean date of 1st clutch of Aphelocoma ultramarina (Mexican Jay) earlier by 10 days (1971-1997); trend is associated with rising minimum temperature in month before & during breeding season	Brown et al. 1999

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
11	Tall Sage Shrubland	Animal species population shift, decline or change	Species	1	Only 36% historic sites of pygmy rabbits (Brachylagus idahoensis) in California and Nevada are currently occupied. Mean elevation of currently occupied sites is 157 m higher than sites where no rabbits were found, suggesting extirpations have occurred at lower elevation sites. This increase in mean elevation is consistent with warming patterns at lower elevations. The authors suggest that warmer temperatures, less snow, and shorter duration of snowpack may increase predation on rabbits. While study sites were only in CA and NV, pygmy rabbits occur in similar habitats in western Utah, where, in this study, we documented a 1.6 deg F rise in temperatures in the last 55 years.	Larrucea and Brussard 2008
12	Subalpine Conifer Forest	Animal species population shift, decline or change	Species	1	~30% of Pika populations known from 20th century in the Great Basin have been extirpated. Extirpated populations occurred in northwestern Nevada and southern Oregon. One of the contributing factors to this trend is warmer temperatures: "...warmer temperatures seem likely to be contributing to the apparent losses that have occurred at a pace significantly more rapid than that suggested by paleoecological records." Temperatures at extirpated sites were 7-10% higher than extant sites.	Beever et al. 2003
12	Subalpine Conifer Forest	Phenological Change; Plant species population shift, change or decline	Species	3	30yr trend of warmer springs and earlier snowmelt leads to earlier flowering dates of subalpine plants. Earlier flowering has led to an increase in frequency of frost damage in summer months. Effected species are: Delphinium barbeyi, Erigeron speciosus, and Helianthella quinquenervis. Changes in phenology is likely to lead to changes in community composition and pollinators.	Inouye 2008, Miller-Rushing and Inouye 2009, Forrest et al. 2010
12	Subalpine Conifer Forest	Phenological Change; Animal species population shift, decline or change	Species	2	As a consequence of warmer spring temperatures, yellow-bellied marmots are emerging from hibernation earlier. Earlier emergence from hibernation has led to greater mean body mass and an increase in population size (~2000-2007 versus 1976-2000). At same site, and associated with similar trend of warmer spring temperatures, robins are migrating from mid elevation sites to high elevation sites earlier.	Ozgul et al. 2010; Inouye et al. 2000

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
12	Subalpine Conifer Forest	Plant species population shift, change or decline	Species	2 (species duplicative with van Mantgem et al. 2009)	Increase in rates of drought-induced mortality observed in 2 species, Abies lasiocarpa (Subalpine fir) and Picea engelmannii (Engelmann spruce), from 1910-2004 in 1 northern Colorado subalpine forest site. The mortality pattern is associated with changes in water deficits (calculated from monthly temperature and precipitation estimates), particularly from 1978-2004, a period of pronounced warming. There were strong intra-specific sensitivites to drought conditions: "...subalpine fir showed most persistent drought-mortality assocation, whereas Engelmann spruce showed a weaker association, and lodgepole pine showed no such assocation."	Bigler et al. 2007
12	Subalpine Conifer Forest	Plant species population shift, change or decline	Species	1	Warm drought (high temperatures + below-average precipitation) was a primary factor for inciting sudden aspen decline (SAD) in 2002 for aspen trees in Southwestern Colorado. A climate moisture index showed greater moisture deficits on sites with high SAD damage than those with lower moisture deficits. For our habitat classification, aspen occurs is transitional between montane forests and subalpine forests.	Worrall et al. 2010
12	Subalpine Conifer Forest	Plant species population shift, change or decline	Species	4	Detected trend in recent decades of increased rate of background mortality for old-growth forest trees across the West; trend is consistent with regional warming and associated increase in water deficits. Study included 8 forest plots in Southwest including following trees found in this habitat: Abies lasiocarpa (subalpine fir) Picea engelmannii (Engelmann spruce) Pinus flexilis (limber pine) Pinus contorta (lodgepole pine)	van Mantgem et al. 2009

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
14	Two-needle Piñon-Juniper Woodland	Plant species population shift, change or decline	Species; Landscape	1	Landscape-scale mortality of Pinus Edulis trees associated with higher temperatures and drought; widespread phenomena throughout southwest	Breshears et al. 2005 Adams et al. 2009
15	Madrean Piñon-Juniper Encinal Woodland	Phenological Change	Species	1	Mean date of 1st clutch of Aphelocoma ultramarina (Mexican Jay) earlier by 10 days (1971-1997); trend is associated with rising minimum temperature in month before & during breeding season	Brown et al. 1999
17	Montane Forest	Plant species population shift, change or decline	Species	1	Detected trend in recent decades of increased rate of background mortality for old-growth forest trees across the West; trend is consistent with regional warming and associated increase in water deficits. Study included 8 forest plots in Southwest including following trees found in this habitat: Pinus ponderosa (ponderosa pine)	van Mantgem et al. 2009
17	Montane Forest	Phenological Change	Species	5	~ 30 year trend (1987-2005) where 5 bird species in montane forest riparian areas in central Arizona are laying their eggs earlier concomitant with increasing average May temperatures. Birds are found in riparian stringers embedded within ponderosa pine forests. Effected bird species are: hermit thrush (Catharus guttatus), orange-crowned warbler (Verminora celata), red-faced warbler (Cardellina rubrifrons), Virginia's warbler (Vermivora virginiae), and gray-headed junco (Junco hyemalis caniceps). Also, duration of breeding season for 2 multi-brood species also increased over this period: gray-headed junco and hermit thrush.	Martin 2007

Label	Habitat Name	Ecological Impact Type	Level of Impact	# effected species	Trend & Geography	Citations
17	Montane Forest	plant species population shift, change or decline; Animal species population shift, change or decline	Species	6 (2 overlapping with Martin 2007 phenological change)	~ 30 year trend (1987-2005) of declining snowfall which is thought to be associated with regional warming (Mote et al. 2005) has resulted on cascading trophic effects on the structure of riparian habitats and bird densities within ponderosa pine sites in central Arizona. Author infers that declining snowfall led to higher browsing by elk and an observed decline in densities of canyon maple (Acer grandidentatum) and New Mexico locust (Robinia neomexicana) trees. These declines in riparian habitat in turn led to higher nest predation rates and declines in bird populations including local extirpation of MacGillivray's warbler (Oporornis tolmiei). Other birds with declining densities: green-tailed towhee (Pipilo chlorurus), orange-crowned warbler (Vermivora celata), and gray-headed junco (Junco hyemalis caniceps).	Martin 2007
17	Montane Forest	Uncharteristic Fire	Landscape		Increase in wildfire activity in mid-elevation forests (1680-2580m) since the mid-1980s across the western US; pattern is strongly associated with increased spring and summer temperatures and earlier spring melt. Spatial extent of increase in wildfire activity is most pronounced in the Northern Rockies; similar trend in Southwest, but region contributes less to regionwide pattern because of limited spatial distribution of forests in Southwest.	Westerling et al. 2006
18	Montane Grassland	Plant species population shift, change or decline	Landscape	-	Montane grassland area declined by 18% in 20th century from pine forest encroachment in a northern New Mexico site. Although the authors conclude that the cessation of fire is the single most important cause of this invasion, they note that the temporal trends of the tree invasion within lower elevation valley bottom grasslands is more episodic, and appears to be tracking summer temperatures. Pine growth and establishment is thought to be controlled by low minimum summer temperatures; mean summer minimum temperatures have risen since ~1975.	Coop and Givnish 2007
23	Shortgrass Prairie	Phenological Change	Species	1	Average body mass of white-throated woodrats, Neotoma albigula, declined in a central New Mexico grasslands site from 1989-1996 and this trend was correlated to ~ 2-3 deg C warmer mean winter and summer temperatures. As with other small mammals, body size of woodrats is apparently sensitive to fluctuations in temperature.	Smith et al. 1998

S5 Endnotes

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