Climate Change Vulnerability and Adaptation Strategies for Natural Communities

Piloting methods in the Mojave and Sonoran deserts

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Executive Summary

The earth's changing climate is forcing reconsideration of strategies for conserving natural resources. Managers need to understand where and when the resources they manage might be vulnerable to climate change. They also need a better understanding of the factors that contribute to that vulnerability. This knowledge is essential to determine which management actions will be suitable over the coming decades.

NatureServe worked with a number of federal, state, and NGO partners in the United States and Mexico to conduct a climate change vulnerability assessment of major natural community types found within the Mojave and Sonoran Deserts. The project focused on ten major upland, riparian, and aquatic community types, including pinyon-juniper woodlands, Joshua tree-blackbrush scrub, creosote-bursage scrub, salt desert scrub, Paloverde-mixed cacti scrub, semi-desert grassland, desert riparian and stream, riparian mesquite bosque, and desert springs. This effort piloted a new Habitat Climate Change Vulnerability Index (HCCVI) approach being developed by NatureServe, as a companion to an existing index for species. The project utilized existing data, much of which had been recently developed through the Bureau of Land Management's rapid ecoregional assessments, or by ongoing research efforts with FWS, NPS, and USGS. Once vulnerability assessments were drafted, an expert workshop was held to review and revise the assessments, and then apply the findings to identify climate change adaptation strategies applicable across managed lands within each ecoregion.

Components of the Climate Change Vulnerability Index for Ecosystems and Habitats (HCCVI)

The HCCVI aims to implement a series of measures addressing climate change sensitivity and ecological resilience for each community type for its distribution within a given ecoregion (in this case, the Mojave vs. Sonoran Desert). Since quantitative estimates may not be feasible for all measures, both numerical index scores (*normalized 0.0-1.0 scores*) and qualitative expert categorizations may be used in the HCCVI. The combined relative scores for **sensitivity** and **resilience** determine the categorical estimate of climate change vulnerability by the year 2060 (i.e., 50 years into the future) for a community type. While the overall index score for each community should be useful for regional and national priority-setting and reporting, the results of these individual analyses should provide insight to local managers for climate change adaptation. Index measures are organized within categories of **direct effects**, **indirect effects,** and **adaptive capacity**. A series of 3-5 measures, each requiring a separate type of analysis, produces sub-scores that are then used to generate an overall score for **sensitivity** (*from direct effects*) vs. **resilience** (*indirect effects + adaptive capacity*).

Direct effects can be addressed through several measures, depending on the natural characteristics of the community type. For example, analysis of downscaled global climate forecasts for temperature and precipitation variables provides an indication of the relative intensity of climate-induced stress. For upland vegetation, climate envelope models can be used to correlate and map current plant community distributions with a suite of key climate variables from a 20th century baseline. Then, the location of that same climate envelope as predicted for 2060 using climate forecasts, provides an indication of the directionality, magnitude, and overlap of geographic shift for species from the community. These can also provide insight about plausible patterns for successional dynamics and transitions across major vegetation on the regional landscape. Dynamic simulations of fire regime or hydrologic regime may be used to forecast trends in the alteration or 'departure' from expected conditions for upland vs. riparian/aquatic communities, respectively.

Indirect effects include trends in ecological integrity. These can indicate the potential for resilience to climate change. Analyses may include spatial models aiming to characterize the degree of landscape fragmentation or other anthropogenic impacts (such as invasive species) in the landscapes supporting a given community type. Dynamic simulations of fire regime or hydrologic regime may be used here, not for forecasting, but instead to characterize the past and current degree alteration or 'departure' from expected conditions for upland vs. riparian communities, respectively.

Adaptive capacity includes inherent characteristics of a natural community that make it more or less resilient to climate change. Attributes can include diversity within groups of species playing key functional roles. It could also include analysis of climate change vulnerability for species that may provide 'keystone' functions in the community. Additionally, the relative breadth of bioclimatic and elevation range that characterizes a communities natural distribution can indicate inherent capacity to cope with climate change.

For the HCCVI, climate-change vulnerability is expressed in four categories, including Very High, High, Moderate, and Low vulnerability. Therefore, the index ratings are quite general, but this is because predictive uncertainty is often high, and our overall intent is a generalized indication of vulnerability. This is analogous to a scoring of "endangered" or "threatened" for a given species, but here focused specifically on climate change vulnerability, and applied to community types.

This pilot analysis resulted in six type/ecoregion combinations being categorized high for climate-change vulnerability. These included Mojave Mid-Elevation [Joshua tree-Black brush] Desert Scrub (Mojave Desert), North American Warm Desert Riparian Woodland and Stream (Mojave and Sonoran deserts), North American Warm Desert Mesquite Bosque (Mojave and Sonoran deserts), Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Sonoran Desert). All other types were categorized as moderate for climate-change vulnerability. No types from this pilot analysis were categorized as either very high or low for climate-change vulnerability.

Given the **direct effects** measures aiming to gauge climate-change sensitivity, all but three types in the analysis resulted in the high-sensitivity category. The three types found to be in the moderate sensitivity category included Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Mojave Desert), Sonora-Mojave Mixed Salt Desert Scrub (Mojave Desert), and Apacherian-Chihuahuan Semi-Desert Grassland (Sonoran Desert). Climate envelope shift and dynamic process forecast scores determined these results.

Indirect effects scores fell between a low resilience score of 0.46 (North American Warm Desert Riparian Woodland and Shrubland (Mojave) and a high resilience score of 0.84 (North American Warm Desert Active and Stabilized Dunes (Sonoran). Eleven of 16 type/ecoregion combinations fell within the medium resilience range for their average scores. On the whole, average resilience scores tended to be pulled lower by either low scores for current landscape condition, current invasive species effects, current dynamic regime departure, or some combination of these three.

Adaptive capacity scores tended to contribute to higher overall resilience scores, with their averages ranging from a medium resilience score of 0.56 (North American Warm Desert Active and Stabilized Dunes- Sonoran) to a high resilience score of 0.83 (Desert Springs and Seeps – Mojave and Sonoran). On the whole, average resilience scores tended to be pulled lower by either low diversity within identified functional species groups (e.g., desert springs, mesquite bosque, mixed salt desert scrub), keystone

species vulnerability (e.g., creosote-bursage scrub, semi-desert grassland), or where types occur across a relatively narrow elevation range (6 types).

Overall resilience scores ranged from medium (8 types) to high (8 types); but these scores all fell into a narrow range between 0.63 and 0.74. A moderate climate-change vulnerability assessment resulted from the combination of 1) high sensitivity with high resilience (7 types), medium sensitivity and medium resilience (2 types) and 3) medium sensitivity and high resilience (1 type) combinations for a given community type.

Climate Change Adaptation includes actions that enable species, systems and human communities to better cope with or adjust to changing conditions. Some have categorized adaptation strategies into three areas, including resistance, resilience, and facilitated transformation. *Resistance* strategies aim to prevent the direct effects of climate change. *Resilience* strategies aim to secure the capacity to cope with the effects of climate change by ensuring that critical ecological process – as currently understood – are restored to a high level of function or integrity. *Facilitated Transformation* strategies anticipate the nature of climate-change induced transitions and, working with these anticipated trends, include actions that facilitate transitions that are congruent with future climate conditions, while minimizing ecological disruption.

There is also critical temporal dimension to climate-change adaptation. While traditional natural resource management has been 'retrospective' – utilizing knowledge of past and current conditions to inform today's management actions – planners are increasingly required to rigorously forecast future conditions. It is no longer sufficient to assess "how are we doing?" and then decide what actions should be prioritized for the upcoming 5-15 year management plan. One must now ask "where are we going, and by when?" and then translate that knowledge back into actions to take in the near-term, or medium-term, or those to monitor and anticipate taking over longer planning horizons.

The link between climate change vulnerability assessment and adaptation strategies was facilitated in this effort by a) selection of major natural communities as our units of analysis, and b) organizing local expert review within each ecoregion, where decisions across jurisdiction pertain to many of the same community types. The latter step was facilitated by a 2-day expert workshop. Workshop participants reviewed and refined each vulnerability assessment, and then most readily identified components of indirect effects scores (e.g., landscape condition, invasive species, dynamic process alteration) as forming the focus of many "no regrets" adaptation strategies that could be pursued by managers. In most cased, these factors relate to the stressors that are best known and are currently being addressed within managed areas. Where indirect effects stressors were less well known, and/or interactions with climate change were less clear, strategies tended to be categorized as "anticipated actions" within the 5-15 year timeframe, where additional information will be required to move forward, but participants could foresee their implementation.

Direct effects, such as climate stress and climate envelope shifts, challenged workshop participants to identify novel climate-change stressors for each community type, such as effects of heat stress or changes in seasonality of precipitation and their potential effects on functional species groups, such as pollinators. Given the limits to current knowledge in these areas, the strategies identified tended to fall in the "wait and watch" category, where research questions are specified and investment will be required over upcoming decades in order to determine appropriate management actions.

Introduction and Project Overview

Climate change represents a globally pervasive stress on natural ecosystems. Temperature and precipitation regimes drive ecosystem productivity and natural dynamics, such as the rate of plant growth, the frequency of natural wildfire, and the seasonal flow of streams. Paleoecology has shown that past episodes of climate change triggered ecosystem change at regional and local scales with varying speed and intensity (e.g., Wells 1983, Betencourt et al. 1990). As the current rate of global change increases, society can expect profound shifts in key ecological processes to cascade through natural systems, resulting in altered productivity, changes to species composition, local extinctions, and many instances of ecological degradation or collapse (IPCC 2007).

We are scarcely prepared for these changes. While the modern scientific study of ecosystems dates back over a century, we do not sufficiently understand the many linkages between key climate variables and ecosystem dynamics across diverse landscapes. Nor do we fully understand the effects of other stressors, such as those tied to land use, that have already reduced the resiliency of many natural ecosystems. One certain conclusion that we can draw from our experience is that *ecosystems will not simply 'move'* as climate changes, *but will instead transform* in unprecedented ways because of the controlling link between climate and many ecosystem processes (Fagre et al. 2009); including the individualistic responses of species (Gleason 1926, Finch 2012). In any given place, we need to better understand and assess the relative vulnerability of ecosystems, natural communities, and habitats to the specific climate-induced stressors that are most likely to occur there. We also need to integrate this assessment with knowledge of other existing stressors, such as land & water use change, non-native species invasions, and pollution effects. An integrated assessment will be needed to directly inform investments in adaptation strategies by all stakeholders.

The task then, is to develop tools that build on our current understanding of ecosystem processes, structure, and composition so that we can begin to evaluate possible vulnerabilities in a transparent way. Transparency is absolutely essential because it allows for measuring key inputs and outputs, documenting uncertainty, and revising assessments as new information becomes available (Nichols et al. 2011).

In sum, the challenges of climate change for conservation science in the coming decades are:

- to develop transparent, scientifically grounded forecasts of ecosystem characteristics that may enhance or inhibit their transformation under anticipated climate regimes;
- to clarify conservation strategies that strengthen ecosystem resilience and minimize the potential for ecological degradation or collapse through a loss of ecological integrity;

- to facilitate the natural transformation of ecosystems in ways that maximize retention of biodiversity and food-web dynamics, and;
- to identify adaptation action that has the greatest probability of success.

In order to address these challenges, NatureServe worked within the context of the Desert Landscape Conservation Cooperative (LCC) and with a number of federal, state, and private partners in the U.S. and Mexico, to pilot a climate change vulnerability assessment of major ecological community types found throughout the Mojave and Sonoran deserts. With advice and assistance from a project advisory committee[1] we identified high-priority community types for analysis. This pilot assessment addressed ten major upland, riparian, and freshwater types. The analysis drew largely on existing data from the Bureau of Land Management's (BLM) Rapid Ecoregional Assessments in the region, and from ongoing research efforts with FWS, NPS, USGS, and others. Managed areas that were represented in the effort included National Wildlife Refuges, Wilderness Areas, National Park units, other lands managed by BLM and by state agencies, and protected areas in Mexico as defined by the National Commission for Protected Natural Areas.

The primary aim of this effort was to characterize relative climate-change vulnerabilities of each community type, and then bring the results to local specialists to review, refine, and use in identifying adaptation strategies. As the project was initiated, an online survey was used to document the community types, climate change threats, and information needs that field specialists from the region perceived as most important. Once vulnerability assessments were drafted for the selected community types, regional specialists were gathered in a workshop to review and refine the assessment results, prioritize non-climate and novel climate-change stressors, and to clarify plausible climate-change scenarios for upcoming decades. Workshop participants then identified and initial, pragmatic list of adaptation strategies that might be pursued across multiple managed lands.

Assessment of climate change vulnerability for ecosystems and habitats can directly inform key conservation and resource management decisions in the 2012-2060 timeframe. It helps to determine those ecosystem types that, in all or part of their distribution, are most at risk of specific climate change effects; and assist with targeting species-based assessments. This information provides the baseline for developing scientifically grounded strategies for climate change adaptation. It also provides decision makers with the information to determine which adaptation options might have a higher probability of maintaining ecosystem resilience.

This project should contribute to the Desert LCC's mission of enhancing communications among agencies to facilitate achieving individual agency missions and goals through landscape scale approaches to resource conservation and stewardship. The vulnerability assessments, resulting adaptation strategies, and other recommendations by regional specialists were documented here for further consideration and development by partners of the Desert LCC.

[1] See Acknowledgements section for full listing of project advisory committee members and affiliated agencies.

Defining Climate-Change Vulnerability and Adaptation Strategies

The societal response to climate change involves much new science. Along with new science, comes new terminology. Here we define and summarize some key terminology and concepts applied throughout the project. First, the notion of vulnerability to climate change has been succinctly defined by the Intergovernmental Panel on Climate Change (IPCC 2001, 2007) as:

Climate Change Vulnerability - The degree to which a system is susceptible to - and unable to cope with - adverse effects of climate change; including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007).

This overall definition points to several contributing components of climate change vulnerability commonly used in current science. These include concepts of climate-change exposure, sensitivity, and adaptive capacity. These terms have been defined as:

- **Exposure** – The degree of climate stress upon a particular unit analysis; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events.
- **Sensitivity** – The degree to which a system will be affected by, or responsive to climate stimuli.
- **Adaptive Capacity** - the potential or capability of a system to adjust to climate change, including climate variability and extremes, so as to moderate potential damages, to take advantage of opportunities, or to cope with consequences.

Gauging climate change exposure involves evaluation of climate information, including past, current, and forecasted future conditions, in areas relevant to the resource of concern. These analyses may be applied at continental, or more local, spatial scales tailored to the distribution of the resource of concern. Gauging climate change sensitivity requires knowledge of the ecology of communities, and/or biology of component species, in order to measure the potential effects of climate change exposure. Gauging adaptive capacity builds on knowledge of the ecology of communities to consider factors that may – or may not – mitigate climate change sensitivities that have been identified.

By understanding the components of climate change vulnerability for a given resource of concern, resource managers and decision makers are better positioned to evaluate alternative actions to respond to climate change, even in the face of considerable uncertainty (Nichols et al. 2011). These alternative actions are known as climate change adaptation strategies.

Climate change adaptation strategies

Climate Change Adaptation includes actions that enable species, systems and human communities to better cope with or adjust to changing conditions. These strategies may take a number of forms. Some have categorized strategies into three areas, including resistance, resilience, and facilitated transformation (Biringer et al. 2003, Millar et al. 2007, McLachlin et al. 2007). *Resistance* strategies for adaptation aim to prevent the direct effects of climate change. Frequently cited examples include building sea walls and coastal hardening to prevent effects of coastal sea-level rise (Klein and Nicholls 1999). Preventive measures to head off effects of invasive species, or uncharacteristic landscape-scale fires, could also fall

into this category. *Resilience* strategies aim to secure the capacity to cope with the effects of climate change by ensuring that critical ecological process – as currently understood – are restored to a high level of function or integrity. For example, by securing large and interconnected natural landscapes, patterns of species dispersal and migration are secured to protect food-web dynamics. *Facilitated Transformation* strategies anticipate the nature of climate-change induced transitions and, working with these anticipated trends, include actions that facilitate transitions that are congruent with future climate conditions, while minimizing ecological disruption. Somewhat radical expressions of these strategies might include assisted migration of sensitive species from current habitats to locations where changing climates might provide new habitat into the future (McLachlin et al, 2007, Milly et al. 2008). Some have characterized these *resistance* and *resilience* strategies as 'retrospective' because they emphasize utilization of knowledge about historical or current ecological pattern and process; i.e., protection and restoration of natural conditions as they are currently understood. *Facilitated Transformation* is therefore a 'prospective' set of strategies in that they are based on the hypothesis of future conditions (Magnuss et al. 2011).

Finally, there is a critical temporal dimension to adaptation strategies. Conservation decisions are made by people, often within the policy constraints of current law and institutions. While traditional natural resource management has been 'retrospective' – utilizing knowledge of past and current conditions to inform today's management actions – planners are increasingly required to rigorously forecast future conditions (see e.g., Comer et al. 2012). This forecasting must strive to determine the nature and magnitude of change likely to occur, and translate that knowledge to current decision-making. It is no longer sufficient to assess "how are we doing?" and then decide what actions should be prioritized for the upcoming 5-15 year management plan. One must now ask "where are we going, and by when?" and then translate that knowledge back into actions to take in the near-term, or medium-term, or those to monitor and anticipate taking over multiple planning horizons. Considerable new science and policy will be required to support this new type of natural resource decision making.

Scales of Ecological Organization

Climate change vulnerability assessments can be aimed at different scales of ecological organization, including species, communities, or landscapes, just as conservation planning can target these same scales (Groves et al. 2002). Species, as well as subspecies, varieties, and populations, are concepts intuitively understood by the conservation community despite academic disagreement over just what they represent (de Quieroz 2007). Communities could include a variety of units (e.g., habitats for one or more species, vegetation communities, aquatic communities, etc) that have been defined in different ways but generally refer to assemblages of species that co-occur in space and time and interact with each other and their local environment. Landscapes (as units of analysis) typically describe recurrent patterns of communities and occupy geographical areas of varying size.

Regardless of the scale of ecological organization, climate change vulnerability assessments can and should address exposure, sensitivity, and adaptive capacity; the three main components of vulnerability. Different approaches are called for depending on the level in question. The **species** is perhaps the most common focus for vulnerability assessment and consequently has received extensive attention in the literature (e.g., Thomas et al. 2004, Laidre et al. 2008, Rowland et al. 2011). Trait-based approaches examine projected climate change where the species occurs, aspects of the genetic variation, natural history, physiology, and landscape context to assess sensitivity and adaptive capacity (Foden 2009, Young et al. 2012). Bioclimatic modeling approaches how climatic "envelopes" of suitable climate

conditions might change and move over time (Peterson et al. 2002, Thomas et al. 2004, Thomas et al. 2012, Comer et al. 2012). Species-based vulnerability assessments are particularly useful where a relatively small number of individual species form the focus of conservation effort.

Assessments of **landscapes** often center on producing spatially explicit results at regional scales. Evaluation of exposure may result in maps showing where climate stress is projected to be greatest, whereas examination of the potential climate-change effects on disturbance regimes or invasive species, can address sensitivity (Enquist and Gori 2008, Swantson et al. 2010, Rustad et al. 2011). Adaptive capacity can be measured through examination of the heterogeneity of topography, moisture gradients, or microclimates under the assumption that more diverse landscapes provide more opportunities for organisms to find climate refugia than homogeneous ones. Assessments of landscape vulnerability are useful when examining the potential effects of climate change on land use patterns and on biodiversity that is influenced by large-scale processes such as riparian systems where mountain headwaters affect lowland rivers.

A vulnerability assessment of a **community type** requires understanding of the ecological processes such as fire regime, hydrological regime, or food web dynamics that define the community at relatively local scales. As for species, exposure estimates relate to the magnitude of projected changes in temperature and precipitation over the area where the community occurs. Sensitivity estimates can include how the defining ecological processes are affected by changing climates, and synergies between climate and non-climate stressors of the community. Adaptive capacity estimates of a community can include the roles of component guilds of organisms, the vulnerability of important component species, and the natural biophysical variability across the range of the community. Assessing the vulnerability of communities can provide a useful compliment to both landscape and species assessments. Where landscape assessments indicate a high potential for climate-change impacts in certain subregional areas, analysis of component communities could be the next logical step to identify practical adaptation strategies. Assessment of communities also presents the opportunity to avoid time-consuming analyses of long lists of sympatric species, or when the community itself is an effective focus for conservation.

Coping with Uncertainty

While uncertainty is inherent in climate change vulnerability and adaptation planning, it is important to clarify areas of uncertainty so that users may appropriately interpret, and investments in new knowledge to reduce uncertainty can be effectively focused (Risbey and Kandlikar 2007, Swart et al. 2009). Given that all climate change assessments thus far bring together data, models, and expert knowledge, the approach taken for this effort concentrated on identifying the various sources of uncertainty (e.g., in available data, in current models, and in limits to current knowledge) and then attempted to describe the relative confidence throughout the vulnerability assessment with probability statements (i.e., “high” confidence implies a >70% certainty of being correct, “moderate” = 30-70% certainty, and “low” = <30% certainty).

Survey of Field Specialists

A major goal of the project is to develop methods and outcomes useful for natural resource managers. To better understand the needs, concerns, and interests of managers in the Desert LCC, and therefore enhance the chances of creating products useful for them, we initiated the project with a survey of the potential

user audience. The survey sought to understand the natural communities managed, the most important stressors to these systems, the communities perceived to be most vulnerable to climate change, the climate change factors causing these stresses, and the greatest needs for scientific information about climate change. Besides providing a general picture of managers' needs and perceptions about climate change, the survey also allowed us to choose ten plant community types to focus our pilot study on vulnerability of desert habitats to climate change.

See Appendix 1 for discussion of survey methods and results. Thanks to a healthy response rate, the survey succeeded in providing a snapshot of Mojave and Sonoran Desert land managers' perceptions about climate change in the larger context of stressors to the biodiversity they manage. Climate change is but one of numerous stressors that the respondents are confronting, ranking noticeably behind invasive species in importance. Managers are concerned about climate change affecting a wide range of communities via mechanisms that relate to increased water stress, isolation of mountaintops, loss of keystone or endemic species, and storm surge in coastal systems. Their top climate change-related information needs are vulnerability assessments of communities and species as well as predictions of how climate change will influence hydrological cycles. Finally, the survey allowed us to select for vulnerability assessment 10 community types that are relevant to a broad spectrum of land managers.

Overview of Methodology for Vulnerability Assessment

The methods developed for this Habitat Climate Change Vulnerability Index (HCCVI) will be applicable to any given ecosystem or community type that the user might select. For this pilot, we used NatureServe's terrestrial ecological systems classification. The advantage of using this classification system to test the approach is that it represents an established nationwide classification of several hundred upland and wetland types mapped for use by federal and state resource managers (Comer et al. 2003, Comer and Schulz 2007). However, the HCCVI methods are consciously designed to support other ecosystem or community concepts as well; for example, habitats described for individual bird or ungulate species of conservation concern. The 10 selected types for this pilot effort are listed in Table 1. A map of these types is included in Figure 2 later in this report.

Table 1. Focal Natural Communities and Primary Desert of Occurrence.

Type Name	Desert
North American Warm Desert Riparian Woodland and Shrubland and Stream	both
North American Warm Desert Mesquite Bosque	both
Mojave-Sonoran Desert Springs and Seeps	both
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	Sonoran
Sonoran Paloverde-Mixed Cacti Desert Scrub	Sonoran
Sonora-Mojave Mixed Salt Desert Scrub	both
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	both
North American Warm Desert Active and Stabilized Dune	Sonoran
Mojave Mid-Elevation Mixed Desert Scrub	Mojave
Great Basin Pinyon-Juniper Woodland	Mojave

Index Framework

An index approach to documenting climate change vulnerability aims to organize a series of sub-analyses in a coherent structure that will shed light on distinct components of vulnerability, so that each can be evaluated individually, or in combination. This approach follows a number of related indexing approaches to documenting at-risk status of biodiversity (Faber-Langendoen et al. 2007), or climate change vulnerability for species (Young et al. 2010). The structure implemented here organizes the components of climate change vulnerability in to three main categories: Direct Effects, Indirect Effects, and Adaptive Capacity (Figure 1). These are defined as follows:

Direct Effects encompass the current and forecasted exposure to climate change and their likely effects on ecosystem-specific processes. Analyses of direct effects consider climate forecasts themselves, and their likely implications for increasing ecosystem stress, changing dynamic processes such as wildfire or hydrological regime; and for changing species composition.

Indirect Effects encompass predisposing conditions affecting ecological resilience, with ecological resilience as initially defined by Holling (1973) and Gunderson (2000), and later Walker et al. (2004). Walker et al. (2004) defined it as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks." Analyses of indirect effects consider human alterations to characteristic pattern and process, such as landscape fragmentation, effects of invasive species, or human alterations to dynamic processes. Here, these human alterations are considered independent of climate change, but once identified, have some potential interactions with forecasted climate change. These analyses also include a temporal dimension, considering both legacies of past land use along with current conditions.

Adaptive Capacity encompasses natural characteristics that affect the potential for ecological resilience in light of climate change. Analyses of adaptive capacity for climate change consider the inherent variability in climate regime or geophysical features that characterize the distribution of a given ecosystem or community. They also consider aspects of natural species composition, such as the relative diversity within groups of species that provide functional roles, or the relative vulnerabilities of individual species that provide "keystone" functions.

Authors of this index drew inspiration from Magnuss et al. (2011) and others in structuring analyses with a logic model to combine information in two stages, with the first analyses gauging relative ecological resilience by matching results from indirect effects against adaptive capacity. The direct effects of climate exposure and sensitivity are then considered to arrive at an overall gauge of climate change vulnerability (Figure 1).

Numerical and Categorical Summaries of Vulnerability

The index aims to use component analyses to consistently arrive at a 3-level series of scores; i.e., High, Medium, and Low (Figure 1). Where quantitative data are available, numerical scores should aim to be normalized to a 0.0 to 1.0 scale. Numerical results for component analyses are then averaged. However, where quantitative models are unavailable for a given analysis, expert categorization for each score is sufficient (with documented justification). The H/M/L result for resilience is the average of scores for indirect effects and for adaptive capacity. The H/M/L result for sensitivity is the average of scores for

direct effects. From this point, a simple logic model combines categorical results for resilience and sensitivity to arrive at an overall categorization of climate change vulnerability.

Very High climate change vulnerability results from combining high sensitivity with low resilience. These are circumstances where climate change stress and its effects are expected to be most severe, and relative resilience is lowest. Ecosystem transformation is most likely to occur in upcoming decades.

High climate change vulnerability results from combining either high or moderate sensitivity with low or medium resilience. Under either combination, climate change stress would be anticipated to have considerable impact.

Moderate climate change vulnerability results from a variety of combinations for sensitivity and resilience; initially with circumstances where both are scored as moderate. However, this also results where resilience is scored high, if combined with either high or medium sensitivity. Where both resilience and sensitivity are low, some degree of climate change vulnerability remains.

Low climate change vulnerability results from combining low sensitivity with high resilience. These are circumstances where climate change stress and its effects are expected to be least severe or absent, and relative resilience is highest.

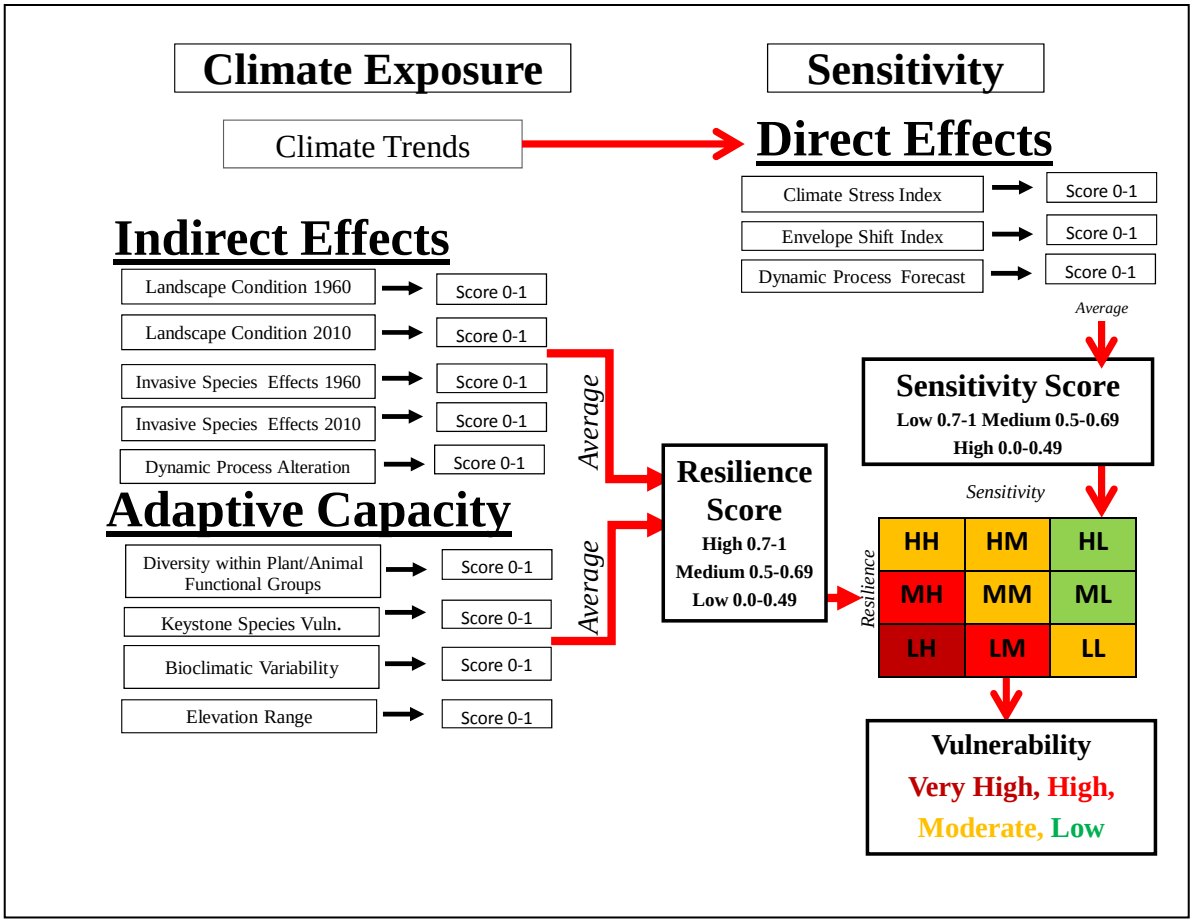


Figure 1. Flow Chart for Habitat Climate Change Vulnerability Index (HCCVI).

Spatial and Temporal Dimensions for Documenting Vulnerability

Climate change vulnerability for ecosystems and habitats was placed here within an explicit spatial and temporal framework. Spatially, a vulnerability assessment initially applies to the distribution of the type within an EPA Level III ecoregion[2]. Across North America, these equate with Level III ecoregions from the Commission for Environmental Cooperation (CEC). Scores for each type are summarized for each applicable ecoregion of their natural distribution. For this project, we focused on the distribution of each target community type within the Mojave and/or Sonoran Desert ecoregions (Figure 2).

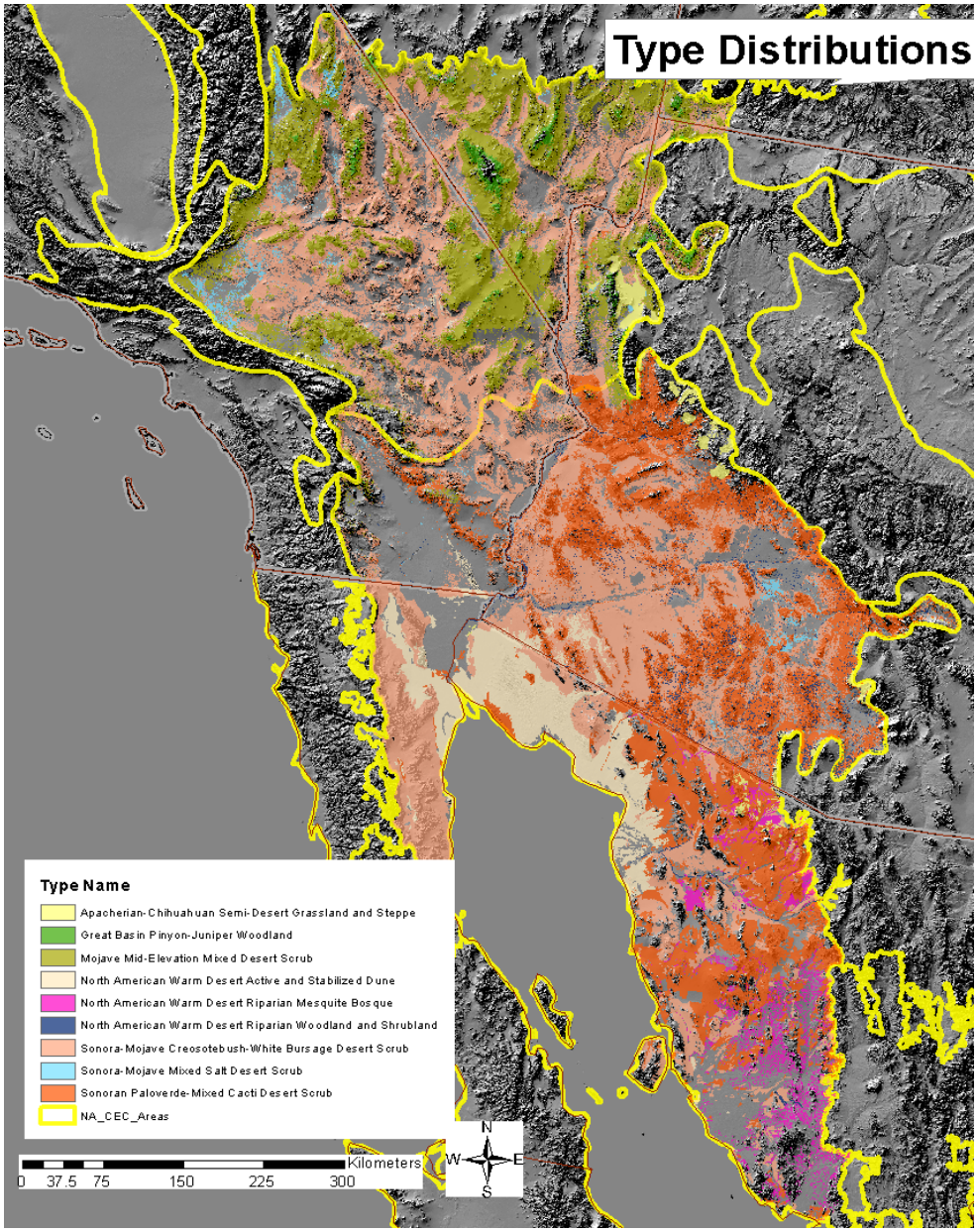


Figure 2. Level III ecoregions and focal community distribution for HCCVI pilot in the Mojave and Sonoran deserts.

[2] http://www.eoearth.org/article/Ecoregions_of_the_United_States-Level_III_%28EPA%29

One might apply the same analyses and gauge vulnerability for narrower or broader distributions of a given community type, but this level of ecoregionalization was selected because it likely reflects regional pattern of climate-change exposure and effects. It therefore should provide a practical starting point for efforts to systematically document climate change vulnerability at national or regional scales.

Similarly, one must explicitly consider the temporal dimension of climate change vulnerability, as the magnitude of climate exposure varies over the upcoming decades. By utilizing forecasts of climate exposure and sensitivity over a 50-year timeframe (e.g., between 2010 and 2060) provides a practical time period where realistic climate trends can emerge within acceptable bounds of uncertainty.

Climate Exposure in the Mojave and Sonoran Deserts

Where available, historical climate data can and should be used to characterize a given community types 'climate baseline' over the 20th century. This enables meaningful comparisons of climate trends from subsequent time periods to clarify the significance of measurable change. In the United States, PRISM data (Daly et al. 2004) include monthly maximum and minimum temperature and monthly total precipitation, and are available at 4km^2 spatial resolution from 1900 to the present. An analysis of these monthly variables for the 1900-1980 intervals can then characterize the "expected" variability of historical conditions. That time period is useful because a) it includes the oldest available climate records suitable for developing a climate baseline, and b) around 1980 was the point at which a human influence on climate change was detectable (Lee et al. 2006, Solomon et al. 2007). One can then compare with this baseline summaries of the same climate variables since 1980, and/or climate forecasts, to identify the likely location and magnitude of climate-induced stress across the areas that define the range of the community type.

Here we summarize this analysis taking results from the Rapid Ecoregional Assessment for the Mojave Desert (Comer et al. 2012). See Appendix 2 for detailed explanation of methods and results relative to these analyses, including summaries used for the Sonoran Desert. Again, monthly averages for maximum and minimum temperatures, along with total monthly precipitation, encompass the climate variables used. *For each month and each variable, the mean and standard deviation was calculated, characterizing 80 years of climatic variability*. Then, using an ensemble mean from 6 Global Circulation Models (GCMs) forecasting climate for the decade of 2050-2059 (www.ecoclim.org), we analyzed every 4 km^2 pixel in the Mojave Desert to identify where forecasted values exceeded this measure of 20th century baseline variability.

Overall forecasted climate trends for the Mojave Desert in 2060 can be summarized in a map (Figure 3). This map indicates the pervasive nature of forecasted climate change anticipated for the Mojave Desert, where almost no area escapes a >2 stdv departure in at least one monthly climate variable. Statistically, a >2 stdv departure indicates that forecasted climate variables fall outside of 95% of the 20th century baseline values. This map also displays a count for each pixel where up to 12 of the 36 monthly temperature variables (maximum and minimum temperature, each x 12 months) and total precipitation (x12) are forecasted to depart by at least 2 standard deviations from the 20th century baseline mean values. This analysis provides an initial suggestion of areas where climate-change impacts might be more or less intense. Table 2 provides a concise summary of these results. Each row included in the table represents the monthly variable where forecast models indicate that the variable will exceed 95% (two standard deviations) of the values that occurred during the 1900-1979 baseline period. The second column of Table

2 includes the proportion of the ecoregion affected by significant climate change; with **bolded numbers** indicating where forecasted proportions are above 50% of the ecoregion surface. Other columns indicate the ecoregion-wide averages for each variable, in terms of their forecasted difference (i.e., departure) from the 20th century baseline. Both maximum (daytime) and minimum (nighttime) temperatures (F) stand out from this analysis, with the months of June through October concentrating forecasted change. For midcentury summers, models predict 80-95% of the Mojave Desert will experience elevated temperatures, with extremes reaching a 9.6 degree F increase in some areas. Monthly total precipitation is forecasted to significantly depart from the 20th century baseline only in the month of August. However, natural variability in precipitation is quite high, and climate forecast models are least reliable with precipitation, so caution is required for interpretation of this particular forecast. These climate forecasts provide a foundation for both estimating future climate stress, and for describing plausible climate-change scenarios relevant to communities in the Mojave Desert.

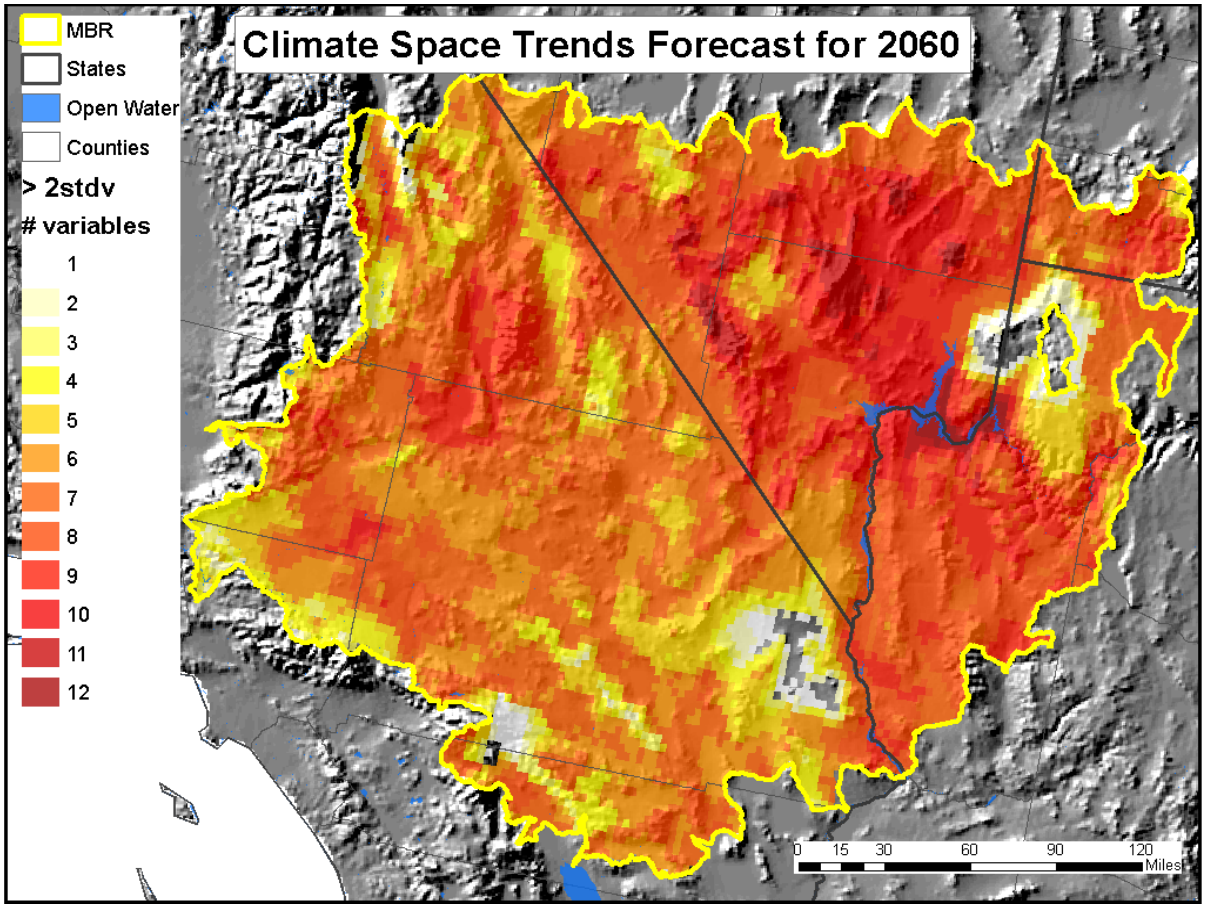


Figure 3. Composite 2060 forecast where climate variables depart by > 2 standard deviations.

Table 2. Summary of areal extent of climate change for individual variables which have at least 2 standard deviations of projected change (2050-2059) from the baseline (1900-1979) mean.

Variable (Month, 2050s forecast)	% of Area with Value >2 stdv departure	Grid Cells > 2 Stdv departure forecast 2050s (degrees F, Precip in Inches)		
		Mean Departure from Baseline	Min	Max
January Min Temp	3.7%	5.9	5.3	7.1
May Min Temp	6.2%	4.8	4.1	5.9
June Min Temp	**57.2%**	5.7	4.4	8.4
June Max Temp	17.1%	6.2	5.2	9.1
July Min Temp	**96.4%**	6.4	4.9	9.0
July Max temp	**91.1%**	5.5	3.9	8.7
August Min Temp	**95.9%**	6.9	5.1	9.6
August Max Temp	**93.8%**	5.9	4.5	8.6
August Tot. Precip	11.3%	0.9	0.3	3.0
Sept. Min Temp	**91.6%**	6.6	4.6	8.8
Sept. Max Temp	7.1%	5.7	5.0	7.5
October Max Temp	4.7%	7.2	6.6	8.5
October Min Temp	**81.3%**	6.5	4.9	8.3
November Min Temp	8.3%	5.4	4.3	7.1
December Min Temp	0.2%	5.3	4.8	6.1

Describing Climate Stress and its Direct Effects

The first three climate-change analyses for the HCCVI aim to measure the overall magnitude of climate-induced stress and its likely effect on the type across the ecoregion (Figure 1). Each analysis produces an index value either in qualitative categories of High, Medium, or Low Sensitivity, or a numerical 0.0-1.0 result, with scores approaching 0.0 indicating higher climate change sensitivity; i.e., with trends in climate forecasted out for 50 years suggest higher ecological impact. Summarized below, these first three measures of climate-change direct effects include a climate stress index, and climate envelope shift index, and a dynamic process forecast.

Climate Stress Index

Ideally, this can be measured using the proportion of the community distribution where the climate is forecasted to depart significantly from 20th century conditions. Using the analysis from the Mojave Desert described above, an index of climate stress was calculated using the weighted average score of climate forecasts for 2060 (in a 4km^2 grid) overlain on the current distribution of each community type. As noted above, up to 12 of 36 monthly variables for maximum temperature, minimum temperature, and total precipitation were forecasted for 2060 in the Mojave Desert to depart by >2 stdv from the 20th century baseline. The number of significantly departed monthly variables for monthly maximum temperature (x12) monthly minimum temperature (x12) or total precipitation (x12) per grid cell formed the basis for weighted averaging. Major upland communities for this project had weighted averages around 7.0. Their resulting index score is therefore 1-7/36 = 0.8. Unfortunately, this type of calculation has yet to be completed for a wide diversity of North American communities, and so the relative

significance of a 0.8 index score remains unclear. However, given comparison of results from Table 1 with generalized results published elsewhere (e.g., US Global Change Research Program 2009); an initial categorization of "High" sensitivity for Mojave and Sonoran desert communities in this project is warranted.

Climate Envelope Shift Overlap Index

A second way to gauge climate-change effects on communities is to predict how climate change may shift the suitable climatic conditions for a given upland type over the upcoming decades. While one should not presume that upland communities will move as a unit with changing climate, this analysis can provide an indication of the direction and magnitude of forecasted change to be experienced by component species of the community type (Pearson and Dawson 2003). In order to complete this analysis, one can first define the characteristic 'climate envelope' for the community by correlating its current range with 20th century averages of climate variables. The identified climate envelope can then be projected into the future using climate forecasts for 2060. In this project, distribution modeling algorithm Maxent (Phillips et al. 2006, Phillips and Dudik 2008) was used in conjunction with spatial climate data from PRISM and EcoClim 4 km^2 (Hamilton, pers. comm. 2012) to model current and future bioclimate of each upland vegetation type within either the Mojave or Sonoran Desert. Maxent is a correlative niche model that uses the principle of maximum entropy to estimate a set of functions that relate environmental variables and known vegetation type occurrences in order to approximate its bioclimate niche and potential geographic distribution. Maxent was chosen because of its established performance with presence-only data relative to alternative niche modeling techniques, and its built-in capacity to deal with multi-colinearity in the environmental variables (Elith et al. 2006, Elith and Leathwick 2009. Elith et al. 2011).

A map of both current and forecasted 2060 distributions was developed and compared for each upland vegetation type (see results and Appendix 2 for map examples). Overlay of map outputs identify where forecasts indicate an overlap between current and 2060 bioclimate distributions. Where forecasted distribution does not overlap current distributions, these indicate a potential 'contraction' or 'expansion' by 2060. Since six forecast models were developed, results were summarized where least two outputs from 2060 climate forecasts were in agreement. The proportion of calculated overlap forms an index score between 0.0 and 1.0. For the upland vegetated types treated in this project, results ranged from 0.12 (High sensitivity) to 0.91 (Low sensitivity).

Dynamic Process Forecasts

Localized hydrologic or fire regime models for aquatic and upland ecosystems, where available, can help account for past alterations, and then provide insight for projected future climate regimes, applying those estimates as a third measure of direct effects or climate-change sensitivity. See Appendix 2 for detailed discussion of methods from these analyses.

Potential effects of climate change on the hydrologic regime were based on 1) ecological literature identifying the key surface water, groundwater, and hydrogeomorphic dynamics that affect the aquatic/wetland/riparian systems of interest; 2) hydrologic and meteorological literature identifying the key climate variables that have the greatest effect on the ecologically important surface water, groundwater, and hydrogeomorphic dynamics, including studies of prehistoric and historic conditions; and 3) hydrologic and geologic literature identifying the specific ways in which changes in these climate

variables would affect the surface water, groundwater, and hydrogeomorphic dynamics of concern, including studies of prehistoric and historic conditions. Given limitations on the availability of quantitative hydrologic models of use for our purposes in the Mojave and Sonoran deserts, estimates of climate sensitivity were qualitative, scaled between 0.0 and 1.0 for each community type within each desert. In this project, all aquatic/riparian types were scored as "High" sensitivity.

Fire regimes are characterized quantitatively using state-and-transitions models that describe various successional stages and the transitions between them. Using estimates of fire frequency and successional rates, fire regime models predict the relative proportion of natural successional stages one might expect to encounter for a community type across a given landscape. Comparison of the observed vs. predicted aerial extent of successional stages is then used to gauge relative departure from expected proportions (measured in % departure). Models for each upland vegetation type characterizing its expected or "natural" range of variation were compared against current conditions to describe current fire regime departure (see subsequent discussion under Indirect Effects – Dynamic Regime Alteration). The same model, updated to describe current conditions (e.g., with introduced invasive species included) were then run out over several decades to provide a realistic forecast of trends in ecological departure as of 2060. Forecasted departure scores for each upland vegetation type were normalized to a 0.0-1.0 relative score. For the upland vegetated types treated in this project, results ranged from 0.12 (High sensitivity) to 0.72 (Low sensitivity).

Accounting for the Indirect Effects of Climate Stress

Indirect effects address the potential interacting effects of climate-induced stress on the landscape conditions within and surrounding the habitat across its distribution. For example, if the analysis of direct effects indicates the strong need for component species to migrate towards higher elevations or latitudes, and the landscape is fragmented, the relative vulnerability of a community type could increase. In many instances, communities occur in landscapes that were already highly fragmented by the mid-20th century, and are therefore the associated land use legacies make them all the more vulnerable to current and future stressors. Similarly, the introduction of non-native species may also alter natural food-webs or compromise key dynamic processes, such as wildfire regimes, and have high potential for interactions with likely climate stress.

Literature review, and where available, regional maps of landscape condition, land use, invasive species, and fire regime departure, where possible reflecting 1960 and 2010, can provide measures for these effects.

Landscape Condition

Ecological condition commonly refers to the state of the physical, chemical, and biological characteristics of natural ecosystems, and their interacting processes. Many human land uses affect ecological condition, (e.g., through vegetation removal or alteration, stream diversion or altered natural hydrology, introduction of non-native and invasive species, etc.). Landscape condition assessments apply principles of landscape ecology with mapped information to characterize ecological condition for a given area (e.g., USEPA 2001, Sanderson et al. 2002). Since human land uses - such as built infrastructure for transportation or urban/industry, and land cover such as for agriculture or other vegetation alteration – are increasingly

available in mapped form, they can be used to spatially model inferences about ecological stress and ecological condition.

The spatial models of landscape condition used in this project built on a growing body of published methods and software tools for ecological effects assessment and spatial modeling; all aiming to characterize relative ecological condition of landscapes (e.g., Knick and Rotenberry 1995, Forman and Alexander 1998, Trombulak and Frissel 1999, Theobald 2001, Seiler 2001, Sanderson et al. 2002, Riitters and Wickham 2003, Brown and Vivas 2005, Hansen et al. 2005, Leu et al. 2008, Comer and Hak 2009, Theobald 2010, Rocchio and Crawford 2011). The intent of these models is to use regionally available spatial data to transparently express user knowledge regarding the relative effects of land uses on natural ecosystems and communities. For this project, the authors' expert knowledge forms the basis of stressor selection, and relative weightings, but numerous examples from published literature have been drawn upon to parameterize the model for application in this ecoregion. Independent data sets were drawn upon for subsequent model evaluation. This current model has been developed and evaluated for the entire western United States, and then customized for use within each desert ecoregion. Western regional model development and evaluation was completed in cooperation with the Western Governors Association landscape connectivity working group (J. Pierce, pers. comm.).

See Appendix 2 for a detailed description of the models used in the Mojave and Sonoran deserts. Each input data layer is summarized to a 90m grid and, *where the land use occurs*, given a **site impact score** from 0.05 to 0.9 reflecting presumed ecological stress or impact. Values close to 1.0 imply relatively little ecological impact from the land use. For example, a given patch of 'ruderal' vegetation – historically cleared for farming, but recovering towards natural vegetation over recent decades, is given a Very Low (0.9) score for site impact as compared with irrigated agriculture (High Impact 0.3) or high-density urban/industrial development (Very High Impact 0.05). Certainly, there are some ecological values supported in these intensively used lands, but their relative condition is quite limited when compared with areas dominated by natural vegetation.

A second model parameter – *for each input data layer* - represents a **distance decay** function, expressing a decreasing ecological impact with distance away from the mapped location of each feature with Euclidian Distance. Mathematically, this applies a formula that characteristically describes a "bell curve" shape that falls towards plus/minus infinity (Appendix 2). Those features given a high decay score (approaching 1.0) result in a map surface where the impact value dissipates within a relatively short distance. Those features given a low decay score (approaching 0.0) create a map surface where the per-pixel impact value dissipates more gradually with distance away from the impacting feature.

The result is a map surface indicating relative scores per pixel between 0.0 and 1.0 (Figure 4). This provides one composite view of the relative impacts of land uses across the entire ecoregion. Darker blue areas indicate apparently least impacted areas and orange to red areas most impacted.

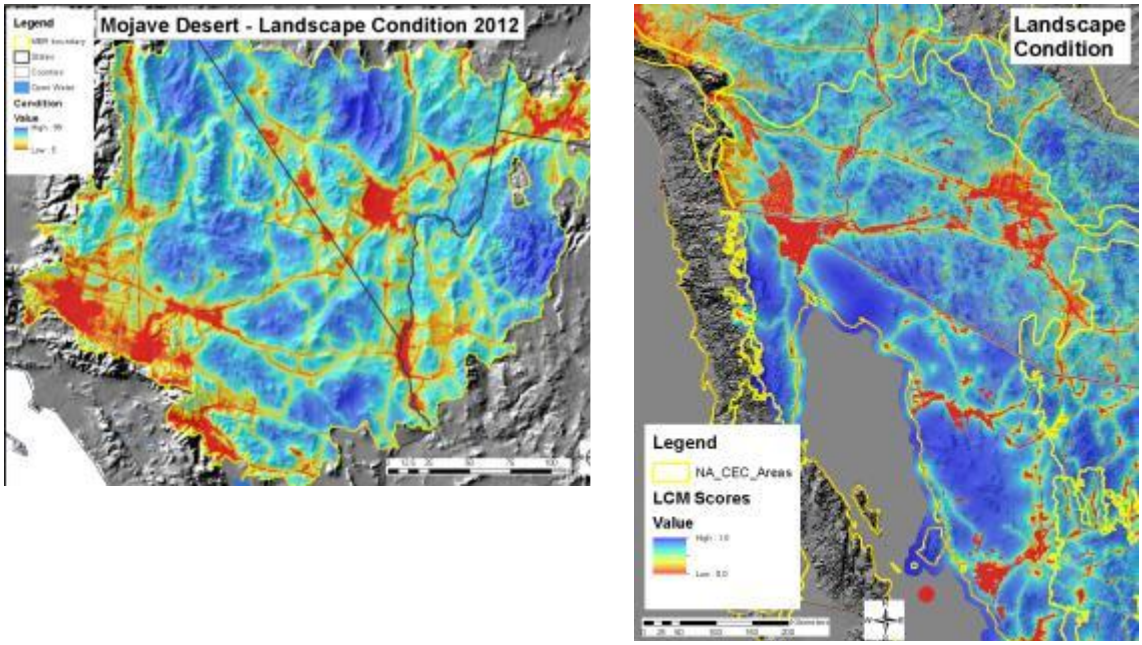


Figure 4. Landscape Condition model (90 m) for the Mojave and Sonoran deserts

Current Landscape Condition (2010): Current Landscape Condition of each community distribution was assessed using the NatureServe (LCM).This indicator is measured by intersecting the community distribution map with the LCM layer and reporting the average per-pixel LCM index value within each ecoregion. The average per-pixel score provides a relative index for landscape condition resulting with a score from 0 to 1 with 1 being very high landscape condition and values close to 0 likely having very poor condition.

Past landscape condition (1960): Historical data were lacking for spatial analysis using an LCM so landscape conditions for 1960 were researched and summarized (0.0-1.0 scale) based on estimated extent of roads and other development and various anthropogenic disturbances. Examples of disturbance include historic ranching (since mid -1800's), which has significantly affected most ecosystems and transportation system of highways and roads have fragmented many areas. Additionally, water diversions and ground water pumping has affected springs and surface flows in riparian ecosystems, and local disturbance from agriculture, urbanization and mining have converted many sites.

Invasive Species

The effects of invasive species on natural communities are well known and there is considerable concern for their interactions with climate change (e.g., Abatzoglou and Kolden. 2011). For example, few annual grasses are native to the region and most of the annual grass cover is from invasive non-native grasses; especially *Bromus tectorum, B. madritensis, B. rubens* and *Schismus barbatus*. Invasive woody riparian species (e.g., *Tamarix ramosissima*) impact focal riparian communities throughout these deserts, while a variety of invasive aquatic species impact freshwater bodies. Potential effects of these species were assessed using spatial models for invasive annual grasses and woody riparian species in the Mojave

Desert (Comer et al. 2012) and Sonoran Desert (Conservation Biology Institute 2012) developed for the BLM rapid ecoregional assessments. These models leverage existing location records of invasive species, spatial models of potential presence and/or abundance were developed for each invasive floristic group (annuals and woody riparian). See Appendix 2 and appendices in Comer et al. (2012) and CBI 2012 from Mojave and Sonoran REAs for further explanation of these models. Using the master database of plant locality records with a suite of environmental variables and inductive modeling with Maxent and CART methods, the resultant surfaces represent their potential presence. Within the Mojave Desert, since georeferenced samples for invasive annual grasses tended to include relative cover values, five distinct models were developed to indicate the potential for their presence in a series of abundance levels (<5%, 5-10%, 10-25%, 25-45%, and >45%). (Figure 5).

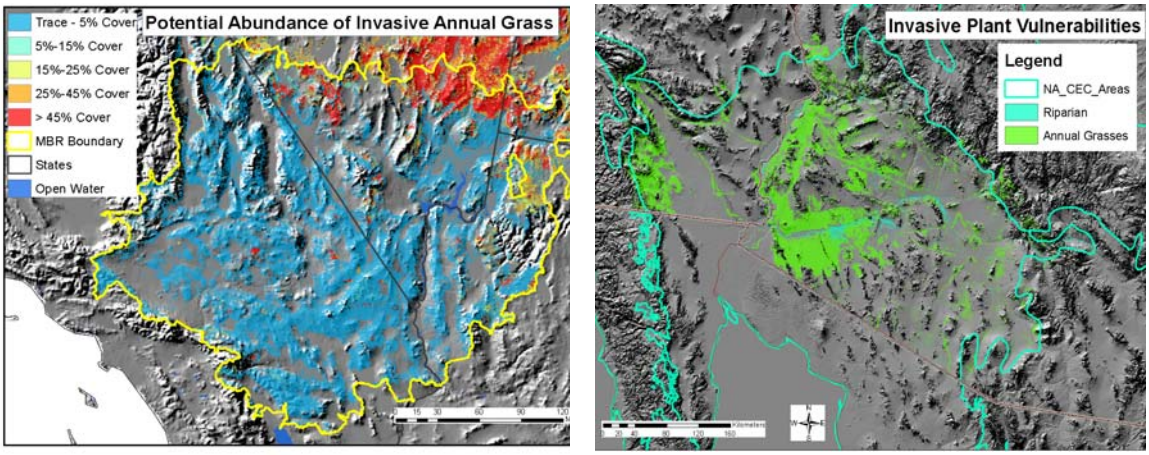


Figure 5. Potential abundance and/or presence models of invasive plant species in the Mojave and Sonoran deserts (from BLM REAs).

Invasive Species Effects (2010): Like the landscape condition model, potential invasives effect is measured by intersecting the community distribution map with the invasives model output and reporting the average per-pixel invasives index value. The invasives index is a scaled from 0 to 1 with 0 representing high potential of lands in the pixel to experience annual grass encroachment and 1 representing no encroachment. Within the US portion of the Sonoran Desert, since presence/absence information is all that is available, the index results from calculating the percentage of the community type distribution overlapping the invasive map. Building from these overlays, qualitative estimates were derived for Mexican portions of the Sonoran Desert. Because invasive annual grass models in the Mojave Desert included relative abundance values, the per-pixel scores also represent a potential abundance of invasive grasses as follows: <5% = 1.0, 5-10% = 0.9, 11-20% = 0.8, 21-40% = 0.6, 41-60% = 0.4, 60-80% = 0.2, and >80% = 0.1. Across upland types, annual grass model scores ranged from 0.4 to 1.0.

Past Invasive Species Effects (1960): Given a lack of historical mapped information on invasive species, an expert estimate built upon a review of available literature and evaluation of the 2010 results. Across all types, scores ranged from 0.5 to1.0.

Dynamic Process Alterations

As noted previously under Dynamic Process Forecasts, localized hydrologic or fire regime models for aquatic and upland ecosystems can provide insight for projected future climate regimes. They apply equally for characterizing current conditions. Given limitations on the availability of quantitative hydrologic models of use for our purposes in the Mojave and Sonoran deserts, estimates of 2010 hydrologic regime alterations were qualitative for each community type, scaled between 0.0 and 1.0 for each community type within each desert. In this project, all aquatic/riparian types were scored at the "medium" to "low" threshold (0.5) for current resilience. For fire regime models mentioned previously, the same model for each upland type, updated to describe current conditions (e.g., with introduced invasive species included) were used to describe current departure relative to the 'expected' proportions of successional stages (see Appendix 2 for detailed explanation). Departure scores for each upland vegetation type were normalized to a 0.0-1.0 relative score. For the upland vegetated types treated in this project, results ranged from 0.23 (Low resilience) to 0.72 (High resilience).

Adaptive Capacity for Responding to Climate Stress

As described previously, adaptive capacity is the potential or capability of a system to adjust to climate change, including climate variability and extremes, so as to moderate potential damages, to take advantage of opportunities, or to cope with consequences (IPCC 2007). As climate changes, community types with the capacity to support more gradual ecological transformation will have a higher likelihood of maintaining essential ecological relationships than those where transformations are more abrupt. Natural characteristics of ecosystems and communities therefore can make them more or less vulnerable to abrupt transformation brought on by rapid climate change. This inherent adaptive capacity may be initially measured in terms of natural composition and environmental variability characterizing the given community type across its distribution. Below are described four measures of adaptive capacity.

Diversity *within* characteristic functional groups

Natural communities may include a number of functional groups, or groups of organisms that pollinate, graze, disperse seeds, fix nitrogen, decompose organic matter, depredate smaller organisms, or perform other functions (Rosenfeld 2002, Folke et al. 2004). Experimental evidence gathered over the last two decades supports the theoretical prediction that communities with functional groups made up of increasingly diverse members tend to be more resilient to perturbations (Walker et al. 2004, Folke et al. 2005, Nyström et al. 2008). Since individual species respond differently to disturbances, where there is high species diversity within a given group, as individual species are lost over time, it is more likely that the community will retain key functions and therefore have greater resilience to stressors. The more diverse the group, the greater the likelihood that at least one species will have characteristics that allow it to continue to perform its function in the community even if, say, precipitation patterns or the fire regime changes. For example, a study of semi-arid grasslands showed where sites with a diversity of grass species, including some seemingly "redundant" ones, was more resilient to changing states because different grass species dominated under different grazing and precipitation conditions (Walker et al. 1999). Thus a factor contributing to the adaptive capacity of a community is the diversity within its component functional groups.

However, the challenge remains to reliably describe functional groups of species for a given community type. Common approaches center on analysis of plant growth forms or specific traits in response to

environmental constraints (Lavorel et al. 1997; Diaz and Cabido 2001). In this pilot effort, plant functional groups were initially identified by evaluating characteristic growth forms among plant species, and specific groups related to plant responses to drought. Pollinator diversity was also identified as an important functional species group to evaluate; although information on within-group diversity was limited. In each instance, expert knowledge was brought to bear in order to document each group, and score them along a 0.0 to 1.0 scale; with 1.0 indicating high species diversity within a functional group. Results from multiple functional groups were averaged together for an overall estimate. Estimates for types within this pilot ranged from 0.3 to 1.0.

CC Vulnerability among keystone species

Assessing the vulnerability of all species in a community would be a daunting task. A more pragmatic approach is to assess the vulnerability of the species playing the most important functional roles in the community. These species, when lost or reduced in abundance, will cause significant cascading effects on the populations of other species. We use the term "keystone species" to describe these species, recognizing that this use might be interpreted as different from some definitions in the ecological literature that equates keystone species with those that affect communities in a manner disproportionate with their abundance or biomass (Power et al. 1996). The Power et al. (1996) definition excludes dominant structural species, yet assessing the capacity of a community to adapt to climate change may require knowledge of how these dominant species might respond. Here keystone species refer to any species that, when extirpated or reduced in abundance, could cause disproportionate effects on the populations of other species that characterize the community.

Determining which species can be considered keystone requires an understanding of the natural history of many species in the community being assessed. Although there are quantitative means of identifying keystone species via food web analysis (Ebenman and Jonsonn 2005), these methods can be time and data intensive. However, identification of potential keystone species may follow directly from the above process to clarify functional groups of species. That is, if an important ecosystem function is represented by just one species, that species is likely providing some 'keystone' function for purposed of this analysis.

Alternatively, species can be selected by answering a series of questions about which species play dominant roles in the community. Threatened and endangered species, although frequently the targets of conservation action are often too rare to qualify as keystone species. Exceptions are endemic but locally common species that structure communities or top predators. Questions, to ask when identifying keystone species to assess include:

1) Which species provide essential community structure?

2) Are there ecosystem engineering species that create habitat to others, such as beavers, cavity-excavating woodpeckers, or prairie dogs?

3) Are there specific pollinators required for dominant plants?

4) Are there species that are primarily responsible for seed predation?

5) Are there species that provide limiting nutrients in the community?

6) Is there a top predator that keeps meso-predators in check?

7) Are there plants that produce unusually large amounts of nectar, fruits, or nuts that support populations of several animal species during times of scarcity?

8) Is there a fungus or disease agent that keeps populations in check?

9) Is there a species that influences fire frequency and intensity through its growth?

10) Is there an herbivore or grazer that prevents rapid expansion of plant populations?

A number of methods are available to then determine the climate change vulnerability of the keystone species once they are determined. As mentioned above, these methods can be grouped into trait-based and bioclimatic envelop modeling approaches. For the HCCVI, we assessed species vulnerability using the NatureServe Climate Change Vulnerability Index (CCVI), a trait-based tool that allows relatively rapid assessment of suites of species and is applicable to all terrestrial and aquatic plant and animal species (Young et al. 2012). The CCVI places species on a categorical scale from being extremely vulnerable to being likely to benefit from climate change. For this effort, the CCVI was applied to the distribution of each species within each ecoregion. The CCVI categories were translated to a numerical scale, and where multiple species were identified and treated for a given community type their resulting scores were averaged to arrive at a single index score (0.0-1.0 scale) for use in the HCCVI.

Characteristic Bioclimate Variability

Natural communities occur across a range of macro and micro-climates. For example, some vegetation types form the upland 'matrix' of an ecoregion. Their distribution responds to regional scale patterns of temperature and precipitation. Other community type might occur in relatively limited climates, such as alpine communities that only occur in limited high-elevation area of a 'basin-and-range' ecoregion. The variability in climate expressed by the distribution of a given communities can provide another useful indication of adaptive capacity. As compared to community type occurring in a limited range of climates, those types occurring across a wide range of climates have a higher likelihood of coping with the likely climate change of the upcoming decades.

The task then is to characterize bioclimate, the climate that characterizes the distribution of the community, and comparing that to the bioclimates of other community types to arrive at a relative score (high/medium/low). Fortunately, bioclimate classifications exist for much of the world. These maps effectively hold climate variability constant in an established set of classes and allow for comparison among overlain community type distributions. One map and approach utilized in the conterminous United States (Sayre et al. 2009) used climate station data from across the country and applied classifying criteria established by Rivas-Martinez et al. (1999). The combination of ombrotypes (precipitation-base classes) and thermotypes (temperature-based classes) define over 120 unique isobioclimates for the nation. Overlay of a given community distribution on this map surface provides one initial measure of bioclimate variability. In order to provide a relative measure, several hundred terrestrial ecological system types for the western United States were overlain to establish a plausible range of characteristic isobioclimates for community types treated in this project. From one to 20 isobioclimates characterize the range for all of western ecological system types. The result from each of the focal community types in this project was divided by 20 to arrive at a 0.0 – 1.0 relative score. Results varied from 0.4 to 1.0.

Characteristic Elevation Range

Following a similar logic to measuring isobioclimates, elevation range can serve as an additional and distinct measure of biophysical variability that characterizes the distribution of a give community type. Elevation belts of 500 foot (152 meters) intervals were used for this measurement. Elevation belts of this interval may help to indicate local-scale microclimatic variation not well expressed by isobioclimates. Again, with an overlay of several hundred terrestrial ecological system types for the western United States, a maximum score of 12 elevation belts (i.e., 6,000 ft/ 1829 m) was established for comparison with the elevation range measured for each community type. Results ranged from 0.3 to 1.0.

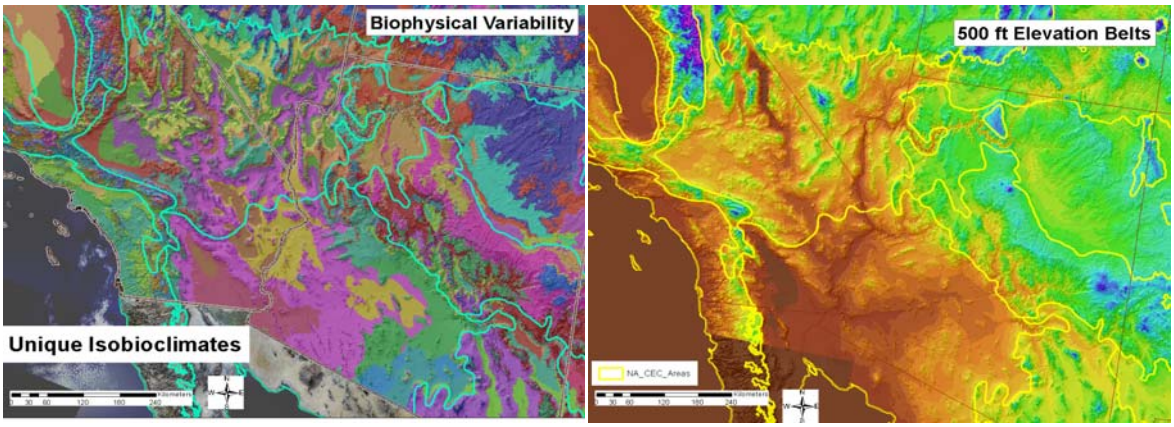


Figure 6. Isobioclimates and elevation belts used to gauge relative biophysical variability for each community type.

Workshop Process for Adaptation Strategies

To identify strategies that could facilitate adaptation of the focal communities to climate change, we held a two-day workshop with the participation of land managers and protected area biologists from the Mojave and Sonoran deserts. Workshops are an effective means of developing these strategies because they bring together a wide range of knowledge and experience, promote stimulating discussion, and engage important stakeholders, paving the way for future implementation (Cross et al. 2012). Planning for the workshop covered three areas: defining the overall goal, objectives, and major activities of the workshop to create a workshop description; recruiting participants; and developing a detailed agenda and workflow.

The overall goal of the workshop was to facilitate interactions among land managers within each ecoregion that support these major community types. The aim of this interaction was to collaboratively identify management strategies that can be readily implemented to promote adaptation of natural communities and associated species. Through discussions with the project advisory team, we enumerated five specific objectives for the workshop. These objectives reflected not only our desire to achieve results in terms of naming management strategies to address climate stressors and their synergistic effects on non-climate stressors, but also the need to receive feedback on the methods used to assess community vulnerability and create awareness among the participants about how climate change might play out in desert communities. The final set of objectives was:

- Communicate the results of climate change vulnerability assessments of ten focal community types of the Sonoran and Mojave deserts to biologists and managers of U.S. and Mexican protected areas that contain these communities.
- Receive feedback on the methods employed and results obtained in the vulnerability assessments.
- Document ecological stressors commonly affecting these communities within managed lands.
- Discuss and identify specific strategies that can be employed on the ground in protected areas to reduce climate change impacts on the characteristic mosaic of natural communities.
- Create awareness about climate change in desert ecosystems, potential synergies among non-climate and climate-induced stressors, and the options for managing for change, as well as resources available for managers.

To achieve these objectives, we determined that the first day should be devoted to explaining the methods and discussing the results of the community vulnerability assessments, and encouraging participants to contribute their knowledge and experience to enhance the analyses prepared in advance. A key activity would then be to document and prioritize synergies between climate and non-climate stressors. During the second day, the participants would build on the outcome of the first day to identify adaptation strategies as well as to clarify monitoring and research needs to lower uncertainty around identified strategies. Because the participants would need to complete these tasks for 10 communities, we determined that they would need to break into three working groups to complete the task. Using this information, we drafted a workshop description to send with invitations.

We worked through the project advisory team to recruit participants. Each member sent invitations to appropriate staff at their institutions. Appropriate staff included (1) areas managers with on-the-ground management experience and authority, and (2) managed area biologists, ecologists, wildlife biologists, vegetation managers, hydrologists, and wildfire managers. Because we had a target number of participants and needed specific expertise represented, we could not open invitations to anyone interested in attending the workshop. We considered requests to attend from those not specifically invited on a case by case basis, considering familiarity with one or more of the community types and space availability.

To plan the agenda, we took into consideration the relative inexperience that many of the participants would have in the fields of climate change vulnerability assessment and adaptation planning. These areas of conservation research and practice are rapidly expanding and taking on their own specialized vocabularies. We therefore scheduled introductory talks in plenary to explain terms and concepts as well as presentations on the methodology itself. We also considered effective means of catalyzing discussion and capturing input. To organize the discussion on synergies between climate and non-climate stressors, we developed a spreadsheet to fill out for each community type. The final agenda listed the talks and activities as well as the charges for the working groups each day (Appendix 4). To further prepare participants (Appendix 5), we sent them two fact sheets developed by EcoAdapt on vulnerability assessment and adaptation planning and recommended two papers (Rowland et al. 2011, Cross et al. 2012) and two books (Glick et al. 2011, Hansen and Hoffman 2011) on these topics one week in advance of the workshop.

Results

The complete set of summarized results for climate change vulnerability assessment and adaptation strategies is found in Appendix 3. Here we provide an overview of these results and include three examples from the full set of community types. These three examples provide a characterization of typical results found across all types. Table 3 includes a high-level summary of analysis scores and overall results for each community type as they occur within either the Mojave or Sonoran desert. When considering the unique combination of type by ecoregion, a total of 16 types are summarized here; one for each row of Table 3.

Six types were categorized high for climate-change vulnerability. These included Mojave Mid-Elevation [Joshua tree-Black brush] Desert Scrub (Mojave), North American Warm Desert Riparian Woodland and Stream (Mojave and Sonoran), North American Warm Desert Mesquite Bosque (Mojave and Sonoran), Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Sonoran). All other types were categorized as moderate for climate-change vulnerability. No types from this pilot analysis were categorized as either very high or low for climate-change vulnerability.

Given the **direct effects** measures aiming to gauge climate-change sensitivity, all but three types in the analysis resulted in the high-sensitivity category. For all types, scores ranged from 0.32 (high sensitivity) to 0.58 (medium sensitivity). The three types found to be in the moderate sensitivity category included Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Mojave), Sonora-Mojave Mixed Salt Desert Scrub (Mojave), and Apacherian-Chihuahuan Semi-Desert Grassland (Sonoran). Climate envelope shift and dynamic process forecast scores determined these results.

Indirect effects average scores fell between a low resilience score of 0.46 (North American Warm Desert Riparian Woodland and Shrubland (Mojave) and a high resilience score of 0.84 (North American Warm Desert Active and Stabilized Dunes (Sonoran). Eleven of 16 fell within the medium resilience range for their average scores. On the whole, average resilience scores tended to be pulled lower by either low scores for current landscape condition, current invasive species effects, current dynamic regime departure, or some combination of these three.

Adaptive capacity scores tended to contribute to higher overall resilience scores, with their averages ranging from a medium resilience score of 0.56 (North American Warm Desert Active and Stabilized Dunes- Sonoran) to a high resilience score of 0.83 (Desert Springs and Seeps – Mojave and Sonoran). On the whole, average resilience scores tended to be pulled lower by either low diversity within identified functional species groups (e.g., desert springs and seeps, mesquite bosque, mixed salt desert scrub), keystone species vulnerability (e.g., creosote-bursage scrub, Apacherian grassland), or where types occur across a relatively narrow elevation range (6 types).

Overall resilience scores ranged from medium (8 types) to high (8 types); but these scores all fell into a narrow range between 0.63 and 0.74. A moderate climate-change vulnerability assessment resulted from the combination of 1) high sensitivity with high resilience (7 types), medium sensitivity and medium resilience (2 types) and 3) medium sensitivity and high resilience (1 type) combinations for a given community type. Because no types score low for sensitivity, no types were scored overall as low vulnerability. Likewise because no types scored low for resilience, no types were scored overall as very high vulnerability.

Table 3. Summary of climate change vulnerability scores for terrestrial ecological system types treated for the Mojave and Sonoran Deserts.

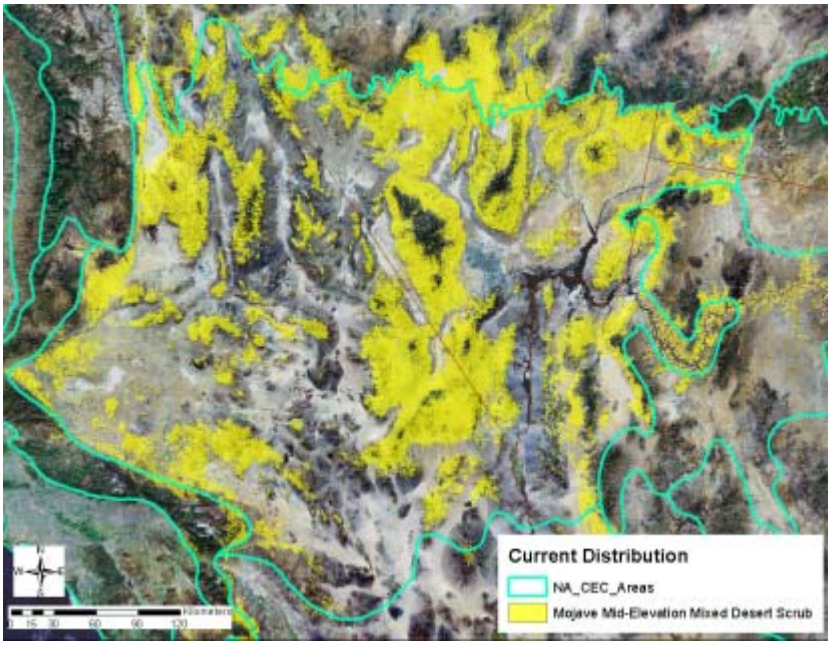
Type Name	Ecoregion	Direct Effects			Sensitivity Score		Indirect Effects						Adaptive Capacity					Resilience Score		CC Vulnerability
		CC Stress	Climate Envelope	Dynamics Forecast			LC 1960	LC 2010	IS 1960	IS 2010	Dynamics Current	Average	Diversity within Functional Group	Keystone Species Vuln.	Bioclim	Elev.	Average			
Great Basin Pinyon-Juniper Woodland	Mojave	0.35	0.17	0.49	0.34	H	*0.9*	*0.76*	*0.8*	*0.65*	*0.35*	**0.69**	*0.5*	*0.9*	*0.9*	*0.5*	**0.70**	**0.70**	H	Moderate
Mojave Mid-Elevation (Joshua Tree-Blackbrush) Mixed Desert Scrub	Mojave	0.35	0.12	0.44	0.30	H	*0.7*	*0.6*	*0.7*	*0.45*	*0.7*	**0.63**	*0.9*	*0.78*	*0.7*	*0.5*	**0.72**	**0.68**	M	High
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	Mojave	0.35	0.8	0.57	0.57	M	*0.8*	*0.73*	*0.8*	*0.59*	*0.1*	**0.60**	*0.7*	*0.6*	*0.7*	*0.6*	**0.65**	**0.63**	M	Moderate
Sonora-Mojave Mixed Salt Desert Scrub	Mojave	0.35	0.91	0.48	0.58	M	*0.9*	*0.72*	*0.8*	*0.54*	*0.26*	**0.64**	*0.7*	*1*	*0.7*	*0.8*	**0.80**	**0.72**	H	Moderate
North American Warm Desert Active and Stabilized Dunes	Mojave	0.35	*NA*	NA	0.35	H	*0.9*	*0.77*	*1*	*0.54*	*NA*	**0.80**	*0.9*	*0.75*	*0.4*	*0.3*	**0.59**	**0.70**	H	Moderate
North American Warm Desert Riparian Woodland and Stream	Mojave	0.35	*NA*	0.3	0.33	H	*0.6*	*0.4*	*0.5*	*0.4*	*0.4*	**0.46**	*0.8*	*1*	*0.8*	*0.6*	**0.80**	**0.63**	M	High
North American Warm Desert Riparian Woodland and Stream	Sonoran	0.45	*NA*	0.3	0.38	H	*0.6*	*0.4*	*0.7*	*0.5*	*0.4*	**0.52**	*1*	*0.85*	*0.8*	*0.6*	**0.81**	**0.67**	M	High
North American Warm Desert Mesquite Bosque	Mojave	0.35	*NA*	0.3	0.33	H	*0.7*	*0.6*	*0.5*	*0.5*	*0.5*	**0.56**	*0.6*	*0.85*	*0.7*	*0.7*	**0.71**	**0.64**	M	High
North American Warm Desert Mesquite Bosque	Sonoran	0.45	*NA*	0.3	0.38	H	*0.7*	*0.6*	*0.7*	*0.5*	*0.5*	**0.60**	*0.6*	*0.85*	*0.7*	*0.7*	**0.71**	**0.66**	M	High
Desert Springs and Seeps	Mojave	0.35	*NA*	0.3	0.33	H	*0.8*	*0.7*	*0.7*	*0.5*	*0.5*	**0.64**	*0.5*	*NA*	*1*	*1*	**0.83**	**0.74**	H	Moderate
Desert Springs and Seeps	Sonoran	0.45	*NA*	0.2	0.33	H	*0.8*	*0.7*	*0.7*	*0.5*	*0.5*	**0.64**	*0.5*	*NA*	*1*	*1*	**0.83**	**0.74**	H	Moderate
Sonoran Palo Verde – Mixed Cacti Desert Scrub	Sonoran	0.45	0.21	0.62	0.43	H	*0.8*	*0.7*	*0.9*	*0.84*	*0.72*	**0.79**	*0.7*	*0.7*	*0.7*	*0.4*	**0.63**	**0.71**	H	Moderate
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	Sonoran	0.45	0.39	0.6	0.48	H	*0.9*	*0.6*	*0.9*	*0.7*	*038*	**0.70**	*0.7*	*0.63*	*0.7*	*0.6*	**0.66**	**0.68**	M	High
Sonora-Mojave Mixed Salt Desert Scrub	Sonoran	0.45	0.21	0.6	0.42	H	*0.9*	*0.7*	*0.9*	*0.4*	*0.38*	**0.66**	*0.5*	*1*	*0.7*	*0.8*	**0.75**	**0.70**	H	Moderate
North American Warm Desert Active and Stabilized Dunes	Sonoran	0.45	*NA*	*NA*	0.45	H	*0.9*	*0.85*	*0.9*	*0.7*	*NA*	**0.84**	*0.85*	*0.7*	*0.4*	*0.3*	**0.56**	**0.70**	H	Moderate
Apacherian-Chihuahuan Semi-Desert Grassland	Sonoran	0.45	0.24	0.86	0.52	M	*0.6*	*0.5*	*0.9*	*0.8*	*0.43*	**0.65**	*1*	*0.5*	*0.7*	*0.4*	**0.65**	**0.65**	M	Moderate

Type Summaries

Here are included three examples of summaries of the natural community types treated in this effort. These examples include Mojave Mid-elevation Mixed Desert Scrub, North American Warm Desert Riparian Woodland and Shrubland, and Sonoran Palo Verde Mixed Cacti Scrub. These three types represent a cross-section of treated types, and well characterize the range of results for both vulnerability assessment and for adaptation strategy development. All type summaries are found in Appendix 3.

Mojave Mid-Elevation (Joshua Tree-Blackbrush) Desert Scrub

CONCEPT



This ecological system represents the extensive desert scrub in the transition zone above Creosote-Bursage desert scrub and below the lower montane woodlands (700-1800 m elevations) that occur in the eastern and central Mojave Desert. It is also common on lower piedmont slopes in the transition zone into the southern Great Basin. The vegetation in this ecological system is quite variable. Codominants and diagnostic species include *Coleogyne ramosissima, Eriogonum fasciculatum, Ephedra nevadensis, Grayia spinosa, Lycium* spp., *Menodora spinescens, Nolina* spp., *Opuntia acanthocarpa, Salazaria mexicana, Viguiera parishii, Yucca brevifolia*, or *Yucca schidigera*. Less common are stands with scattered Joshua trees and a saltbush short-shrub layer dominated by *Atriplex canescens, Atriplex confertifolia*, or *Atriplex polycarpa*, or occasionally *Hymenoclea salsola*. In some areas in the western Mojave, *Juniperus californica* is common with the yuccas. Desert grasses, including *Achnatherum hymenoides, Achnatherum speciosum, Muhlenbergia porteri, Pleuraphis jamesii, Pleuraphis rigida*, or *Poa secunda*, may form an herbaceous layer. Scattered *Juniperus osteosperma* or desert scrub species may also be present.

Overall Climate Change Vulnerability Score: High

DIRECT EFFECTS

Forecasted Climate Stress Index Result 0.**35 High Sensitivity**

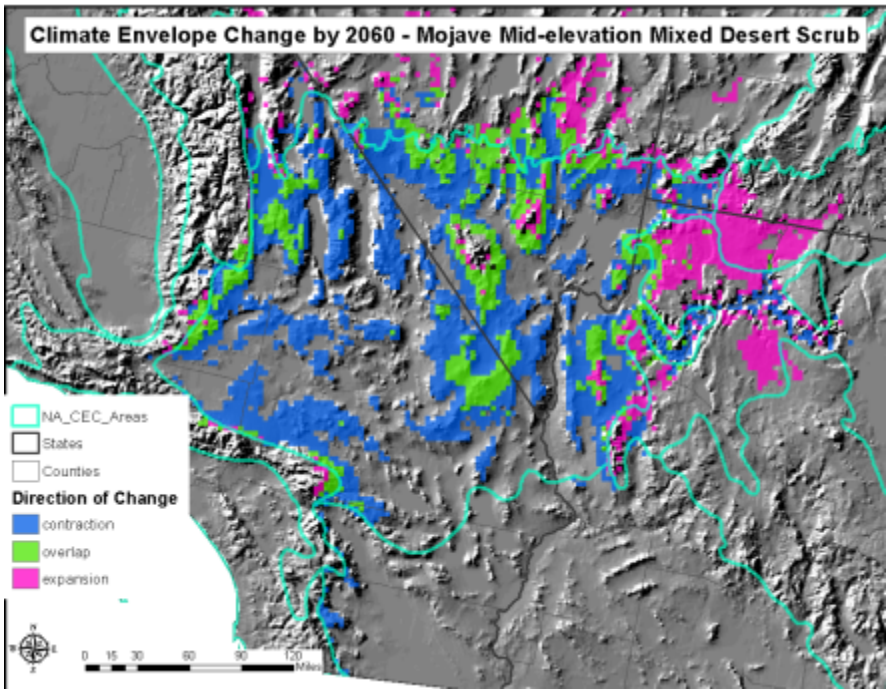
For the distribution of this community type within the Mojave Desert, 2060 forecasted temperatures in the months of July-September define this stress, with increases reaching extremes of 9 degrees F. Climate

models indicate that the Mean Maximum (daytime) Temperatures for July-August and Mean Minimum (night-time) Temperatures for June-September will increase by approximately 6 degrees F) for the majority of the Mojave Desert. The increased aridity from additional evapo-transpiration will likely cause decline in vegetation cover especially at the lower, hotter elevation sites. The model results also indicate a 0.9 inch (0.3-3.0 inch) increase in mean precipitation in August for the Spring Mountains and other nearby ranges.

The stress of increased mid-summer temperatures could take several forms. While many plants are already dormant, there may be interacting effects from wildlife if isolated springs dry up sooner. If additional moisture does occur in August, it could locally favor pinyon-juniper woodlands and other higher elevation communities commonly located adjacent to this desert scrub. There could also effects on cryptobiotic soil crusts, which are vulnerable to wetting without time to recover carbohydrate losses. They are adapted to arid summers and can get killed by multiple wetting. They are stabilize soils and could form a key functional group of species for soil stabilization.

Forecasted Climate Envelope Shift Index Result **0.12 High Sensitivity**

A substantial shift from the current climate envelope suggests potential movement of species from this community into the higher elevation pinyon-juniper woodlands and invasion from lower elevation stands of creosotebush desert scrub. This lower elevation conversion could be composed of shorter-lived, faster colonizing species such as *Ambrosia dumosa*, and years later, *Larrea tridentata*.



Dynamic Process Forecast

Fire Regime Departure Index 2060: Result **0.44 High Sensitivity**

While currently this community is somewhat departed from natural conditions (see indirect effects), largely by increase fire frequency resulting from invasion of non-native annual grasses, simulation models indicate a continued trend toward significant fire regime departure by 2060.

INDIRECT EFFECTS

Landscape Condition 1960: Result **0.70 High Resilience**

In 1960, land conversion from urbanization had begun. Impacts from the transportation infrastructure (fragmentation) consisted of a several highways and railroad lines and a sparse network of unimproved roads. Major economic activities with ecological impacts were mining (high intensity localized disturbance), cattle grazing (variable intensity, concentrated in areas), and military training and development near Las Vegas. Intensive cattle grazing dates back to the 1920s, with many Mojave yuccas were pulled or otherwise impacted.

Landscape Condition 2010: Result **0.60 Medium Resilience**

Fragmenting effects of urbanization have increased since 1960; primarily in concentrated areas surrounding established development (e.g., Las Vegas). Current ecological impacts from transportation (fragmentation), mining (high intensity localized disturbance), and recreation use (ORVs) has also increased. Increase in off-highway vehicles and urbanization and less grazing has occurred since 1990 due to protection of tortoise. Overall though, this type remains the most heavily used type for cattle grazing in the Mojave Desert (Keeler-Wolf 2007).

Invasive Species Effects 1960: Result **0.7 High Resilience**

Invasive, non-native plant species such as annual grasses *Bromus rubens* and *Schismus barbatus* invaded much of the Mojave Desert largely introduced from historic cattle grazing. While present and established by 1960, its relative impact was presumed to be limited.

Invasive Species Effects 2010: Result **0.45 Low Resilience**

Current spatial models suggest a massive expansion of introduced, non-native plant species since 1960. Invasion of non-native grasses have increased fire frequency and led to destruction of fire sensitive desert scrub (Sawyer et al. 2009).

Dynamic Process Alteration

Fire Regime Departure Index 2010: Result **0.70 High Resilience**

Introduction of fine fuels have an increasing effect on this types throughout many portions of the Mojave Desert. While significant departure has occurred in concentrated areas throughout the ecoregion, overall scores for the ecoregion keeps this score just within the range of ‘high’ resilience.

ADAPTIVE CAPACITY

Diversity within Plant/Animal Functional Groups: Result **0.9 High Resilience**

The key species functional group is species that are tolerant to severe drought (severity and length). The diversity of characteristic dominant species is high (33 species). *Additional consideration should be given for treatment of cryptobiotic soil crusts within this category*.

Keystone Species Vulnerability: Result **0.78 High Resilience**

Species were tentatively identified as those that could likely have cascading ecological impacts on community function. Selection criteria included dominant plant species and pollinators for *Yucca*. Once selected, a climate change vulnerability index was scored for their distribution within the ecoregion. Categorical scores were transformed to a 0.0 – 1.0 scale and averaged together for an overall index score.

Blackbrush (*Coleogyne ramosissima*) (0.7 High)

This species might be moderately vulnerable to climate change effects in the region, despite its high genetic variation and reliance on a variety of methods for seed dispersal. The increased vulnerability may be the result of changes in the moisture availability within the assessment area. Given these caveats, a 0.7 score still placed it within the high resilience range.

Black-throated Sparrow (*Amphispiza bilineata*) (1.0 High):

This bird may not be vulnerable to climate change in the region. Although it may be negatively affected by possible land use changes resulting from human responses to climate change and could experience detrimental effects from projected changes in moisture availability, it is a good disperser and ecologically versatile.

Yucca moth (*Tegeticula synthetic*) (West Mojave) (0.7 High)

Although this species may be a fairly good disperser and is associated with common geological features or derivatives, it may be negatively affected by projected changes in moisture availability. It is dependent on just one plant species (Joshua tree) for habitat and food, and that plant may be highly vulnerable to climate change within the assessment region. It could be negatively affected by land use changes resulting from human responses to climate change. Overall, it may be moderately vulnerable to climate change, but its borderline score of 0.7 places it with the high resilience category.

Yucca moth (*Tegeticula altiplanella*): (East Mojave) (0.7 High)

Although this species may be a fairly good disperser and is associated with common geological features or derivatives, it may be negatively affected by projected changes in moisture availability. It could be negatively affected by land use changes resulting from human responses to climate change. It is dependent on just one plant genus (*Yucca*) for habitat and food (in this assessment, yuccas were assumed to be at least somewhat vulnerable to climate change within the assessment region). Overall, the moth may be moderately vulnerable to climate change, but its borderline score of 0.7 places it with the high resilience category.

Bioclimate Variability: Result **0.7 High Resilience**

This type occurs in a moderately high number of isobioclimates (14/20) which is expected for a widespread type. It therefore is placed into the high resilience category.

Elevation Range: Result **0.5 Medium Resilience**

Number of 500' (152 m) elevation belts that encompass the type distribution is 6 of 12. It therefore is placed into the medium resilience category.

Expert Workshop: Ecosystem Stressor Worksheet

Non-Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description of linkages to CC scenarios	Mgmt Opportunity
Altered fire regime, invasive plants Rank 1	High	moderate	Increased summer temp, possible summer moisture through storm events	likely with range where invasives will not be limited by increasing aridity	Same as creosote-bursage
N deposition, ozone Rank 2					low
Livestock grazing Rank 3	Hi – mod locally	Hi-mod locally			High
Military training Rank 3	L	L			Same as above

Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description	Mgmt Opportunity
Summer precipitation effects on crytobiotic soil crusts	low	low	Increased summer temp, possible summer moisture through storms		Mod. protections from all forms of surface disturbance

Potential Climate Change Adaptation Strategies

Agency Management Goals related to this community type:

FWS: keep intact for desert tortoise and plant recovery, water development for game species

USFS: Recreation opportunities

"No-regrets" actions to take within the next 5 years:

- Invest resources into minimizing effects of fire using strategic planning – reduce response time to fires in year after high rains in Nov/Dec
- Soil stabilization
- Control of off road vehicles
- Restore hydrological function e.g., improve culverts, restore flows, remove diversions, prevent soil compaction, maintain natural litter fall, restore natural channels where altered, ensure herbicide application allows biomass to remain

- Closer management of grazing intensity
- Fine fuel reduction
- Prevention and control of invasive plants
- Reduce drought stress through thinning in PJ
- Reduce drought stress by preventing soil compaction in salt desert and creosote and blackbrush

Anticipated actions over the coming 5-15 years:

- Consider water developments where springs are drying up.
- Consider earthwork modifications that increase residence time of water in an area (check dams, low long berms)
- Encourage discussions among botanists, entomologists, etc. to develop indicators of ecosystem health and use these to guide adaptive management of all these habitats.
- Develop decision support system and adaptive management for when not to intervene and how to intervene
- Land Fire improvement: complete field verification of existing map and model outputs and monitor with aim to evaluate their predictions
- Downscaling CC modeling to a useful scale; need to determine what scales are useful for which purposes.
-

Wait and watch actions: Potential actions to anticipate over the 15-30 timeframe, with indicators to monitor and inform that future decision

- #1 How successful are re-vegetation efforts and mitigations that have been used?
- #2 Soil crust impacts, succession, function, under changes in rainfall pattern

Research and Monitoring Priorities

- Monitor effectiveness of mitigations for renewable energy impacts
- Research how to use mitigations to alleviate climate change – opportunistic, open ended
- Impacts of retiring grazing allotments – not only to protect desert tortoise, contrast where still in effect, and controlled livestock in vegetation near conservation areas.
- Monitor extent of nitrogen and ozone deposition and impacts to vegetation & nutrient cycling.
- Large scale fuel reduction strategies for adjacent creosote scrub, and use of additional pathogens.
- Monitor invertebrates that are key to ecosystem services and processes
- Research – focus on plant pollinator relations (rare plants)
- Pollutant/toxic impacts under climate change
- We talk about what we are losing, but not about what we are gaining. May want to manage for the changes. Is it all going to become desert pavement? What do we want to facilitate that provides the ecological services?
- Do we have our monitoring set up to pick up the shifts in functional groups?

North American Warm Desert Riparian Woodland, Shrubland and Stream

CONCEPT

This ecological system consists of low-elevation (<1200 m) riparian corridors along medium to large perennial streams throughout canyons and desert valleys of the southwestern United States and adjacent Mexico. Major rivers include the lower Colorado (into the Grand Canyon), Gila, Santa Cruz, Salt, lower Rio Grande, and the lower Pecos. The vegetation is a mix of riparian woodlands and shrublands. Dominant trees include *Acer negundo, Fraxinus velutina, Populus fremontii, Salix gooddingii, Salix lasiolepis, Celtis laevigata var. reticulata, Platanus racemosa*, and *Juglans major*. Shrub dominants include *Salix geyeriana, Shepherdia argentea*, and *Salix exigua*. Woody vegetation is relatively dense, especially when compared to drier washes, and phreatophytes draw alluvial groundwater from below the streambed elevation when surface flows stop. Alluvial groundwater levels depend on seasonal precipitation and runoff, and on basin-scale hydrogeology including connections between the alluvial aquifer and surrounding basin-fill and bedrock aquifers. Vegetation depends for growth and reproduction upon annual or periodic flooding and associated sediment scour and/or on annual rise in the water table, with this rise driven by precipitation. The system thus depends on both surface and groundwater regimes, and is sensitive to changes in both.

Overall Climate Change Vulnerability Score: High (Mojave Desert)
Overall Climate Change Vulnerability Score: High (Sonoran Desert)

DIRECTS EFFECTS

Forecasted Climate Stress Index: Mojave Desert Result **0.35 High Sensitivity**
Sonoran Desert Result **0.45 High Sensitivity**

Sonoran Desert may warm by, on average, 2-4 degrees F; whereas the Mojave Desert is predicted to have a 4-9 degree F increase. Precipitation is less predictable. If precipitation increases significantly, this may change the timing or magnitude of peak and low stream flows which may be beneficial to some species and detrimental to others. Given the higher probability of warming, the stress on component species is high for drought and heat intolerant species. With the higher uncertainty on how precipitation may change, it is difficult to rate the stress this may have on this ecosystem. The direct effect on the hydrologic regime is considered separately.

Dynamic Process Forecast
Hydrologic and Fire Regime Change 2060: Mojave Desert Result **0.3 High Sensitivity**
Sonoran Desert Result **0.3 High Sensitivity**

Current and forecasted trends in both deserts show potential for moderate increases in precipitation in July and August months; although some models show a decrease or no change in the amount of moisture. The latter could result in:

- **higher evapo-transpiration rates** leading to an earlier, more rapid seasonal drying-down of stream/riparian communities;
- **increased water stress** in nearby basin-floor phreatophyte communities (e.g., Mesquite Bosque), and later, less frequent, briefer wetting of nearby playas;
- **shrinkage of areas of perennial flow/open water**, coupled with higher water temperatures at locations/times when water temperatures are not controlled by groundwater discharges or snowmelt;
- persistence of these hydrologic conditions later into the fall or early winter; and
- **reduced groundwater recharge** in the mountains and reduced recharge to basin-fill deposits along the mountain-front/basin-fill interface.
- Where <u>increases</u> in precipitation, especially in July and Aug, might occur this may result in:
- Increased soil erosion from increased surface flows, which may negatively impact water quality;
- Increased stream flow magnitude in summer time;
- No change, as these results from Sonoran have not yet been compared to historic variation in precipitation.
-

Increased fire frequency and intensity in the watersheds of these systems will have enormous post-fire effects on riparian systems.

- Increased winter precipitation causes increased fire in low/mid elevation shrublands, which causes decreased short-term evapotransporation. This leads to increased groundwater recharge, which increases post-fire runoff, changing riparian geomorphology and water chemistry.
- Long-term decreased precipitation (e.g., drought) causes increased fire in woodlands and forests, which causes decreased evapotransporation. This leads to increased groundwater recharge, which increases post-fire runoff, changing riparian geomorphology and water chemistry.
- Example 1: Mogollon Rim. Decreased precipitation caused increased fire intensity/size/ frequency, which led to increased post fire watershed effects to downstream riparian and spring systems.
- Example 2: Increased August precipitation in high-elevation woodlands caused increased intensity post-fire watershed events following June fires.

Fires also have direct effects on these systems, changing water chemistry, increasing invasive spp. spread, and increasing inflammability.

Primary concerns include:

- **Increased flammability** due to tamarisk and fountain grass causes increased fire frequency and fuel continuity, which results in changes in species composition and structure.
- Many of the hydrological regime changes could be exacerbated by fire.
- Compounding effects of in situ climate change on **post-fire regeneration of dominant species** (e.g., mesquite regeneration by seed germination).

<u>INDIRECT EFFECTS</u>

Landscape Condition 1960: Mojave Desert Result **0.6 Medium Resilience**

Sonoran Desert Result **0.6 Medium Resilience**

Ample evidence suggests Native American impacts in the Salt/Gila basin from their own irrigation systems. Ranching and farming have been drawing groundwater and diverting surface water from the relevant streams/rivers since the late 1800s. Maps of the extent of perennial flow in Arizona, for example, show a drastic decline that started in the late 1800s, due to diversions and groundwater withdrawals. Physical collapse of basin-fill aquifers due to the groundwater removal, date to the mid-1900s; along with the effects of domestic livestock grazing. This would have significantly altered the distribution of this community type, greatly reducing its extent.

Landscape Condition 2010: Mojave Desert Result **0.4 Low Resilience**
Sonoran Desert Result **0.4 Low Resilience**

The Sonoran Desert has a very similar footprint to the Mojave Desert with several large urban and agricultural areas along with many relatively unfragmented watersheds. Long-distance canals and impoundments feed water to urban areas and cause impacts from a great distance. There are also cumulative effects of groundwater withdrawals from ranches and numerous small towns. Intensive farming along the riparian corridors fragments floodplain and riparian habitat. Riparian corridor areas are impacted by domestic livestock grazing that reduces bank stability and causes high soil erosion, channel widening and increased in-channel water temperatures. In addition there are watershed-scale impacts of domestic livestock grazing, including soil compaction and removal of runoff-retaining vegetation.

Invasive Species Effects 1960: Mojave Desert Result **0.5 Medium Resilience**
Sonoran Desert Result **0.7 High Resilience**

Historic cattle grazing introduced invasive plant spp. Late-19th -early 20th century. Deliberate introductions of tamarisk, Russian olive, and annual grasses in residential areas and grazing lands brought these species into riparian corridors.

Invasive Species Effects 2010: Mojave Desert Result **0.4 Low Resilience**
Sonoran Desert Result **0.5 Medium Resilience**

The current extent of exotic species is incompletely mapped, however spatial models of areas within the Unites States likely to contain significant amounts of tamarisk, Russian olive, and annual grasses indicate >50% of the riparian areas are affected. In addition, there are aquatic invasive species such as mollusks, non-native fish, bullfrogs and crayfish, which could completely change the aquatic food chain dynamics and eliminate native aquatic species.

Dynamic Process Alteration
Hydrologic Change 2010: Mojave Desert Result **0.4 Low Resilience**
Sonoran Desert Result **0.4 Low Resilience**

Agricultural and residential/urban use has dropped groundwater levels significantly, already reducing or eliminating many gaining reaches. This began in the late 1800s, and the effects were coupled with a climate-change episode and/or impacts of cattle grazing on watershed runoff (the debate is ongoing) that resulted in a period of significant channel downcutting during the 1930s across the Sonoran region. This resulted in the death of large riparian woodlands on what became hydrologically stranded elevated terraces, and re-establishment of the system on new lower terraces that the entrenched streams carved out.

ADAPTIVE CAPACITY

Diversity within Plant/Animal Functional Groups: Mojave Desert Result **0.8 High Resilience**
Sonoran Desert Result **1.0 High Resilience**

These communities include a variety of plant and animal life, from woody phreatophytes to warm season grasses, and freshwater and alkaline tolerant species. Within each functional group there are a moderate number of species such as several warm season grasses that are alkaline tolerant, several broad-leaf woody tree and shrub species although none are nitrogen fixers, and multiple nutritious forb species.

Keystone Species Vulnerability: Mojave Desert Result **1.0 High Resilience**
Sonoran Desert Result **0.85 High Resilience**

American Beaver (*Castor canadensis*) (*tbd*)
This species plays an obvious 'keystone' role in stream and riparian ecosystems where they occur. They would only be expected to occur in the largest portions of this system along the eastern margins of the Sonoran Desert. Evaluation of their relative vulnerability to climate change within this ecoregion has yet to be completed.

The following two species were selected for their relative structural contributions to these communities, with cottonwoods forming primary tree canopy constituents, and indicative of functioning hydrodynamics. Gilded flicker was chosen due to its cavity-nesting behavior and related influence on other species habitat requirements.

Fremont's cottonwood (*Populus fremontii*) (1.0 High)
This species might be potentially stable (with high confidence) in the region despite climate change effects. This may be a result of high genetic variation in Fremont cottonwood that affects whole-tree physiological processes which help adapt a tree to its environment including whole-tree water use and also net primary productivity**.**

Gilded flicker (*Colaptes chrysoides*) (1.0 High)
This species exhibits characteristics that both increase and decrease its vulnerability to climate change, but overall it may not be vulnerable to climate change and might actually expand its range in the region. It relies heavily on a small number of species that are critical in providing suitable habitat, and land use changes resulting from human responses to climate change could affect it, but these may be overcome by the bird's good dispersal abilities and other aspects of its ecological versatility.

Bioclimate Variability: Mojave Desert Result **0.8 High Resilience**
Sonoran Desert Result **0.8 High Resilience**
This community could occur throughout all local climate regimes that characterize the Mojave, Sonoran, and Chihuahuan deserts. This type occurs in a high number of isobioclimates (16/20).

Elevation Range: Mojave Desert Result **0.6 Medium Resilience**
Sonoran Desert Result **0.6 Medium Resilience**
Type is limited to elevations <1200 m (3950 ft). This community occurs within a relatively narrow elevation range. Number of 500ft (152m) elevation belts that encompass the type distribution is 8 of 12.

Expert Workshop: Ecosystem Stressor Worksheets

Non-Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description of linkages with CC scenario	Mgmt Opportunity
Human overpopulation Recreational uses	H	H	Y = potential interaction	Hotter temps means that people will aggregate more in cool, wet places.	M

Non-Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description of linkages with CC scenario	Mgmt Opportunity
			with increased aridity and unpredictability in precipitation events	Warming temps will make riparian areas more restricted, so recreation will be more concentrated.	
Land use change (development, energy, agriculture)			Y	Solar panels require a lot of water for washing.	
Surface water withdrawal			Y	Less water will remain in perennial streams due to increased evapotransportion.	
Groundwater depletion			Y		
Non-native herbivorous ungulates	M	H	Y	Will concentrate more around water. Legal cattle grazing may decrease because increased temps may make the activity no longer economically viable.	M/L US/Mex
Fire and post-fire watershed effects	L /but increasing	H	Y	Increasing variability in precipitation will increase fire frequency.	M
Invasive species -plants -animals (includes honey bees)	H	H	Y	Dry conditions can promote the growth of invasives.	Variable (site and sp specific)
Water flow control (dams, aqueducts) – Mainstem (includes trans-basin transport of water, e.g., Col. Riv. water going to LA)	H	H	Y	Climate change will influence the activities and maintenance of dams, which will have an influence on downstream riparian communities.	L
Water flow control (dams, aqueducts) - Tributaries	H	H	Y	Same as for mainstem dams, but severity of the impact is greater.	M
Resource extraction (logging, mining)	L	H	N		H
Contamination/water quality	H	H	Y	Extreme storm events will wash more contaminants from urban areas and upper water sheds into riparian areas. Increased	H

Non-Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description of linkages with CC scenario	Mgmt Opportunity
				evapotransporation will lead to lower water levels and therefore greater concentrations of contaminants.	
Air Pollution/nitrate deposition & acid rain	M	L-M	Y	Higher temps can lead to greater dust deposition.	

Novel Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description
Increased Water Temperature				Can be greater than physiological tolerances and therefore cause distributional shifts or contractions. Increase in metabolism and decrease in dissolved oxygen.
Increased in mean and maximum air temperature				Can be greater than physiological tolerances and therefore cause distributional shifts or contractions. Increase in metabolism. Increased evaporation and evapotransporation. Increase in stress to plants and therefore lower vigor. Can cause de-synchronization of interspecific events. Some springs/seeps may go dry.
Shift in timing of precipitation events.				Plant regeneration could be threatened if there are no spring rains.
Shift in intensity of precipitation events.				Runoff, plant response and insect hatches are all related to rain intensity.
Shift in amount of precipitation.				Influences hydrogeology that maintains these systems. Can cause increased sp-specific mortality. Some springs/seeps may go dry.
Increase in extreme events (freezes, floods, heat waves, droughts, wind, and combinations of these)				Can cause shift in species composition and structure of habitat. Can exacerbate other nonclimate stressors (such fire, invasives).
All Climate Stressors				Climate events in watersheds beyond where these systems occur have a major influence on this system.
Context				These systems have many migratory species that are subject to climate and nonclimate stressors during stages of their life cycle occurring elsewhere.

Potential Climate Change Adaptation Strategies

Generalized strategies and notes:

-Protect and enhance riparian areas and the listed species that depend on them
-Preservation of remnant riparian areas to support migratory birds
-Protect upper watershed
-Reduce invasives
-Maintain biodiversity and processes (such as flooding)
-Maintain and enhance connectivity for fish
-Preserve scenery, water-based natural and cultural resources for public enjoyment
-Identify information needs of land managers, conduct research, and provide information

****This workshop breakout group had no fish advocate so didn't identify any fish-specific strategies, although they suggested ways to restore riparian habitat that will in turn benefit fish.*

"No-regrets" actions to take within the next 5 years:

- Water flow controls on tributaries
- Fully exercise water rights pertaining to protected lands (various legal mechanisms)
- Work with tribes to fully exercise water rights for mutual benefits.
- Work with agricultural water users to adjust timing and use of diverted water to benefit stream inflows.
- Explore management options for existing dams to maintain downstream riparian processes (e.g., controlled floods)
- Explore opportunities to manage return flows (e.g., stormwater, irrigation return, wastewater effluent) to benefit riparian resources and/or processes (geomorphology)
- Comprehensive aquifer mapping to better understand temporal and spatial connectivity between surface and groundwater.
- Improve engineering practices for diverting/allocating flows to maintain more in stream flow.
- Monitor surface flows and losses.
- Fix laws to better maintain in stream flows.
- Fire and invasives
- Increase resistance to fire by removing/controlling fire-tolerant invasive plants (e.g., buffelgrass, tamarisk)
- Selectively transition riparian forest species composition to meet target conservation species while reducing fire hazard (e.g., planting willow/cottonwood pockets to increase after tam beetle)
- Increase and maintain availability of plant propagules for restoration after fire/invasive species treatment (willow, cottonwood, grasses, others)
- Research drought and temperature tolerant genotypes for restoration.
- Education and management to prevent unplanned human ignitions in riparian and adjacent uplands
- Pre-plan post-fire response to minimize impacts of water impacts of watershed effects (EG debris flows, floatable debris, ask, etc) (site specific)
- Pre-plan for invasive species control and post treatment restoration (in general)
- Explore/research restoration techniques

- Monitor – ecological monitoring and treatment effectiveness to define baselines and implement adaptive management

Actions to anticipate over the coming 5-15 years:

- Manage water control structures at the system level to meet multiple demands (including in stream flows).

"Watch and Wait" Potential actions to anticipate over the 15-30 timeframe, with indicators to monitor and inform that future decision:

- All actions were categorized as research and monitoring priorities.

Research and Monitoring Priorities *(numbers refer to number of votes by participants indicating priorities)*

A. Invasives and restoration

-Modeling of spread through regions of greatest risk (with projected new climates)
-Invasive effects of system? (2)
    -Feral animal impacts on systems
    -Synergies, such as cattle/livestock grazing and bufflegrass and fountain grass invasions
-Identification of spring/seep species best for propagation and reintroduction
-Monitor treatment effectiveness (1)
-Monitor past disturbance restoration
    -early invasion
    -establishment of natives
-Research drought and temperature tolerant genotypes and species (1)
-Research restoration techniques to improve efficiency and effectiveness (6)
    -How to improve restoration of agricultural lands to mesquite bosques
-Ecological monitoring to define baselines (1)

B. Hydrology

-Need for spatial information linking recharge zones with springs and riparian systems (3)
-Where are the aquifers and which springs are dependent on which aquifers (1)
-How does recharge effect aquifer levels (2)
-What makes particular springs or riparian areas more vulnerable to climate change
-Better groundwater monitoring
-Better general understanding of hydrological regimes (7)
-Explore management options for existing dams to maintain riparian processes
- Explore opportunities to manage return flows (e.g., storm water, irrigation return, wastewater effluent) to benefit riparian resources and/or processes (geomorphology)
- Monitor surface flows and losses.
- Monitor flows, seasonality and temperature and water chemistry in springs. (1)
- How do we establish buffers around recharge areas?
- Inventory ephemeral drainages in mesquite systems (1)

C. Species traits

- Which species have the genetic diversity that make them better candidates for restoration in the context of climate change?
-What is the vulnerability of species at critical stages (e.g., seedlings) with increased climate variability? (5)
-Need more information about physiological temperature tolerances of key species. (3)
-Identify the species at risk that are especially vulnerable to climate change. (3)

D. Fire

-More information is needed about the natural history of fire in all three riparian/aquatic systems from this effort.

E. Keystone species

-Quantitative selection of keystone species? (5)

-Algae as keystone species for species and seeps?

-Need more thought on which keystone species to select.

F. Synchrony

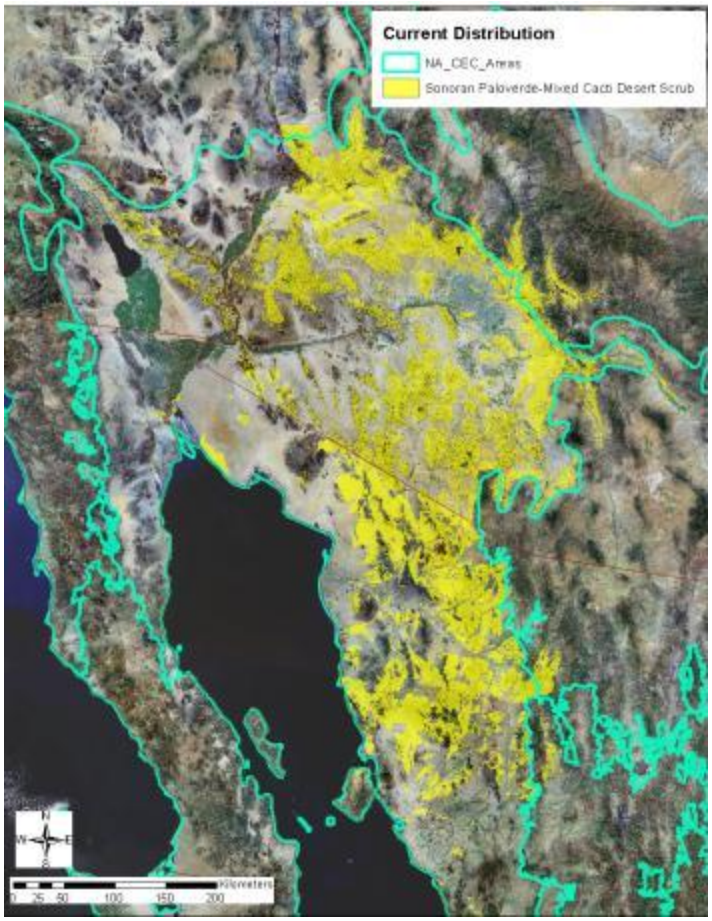
-How precipitation and temperature influence phenology (identifying problem species) (3)

G. Identifying sensitive species

-Establish and maintain long-term monitoring of multi-species and community level variables so we will learn which species are sensitive and what the baseline normal variance is. (2)

Sonoran Palo Verde–Mixed Cacti Desert Scrub

CONCEPT



This ecological system occurs on hillsides, mesas and upper bajadas in southern Arizona and extreme southeastern California. The vegetation is characterized by a diagnostic sparse, emergent tree layer of *Carnegiea gigantea* (3-16 m tall) and/or a sparse to moderately dense scrub canopy co-dominated by xeromorphic deciduous and evergreen tall shrubs *Parkinsonia microphylla* and *Larrea tridentata*, with *Prosopis* spp., *Olneya tesota*, and *Fouquieria splendens* less prominent. Other common shrubs and dwarf-shrubs include *Acacia greggii, Ambrosia deltoidea, A. dumosa* (in drier sites), *Calliandra eriophylla, Jatropha cardiophylla, Krameria erecta, Lycium* spp., *Menodora scabra, Simmondsia chinensis*, and many cacti, including *Ferocactus* spp., *Echinocereus* spp., and *Opuntia* spp. (both cholla and prickly-pear). The sparse herbaceous layer is composed of perennial grasses and forbs with annuals seasonally present and occasionally abundant. On slopes, plants are often distributed in patches around rock outcrops where suitable habitat is present. Outliers of this succulent-dominated ecological system occur as "Cholla Gardens" in the western Mojave in California. In this area, the system is characterized by *Opuntia bigelovii, Fouquieria splendens, Senna armata*, and other succulents, but it lacks the *Carnegia gigantea* and *Parkinsonia microphylla* which are typical farther east. Adjacent and related communities are the Baja California del Norte Gulf Coast Ocotillo-Limberbush-Creosotebush Desert

Scrub (see description at http://www.natureserve.org/infonatura/). While there are floristic overlaps, these limberbush and elephant tree communities are not treated here.

Overall Climate Change Vulnerability Score: Moderate

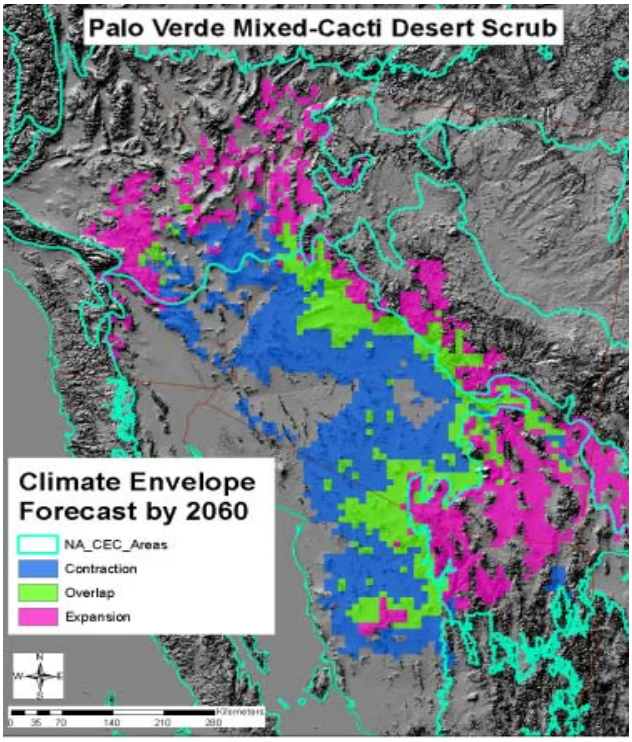
DIRECT EFFECTS

Forecasted Climate Stress Index: Result **0.45 High Sensitivity**

Climate forecasts from an ensemble of downscaled global climate models are summarized for the period around 2050-2060. These forecasts indicate the relative degree of forecasted climate stress, using forecasted change in temperature and precipitation between current and 2060. The Sonoran Desert may warm by, on average, 2-4 degrees F, whereas the Mojave Desert is predicted to have a 4-9 degree F increase. Precipitation is less predictable. If precipitation increases significantly, this may change the timing or magnitude of peak and low stream flows which may be beneficial to some species and detrimental to others. Given the higher probability of warming, the stress on component species is high for a drought and heat intolerant species. With the higher uncertainty on how precipitation may change, it is difficult to rate the stress this may have on this ecosystem.

Forecasted Climate Envelope Shift Index: Result **0.20 High Sensitivity**

This spatial model indicates a very substantial contraction in bioclimate where this vegetation most likely co-occurs with creosote-bursage desert scrub, suggesting a potential expansion of creosotebush and related species throughout this portion of the distribution. A considerable area throughout the eastern margins of the Sonoran Desert contains the 'overlap' zone between current and 2060 bioclimate envelope locations, so while the relative percent area of overlap is low, the predicted core zone is contiguous. Local expert review of model output elicited comment that the prediction might be overstated.



Dynamic Process Forecast

Fire Regime Departure Index 2060: Result **0.62 Medium Sensitivity**

The continued spread of invasive species as fine fuels may continue to introduce a fire regime into this desert scrub. The appearance of additional uncharacteristic successional states resulting from this explains patterns in current and forecasted departure. Local experts comment that the 2060 forecast may be somewhat overstated because increased aridity (higher temp, more/less temperature) may decrease invasive grass cover leading to decline in fuels needed to carry fires

INDIRECT EFFECTS

Landscape Condition 1960: Result **0.8 High Resilience**

Historic ranching and agriculture took place throughout this vegetation; but until substantial urbanization and irrigated agriculture began, their proportional influence was limited. However, concentrated impacts from livestock may have been more substantial throughout the Plains of Sonora.

Landscape Condition 2010: Result **0.7 High Resilience**

With expanded urbanization and irrigated agriculture, more substantial proportions of these communities have been affected by landscape fragmentation.

Invasive Species Effects 1960: Result **0.9 High Resilience**

Building upon spatial model results for current conditions, a review of literature and historical maps supported a relative expert judgment. Past ranching and grazing would have introduced a number of invasive plant species by this time, but their overall distribution and impact would have still been somewhat limited.

Invasive Species Effects 2010: Result **0.84 High Resilience**

Invasive plant species, such as buffelgrass (*Penstimen ciliare*) and other species, have been expanding their distribution and ecological impact by introducing fire regimes in this community types over recent decades. Current spatial models, albeit limited to US distribution, indicated 16% of the current extent infested with substantial invasive plant species (BLM Sonoran Desert REA 2012).

Dynamic Process Alteration
Fire Regime Departure Index 2010: Result **0.72 High Resilience**

The introduction of invasive species as fine fuels has introduced a fire regime into this desert scrub. The appearance of additional uncharacteristic successional states resulting from this explains patterns in current and forecasted departure.

ADAPTIVE CAPACITY

Diversity within Plant/Animal Functional Groups: Result **0.9 High Resilience**

Key ecological function species group is species responses to drought (severity and length), which has high diversity of characteristic dominant species with adaptations to drought (drought deciduous, (33 species).

Keystone Species Vulnerability: Result **0.7 High Resilience**

Gilded flicker (*Colaptes chrysoides*) (1.0 High): This species exhibits characteristics that both increase and decrease its vulnerability to climate change, but overall it may not be vulnerable to climate change and might actually expand its range in the region. It relies heavily on a small number of species that are critical in providing suitable habitat, and land use changes resulting from human responses to climate change could affect it, but these may be overcome by the bird's good dispersal abilities and other aspects of its ecological versatility.

Littleleaf Paloverde (*Parkinsonia microphylla*) (0.7 High): This species might be highly vulnerable (with moderate confidence) to climate change in the region, mainly due to proposed changes in moisture availability (the species is inherently tied to the summer rains) and the effects of climate change on seed dispersal. As a result, the species range may shift and perhaps leave the assessment area.

Saguaro Cactus (*Carnegiea gigantea*) (0.5 Low**):** This species might be highly vulnerable (with moderate confidence) to climate change in the region mainly due to forecasted changes in moisture availability, and its dependence on other species that might be affected by climate change for seed dispersal. The species range might shift and/or perhaps leave the assessment area.

Bioclimate Variability: Result **0.7 High Resilience**

This type occurs in a moderately high number of isobioclimates (13/20) which is expected for a widespread type.

Elevation Range: Result **0.4 Low Resilience**

Number of 500' (152 m) elevation belts that encompass the type distribution is quite limited; with 5 of 12.

Expert Workshop: Ecosystem Stressor Worksheets

Non-Climate Stressor	Current Scope	Current Severity	2060 Climate Scenario	Description
Burro and cattle grazing	High	High/M	Increased summer temperature and variable change in precipitation	No
Loss of pollinators	Low	Unknown		Yes (mining)
Illegal and military activities 100 miles around border (direct surface effects, fragmentation, noise, and fire ignitions)	Med	High		No

Off highway vehicles	Low	Moderate		No
invasive vegetation (buffel grass) and altered fire regime	Moderate	high		Yes (grazing, OHV, urbanization can increase invasives as well)
Urbanization and development including agriculture	Moderate	High		no
Mining (especially in Sonora MX)	Low	High		no
Wood-collection	Low	High		
Roads, canals	Low	high		
Disease, pathogens, pest outbreaks	Low	Unknown		
Decline in genetic variability	Low	Moderate		Limited to rare species

Novel Climate Stressor	**Current Scope**	**Current Severity**	**2060 Climate Scenario**	**Description**
Plant species die-off and lower recruitment associated with warming, extreme drought	L	unknown	Increased summer temperature and variable change in precipitation	already observed, rate of die-off exceeding recruitment
Rapid loss of soils, erosion, dust storms	L	unknown		
Effects of changes of phenology	L	unknown		
Increased variability of precipitation, temperature including extreme events and effects on populations and processes	L	unknown		
Increased solar radiation (less atmospheric moisture) leading to declines in herps	L	unknown		
less water availability in tinajas affects mammals depend upon them	L	unknown		
drought = less plant production = increase herbivory xero-riparian systems	L	unknown		

increased temps and possibly reduced rainfall will lead to less water available for mammals and birds				

Potential Climate Change Adaptation Strategies

Non climate-change Stress: Invasive grass/altered fire regime

Management Intervention: NOTE: within the State of Sonora, state agency primarily provides technical assistance in management planning to private landowners, vs. most US participants who are land managers themselves, with their own planning processes.

When buffelgrass / invasive veg: mechanical removal for small infestations, spraying for large infestations. Mechanical thinning at high-probability ignition sites (e.g., roadsides) and around other sensitive resources.

Novel climate-change Stress: Shifts in seasonality of Precipitation

Management Intervention: monitoring to detect severe shortage, and then subsidize locally with water tanks. Need to look at more investment in water storage.

Novel climate-change Stress: Shifts in Phenology

Management Intervention: monitoring to detect shift to gauge relative vulnerabilities for sensitive resources; i.e., need to understand the nature of phenology change before strategies could be considered. E.g., this year blooming season occurred earlier, especially with trees and columnar cacti.

Primary strategy: establish phenology monitoring program targeting key phonologies of likely influence on sensitive resources.

Novel climate-change Stress: Loss of pollinators

Management Intervention: a) Establish monitoring program b) compare blooming seasons with pollinators (Lepidoptera / migratory pollinators [arrival vs. departure]) c) detect change in behavior of pollinators (specialists and generalists) d) detect changes in bat populations, and e) protect rost colonies in caves (those not currently protected). Detect changes in flower/fruit decline?

"No-regrets" actions to take within the next 5 years:

- Fine fuel reduction (exotic annual grass control) and fire suppression in this fire sensitive system.
- Closer management of grazing intensity
- Planning to maintain contiguous natural blocks
- Aggressive prevention and control of invasive plant species
- Aggressive management of wildland fire

Anticipated actions over the coming 5-15 years:

- Develop monitoring program for bats to detect changes in populations and work towards protecting habitats
- Implement a phenology monitoring protocol to document changes in timing of blooming for columnar cacti and effects on pollinators
- Hold workshops that bring together all managers that focus on an important species, and use workshop to share information (e.g., phenology, abundance), develop hypotheses of change (e.g., bat conservation international)
- Evaluate, share, analyze existing weather station information across managed areas, states, countries; and develop strategy to prioritize locations for new stations.
- Increasing fire ignition with drought years, and expanding fire patch size
- Increased densities of invasive plant populations
- In cases where phenology changes are detected, work with partner land management agencies in places that are more appropriate or suitable for bats
-

Potential actions to anticipate over the 15-30 timeframe, with indicators to monitor and inform that future decision:

Research and Monitoring Priorities

- What is the capacity for invasive grasses to expand and therefore shift fire regime?
- Within the Sonoran Desert, what are the indicator and keystone species and what is the impact of their loss?
- How do you characterize adaptive capacity for sparsely vegetated systems (e.g. sand dunes)?
- What are the displacement effects of invasive species in creosote-bursage system?
- Are soil crusts susceptible to climate change and to what degree?
- What is the potential of strategy to inoculate soils for soil crusts?
- Need guidance and best practices on efficient monitoring protocols to track and detect plant community change associated with climate change.
- What is the relationship of precipitation regime (e.g. seasonal precipitation patterns) with plant recruitment?
- What are the contributing factors and pattern to recent plant die-off in Sonoran Desert ecological systems?
- Need a study that identifies pollinators that serve a keystone role in Sonoran Desert ecological systems.

Discussion

The intent of this pilot effort was to explore approaches to documenting relative climate-change vulnerabilities among major natural communities occurring across managed areas of the Mojave and Sonoran deserts. By integrating available information, this effort identified a) variability in current knowledge and data within these two deserts and across national borders, and b) the relative applicability of this information to climate-change adaptation strategy development. A brief discussion follows identifying some key lessons learned from this pilot effort.

CC Vulnerability Assessment for Communities and Habitats

This effort drew inspiration from many similar efforts on the overall structure, measurements used, and available data. By first assembling the data and completing preliminary analysis, local experts were able to review and critique the approach and preliminary results. This process led to a number of refinements in the approach, HCCVI structure, and results for each community type. The overall approach, attempting to apply a systematic framework to climate change vulnerability assessment, followed by its application to identifying adaptation strategies, appears to have been successful. It also appears that by selecting a clear timeframe for assessment; i.e., "CC vulnerability within the next 50 years" brings a meaningful focus for application to decision making. Specific lessons learned regarding the linkages between vulnerability assessment and adaption strategy development are addressed below.

A number of issues with methodology for the HCCVI were identified through this pilot. Some measures of vulnerability are intended as relative measures, comparing results for a wide diversity of community types. For example, measures of bioclimate variability or elevation range for each community type were relative scores based on an overlay of several hundred mapped community types from across the western United States and (for elevation range) adjacent Mexico. This aspect of the approach – utilizing nationally or regionally available spatial data to generate relative scores – presents the opportunity to rapidly develop preliminary scores for many community types. These preliminary results can then feed into refinements by local experts. However, while those two scores (bioclimate variability and elevation range) are easy to replicate for community types across the conterminous United States, a similar measure for bioclimate variability may be more challenging to develop at this time for Mexican communities.

Of most significant challenge methodologically is the application of the climate stress index. In this pilot, prior spatial analysis for the Mojave Desert was easily applied for the types, and likely provides a robust method for gauging relative climate stress by 2060. A weighted averages of monthly climate variables forecasted to have statistically significant departures from the 20th century baseline values goes quite directly towards the intent of this measure. However, we were not able to apply that same method for communities in the Sonoran Desert, and in order to arrive at a robust relative measure, this same type of analysis needs to be replicated with many community types across North America. Alternative methods to gauging climate stress with readily available climate data should be explored to ease the application of this critical measure of vulnerability.

Other challenges identified with this proposed methodology included the treatment of functional species groups and 'keystone' species. While both of these concepts for vulnerability measures are desirable and likely provide important contributions, limits to current knowledge become apparent when one attempts to identify species for each category.

The HCCVI was structured to arrive at relative scores for climate change sensitivity vs. ecological resilience; with resilience being an average of scores from indirect effects and adaptive capacity measures. This structure likely provides results that are robust for a wide variety of circumstances. With additional knowledge and data, one could likely move to an additional level of detail within the index and provide some relative weighting of individual measures to influence component averages.

CC Vulnerability Assessment across spatial scale and scales of ecological organization

Climate change vulnerability assessment can and should be done at landscape, community, and species scales of ecological organization. In this pilot, climate-stress measures, along with many indirect effects measures, tended to be similar across all of the major community types in this pilot area. Clearly, the selection of ecoregion-scale units, such as the Mojave vs. Sonoran desert ecoregions, provides a practical and useful spatial structure for this purpose. Based on this pilot, pursuit of climate stress measures, along with measures for landscape condition and dynamic regime alteration may be efficiently pursued across multiple ecoregions.

That said, the upland and riparian/aquatic communities selected for this pilot characterize a very high proportion of each of these ecoregions, and appear to provide a very useful scale of analysis if the aim is to clarify adaptation strategies.

These two scales, ecoregion and community, should most certainly be complimented with assessment of species. There are clearly important facets of biodiversity and wildlife conservation that would not be adequately addressed by focusing only at community and/or ecoregion/landscape scales. However, the focus for species assessments can be on those that a) are already vulnerable in some form, and b) those that are thought to provide some 'keystone function.'

One additional role for species identified through this pilot was as useful indicators of the climate-change effects likely to occur among the communities of interest. There are quite likely to be a number of species for which, through monitoring of the presence and/or abundance across seasons, should have very high indicator value for coping with climate change over the upcoming decades. By first clarifying the plausible climate scenario for a given ecoregion, and then considering likely effects on communities, these species may be readily identified. This is certainly an area deserving more attention.

Linking CC Vulnerability Assessment to Adaptation Strategies

As stated previously, the overall approach of this effort was to effectively link climate change vulnerability assessment to the identification of adaptation strategies. This was facilitated by a) selection of major natural communities as one scale of analysis, b) organization of vulnerability measures into direct effects, indirect effects, and adaptive capacity, and c) organizing local expert review within each ecoregion, where decisions across jurisdiction pertain to many of the same community types.

Workshop participants most readily identified components of indirect effects scores (e.g., landscape condition, invasive species, dynamic process alteration) as forming the focus of many "no regrets" strategies that could be pursued by managers. In most cased, these factors relate to the stressors that are best known and are currently being addressed within managed areas.

Where indirect effects stressors were less well known, and/or interactions with climate change were less clear, strategies tended to be categorized as "anticipated actions" within the 5-15 year timeframe, where additional information will be required to move forward, but participants could foresee their implementation. Direct effects, such as climate stress and climate envelope shifts, challenged workshop participants to identify novel climate-change stressors, such as effects of heat stress or changes in seasonality of precipitation and their potential effects on biodiversity, such as pollinators. Given the limits to current knowledge in these areas, the strategies identified tended to fall in the "wait and watch" category, where research questions are specified and work will be required over upcoming decades in order to determine appropriate adaptation strategies.

Finally, workshop participants identified a common list of generalized climate change adaptation strategies suitable for application across all community types for this pilot. These included:

- reduce drought stress
- maintain/promote gene flow
- coordinate movement for pollinators & seed dispersers
- protect functions of invertebrates for ecosystem services & processes
- know when NOT to intervene
- manage transition zones and refugia
- stabilize soils after disturbances
- protect current "pristine" ecosystem areas (few disturbances)
- maintain or restore hydrologic functioning – manage ground disturbance depth
- manage/control all impacts of groundwater use – specific to salt desert scrub, dries out causing PM10 dust from playas
- For dunes need to maintain vegetated buffer around dunes
- Inform the public using diverse media and campaigns about impacts/functions of climate
- Outreach to managers

Recommendations to the Desert LCC. At the close of the workshop, participants were engaged in a discussion to identify how the Desert LCC could carry the process forward. There was a sense that although we had made tremendous progress in two days, time was insufficient to prioritize actions for each of the communities examined; let alone develop synergistic strategies applicable across multiple managed areas. The participants recommended coordination of follow-up meetings to further develop the adaptation strategies identified and to place them in the context of strategies being pursued currently. The meeting would be structured somewhat differently, beginning with training and then examining adaptation strategies. Specific suggestions about the meeting were:

Provide Training in Structured Decision Making. Begin with training on rapid prototyping, the method taught in the National Conservation Training Center (NCTC) course on Structured Decision Making, to help participants learn how to decide whether to alter their current management strategies and, if so, how to do so (e.g., see http://www.structureddecisionmaking.org/). Then use this approach during the remainder of the meeting to identify the most effective and urgent strategies to implement.

Construct Alternative Scenarios. A concern is that by the time we have enough data to be able act with limited uncertainty; it will be too late for the biodiversity concerned. Therefore, the use of scenario planning together with models and projections would be helpful for exploring management alternatives.

Engage More Experts. Invite experts in particular systems or aspects therein to help better understand ecological interactions and to improve the strategies. For example, the Southern Arizona Buffelgrass Coordination Center (www.buffelgrass.org) may be able to provide expertise on the ecology of buffelgrass in these Sonoran Desert communities.

By supporting a follow-up meeting that considers these points, the Desert LCC could help consolidate the understanding generated during this project and catalyze the next step of land managers enacting strategies that begin to address the threats posed by climate change on the systems they oversee.

Glossary of Terms

Adaptive capacity - The potential or capability of a system to adjust to climate change, including climate variability and extremes, so as to moderate potential damages, to take advantage of opportunities, or to cope with consequences.

Climate change adaptation – Management strategies that minimize the effects of climate change on species, ecosystems, and ecological functions (Cross et al. 2012).

Climate change vulnerability – The degree to which a system is susceptible to - and unable to cope with - adverse effects of climate change; including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007).

Climate change vulnerability assessment – The process of determining which species or systems are likely to be most strongly affected by climate change and why they are likely to be vulnerable (Glick et al. 2011).

Climate envelope – The modeled association between current climates (such as temperature, precipitation and seasonality) and present-day distributions (Thomas et al. 2004).

Climate stress – The perturbation caused to a natural community by departures of climate (temperature, precipitation, seasonality, event intensity) from baseline values.

Direct Effects – the current and forecasted exposure of a natural community to climate change and their likely effects on ecosystem-specific processes.

Ecological resilience – The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Holling 1973, Gunderson 2000, Walker et al. 2004).

Exposure – The degree of climate stress upon a particular unit analysis; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events.

Functional group – Groups of organisms that pollinate, graze, disperse seeds, fix nitrogen, decompose organic matter, depredate smaller organisms, or perform other functions in a natural community (Rosenfeld 2002, Folke et al. 2004).

Indirect Effects – The predisposing conditions of a natural community that affect ecological resilience.

Keystone species – Species, which when lost or reduced in abundance, will cause significant cascading effects on the populations of other species occurring in the community.

Landscape condition – An assessment of the state of the physical, chemical, and biological characteristics (including interactions) of a landscape that accounts for the effects of human land uses.

"No-regrets" actions – Management actions that are robust to uncertainty and thus will likely contribute to a desired outcome regardless of other factors.

Sensitivity – The degree to which a system will be affected by, or responsive to climate stimuli.

Stressor – An external agent, event, or condition that causes stress on a species or system.

Common Abbreviation

Bioclim: Bioclimatic variability

BLM: Bureau of Land Management

CART: Classification and Regression Trees

CC: Climate change

CCVI: Climate Change Vulnerability Index (for species)

CEC: Commission for Environmental Cooperation

DOD: Department of Defense

Elev: Elevational range

FWS: Fish and Wildlife Service

GCM: Global Circulation Model

H: High

HCCVI: Habitat Climate Change Vulnerability Index

IPCC: Intergovernmental Panel on Climate Change

IS: Invasive Species index

L: Low

LC: Landscape Condition

LCC: Landscape Conservation Cooperative

M: Medium

MaxEnt: Maximum Entropy (a species habitat modeling algorithm,

see http://www.cs.princeton.edu/~schapire/maxent/)

NCTC: National Conservation Training Center

NPS: National Park Service

NRA: National Recreation Area

Precip: Precipitation

PRISM: Parameter-elevation Regressions on Independent Slopes Model (a climate mapping system,

see http://prism.oregonstate.edu/)

REA: Rapid Ecoregional Assessment

Stdv: Standard deviation

USGS: United States Geological Survey

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Appendix 1. Field Specialist Survey

A major goal of the project is to develop methods and outcomes useful for natural resource managers. To better understand the needs, concerns, and interests of managers in the Desert LCC, and therefore enhance the chances of creating products useful for them, we initiated the project with a survey of the potential user audience. The survey sought to understand the natural communities managed, the most important stressors to these systems, the communities perceived to be most vulnerable to climate change, the climate change factors causing these stresses, and the greatest needs for scientific information about climate change. Besides providing a general picture of managers' needs and perceptions about climate change, the survey also allowed us to choose ten plant community types to focus our pilot study on vulnerability of desert habitats to climate change.

Survey and method. We used an online survey (**www.surveymonkey.com**) to canvass land managers during November and December 2011. Members of a project advisory team, representing four U.S. federal agencies, two Mexican government agencies, one U.S. state agency, two nonprofit environmental organizations, and a botanical garden (see Acknowledgements for members), invited appropriate staff (land managers, refuge biologists) from their institutions to participate in the survey. All invited respondents worked in either the Mojave or Sonoran deserts. The survey was intentionally short to encourage a broader response. We estimated that participants would take no longer than 15 minutes to answer the seven questions that made up the survey.

To understand who actually took the survey, respondents were first given the option of providing their name and contact information and then asked to identify the managed area where they work and the major vegetation communities or habitats that they are tasked with managing. The Survey monkey results also list the IP address of each respondent. Using Internet IP look-up sites, we were able to use this information to identify the institutional servers from which most of the respondents accessed the survey and thus infer the institutional makeup of the respondent pool. The remaining five questions addressed the details of vegetation communities managed and presumed vulnerable to climate change, stressors, and information needs. The questions about stressors and information needs provided options for rating on importance/urgency and allowed respondents to write in additional answers. Respondents simply typed the answers to the other questions.

Results. A total of 66 people filled out the survey. The IP address information indicated their affiliations as follows: U.S. Fish and Wildlife Service (25), Bureau of Land Management (15), National Park Service (9), the State of Arizona (5), Mexican government or NGO (3), State of Nevada (2), U.S. Department of Defense (3), Native American Tribes (1), USDA NRCS (1) and unknown (2). A wide range of protected and managed lands were represented among respondents, with many US Fish and Wildlife Refuges, BLM protected areas (e.g., ACECs, Desert Tortoise critical habitat), National Parks (including Monuments, Conservation Areas, Recreational Areas, and Preserve Units), DoD facilities, tribal lands, and several managed/protected areas and biosphere reserves in Sonora.

The survey showed that respondents manage a wide variety of primary upland vegetation type, wetland or riparian community types, and individual species habitat types. We received a total of 314 answers to this question, most of which were mentioned multiple times under a various names (the survey requested that they list types using whatever nomenclature they commonly used). The most common types were some

sort of riparian, wetland, spring, or wash community (including cottonwood-willow riparian communities), blackbrush scrub, creosotebush communities, desert grasslands, Joshua tree woodlands, sand dunes, mesquite bosques, paloverde associations, pinyon-juniper woodlands, and a variety of desert scrub communities. A few species habitats were also mentioned, including Golden Eagle, desert tortoise, bighorn sheep, and desert pupfish.

Respondents ranked common stressors to the communities for their relative importance (from 1= not important to 5= highest importance). The average scores, listed in decreasing order were:

Stressor	**Mean score**
Invasive species	4.2
Decreased water availability (other than from pumping)	3.6
Altered fire regime	3.6
Current climate change effects	3.4
Groundwater pumping	3.3
Land use change outside borders	3.2
Recreational activities	3.0
Energy development	3.0
Over grazing	2.2
Mining effects	2.0

Other types of stressors listed by respondents included issues such as:

- Air pollution (nitrogen deposition and other effects on desert tortoise)
- Illegal activity associated with drug/human trafficking and related law enforcement
- Military ground training (e.g., causing soil disturbance/compaction, increased erosion, or dust production)
- Effects of large-scale energy development, especially where wildlife species are translocated and/or concentrated.

Management concerns related to climate change were listed and described by respondents relative to distinct community types. These concerns varied widely, and generally involved interaction with non-climate-change stressors, but included:

- Effects of increasing temperature, such as a ‘drying out’ of sand dunes and effect on groundwater dependent species.
- Higher elevation communities and species already at risk, given limited options for movement upslope.
- Fragmentation (due to water-related stress or other source) of existing migratory corridors for wildlife, such as in riparian zones
- Loss of keystone species or increased stress on narrowly endemic species
- Coastal effects, such as increased storm surge intensity and coastal marine habitat impacts

Respondents were also asked to indicate their relative needs for information regarding climate change. In an established list of categories rated from 1-5 (from 1= not needed to 5= greatly needed) the following average scores were tabulated.

Climate change information need	Mean score
Climate vulnerability of vegetation/community/habitats	4.2
Predictions on how climate change will influence the hydrological cycle	4.0
Climate vulnerability of selected species	3.9
Interaction of climate change relative to other stressors	3.8
Climate-induced phenology change in vegetation	3.6
Modeled climate envelope shifts for vegetation/community/habitats	3.6
Guidelines on monitoring for climate change	3.5
Modeled range shift maps for species	3.4
Downscaled climate predictions	3.1

Additional information needs listed by respondents included:

- Information for plant community management and restoration, in order to maintain ecological health and resiliency
- Understanding of wildlife population changes and movement patterns in light of anticipated climate change effects; including for migratory birds
- Baseline information on current community location and health
- Monitoring of trends in key ecological indicators, for better interpretation of climate change effects
- Understanding edaphic constraints on succession; and how edaphically constrained communities are likely to respond to climate stress
- Management strategies that work with unavoidable change to natural disturbance regimes

The survey also asked about the natural community types that respondents were most concerned about being vulnerable to climate change. Although we intended to use the responses to this question to determine the focal community types for the project, several people answered by stating that they were concerned about all of the communities that they listed under the question about communities that they managed. We therefore used the results of the prior question to develop the list of focal communities. To do so, we first related each type to the NatureServe terrestrial ecological systems classification (see http://www.natureserve.org/explorer/). We used this classification because it a) comprehensively describes upland, wetland, and riparian types across the hemisphere, b) describes community types at 'intermediate' scales, suitable for management, c) has been used for national and regional mapping and modeling efforts, such as the USGS Gap Analysis, inter-agency LANDFIRE, and BLM Rapid Ecoregional Assessments, and d) links directly to U.S. federal data standards, such as the U.S. Vegetation Classification. This classification forms a common language for rapidly linking interests of survey respondents and facilitates our use of existing investments in mapped and modeled information to advance project goals.

The result of this exercise was to group the 314 communities named into 15 community types that were suggested by at least four respondents (Appendix 1). Through discussions with the project advisory team, we arrived at a final list of ten focal types for the project. The list includes both upland and riparian systems with representation from both the Mojave and Sonoran Deserts:

- North American Warm Desert Riparian Woodland and Shrubland and Stream
- North American Warm Desert Mesquite Bosque

- Mojave-Sonoran Desert Springs and Seeps
- Sonoran Paloverde-Mixed Cacti Desert Scrub
- Sonora-Mojave Mixed Salt Desert Scrub
- Sonora-Mojave Creosotebush-White Bursage Desert Scrub
- Mojave Mid-Elevation Mixed Desert Scrub
- Great Basin Pinyon-Juniper Woodland
- Apacherian-Chihuahuan Semi-Desert Grassland and Steppe
- North American Warm Desert Active and Stabilized Dune

Conclusions. Thanks to a healthy response rate, the survey succeeded in providing a snapshot of Mojave and Sonoran Desert land managers' perceptions about climate change in the larger context of stressors to the biodiversity they help protect. Climate change is but one of numerous stressors that the respondents are confronting, ranking noticeably behind invasive species in importance. Managers are concerned about climate change affecting a wide range of communities via mechanisms that relate to increased water stress, isolation of mountaintops, loss of keystone or endemic species, and storm surge in coastal systems. Their top climate change-related information needs are vulnerability assessments of communities and species as well as predictions of how climate change will influence hydrological cycles. Finally, the survey allowed us to select for vulnerability assessment 10 community types that are relevant to a broad spectrum of land managers.

Appendix 2. Methods Detail *(see separate document)*

Appendix 3. Type Summaries *(see separate document)*

Appendix 4. Workshop Agenda

Mojave-Sonoran Deserts Natural Community Vulnerability Assessment

Adaptation Strategy Workshop

1-2 August 2012

Arizona Game and Fish Department Headquarters, 5000 West Carefree Highway, Phoenix, AZ

Workshop Goal

Indentify management strategies that can be readily implemented in managed lands of the Sonoran and Mojave deserts to promote adaptation of natural communities and associated species.

Workshop Objectives

- **Communicate the results** of climate change vulnerability assessments of ten focal community types of the Sonoran and Mojave Deserts to biologists and managers of U.S. and Mexican protected areas that contain these communities.
- **Receive feedback** on the methods employed and results obtained in the vulnerability assessments.
- **Document ecological stressors** commonly affecting these communities within managed lands.
- **Discuss and identify specific strategies** that can be employed on the ground in protected/managed areas or areas/programs that have management planning involved to reduce climate change impacts on the characteristic mosaic of natural communities.
- **Create awareness** about climate change in desert ecosystems, potential synergies among non-climate and climate-induced stressors, and the options for managing for change, as well as climate change resources available for managers.

Agenda

<u>Day 1: 1 August 2012</u>

8:00 Coffee, snacks, informal introductions

8:30 Welcome, Introductions, Housekeeping, Lunch plans

Sabra Tonn *(Arizona Game & Fish Department)* **Genevieve Johnson** *(US Bureau of Reclamation)* **Bruce Young** *(NatureServe)*

8:45 Workshop Overview – Goals, Desired Outcomes, Structure, Agenda ***Pat Comer*** *(NatureServe)*

9:00 ABCs of Climate Change Vulnerability Assessments and Adaptation Planning, ***Bruce Young***

9:30 Climate Change Vulnerability Index for Ecosystems and Habitats, ***Pat Comer***

10:30 Break

10:45 (cont'd) Climate Change Vulnerability Index, ***Pat Comer***

11:15 Charge for Breakout Groups, ***Carol Beardmore***, *US-FWS*

11:30 Initiate Work in Groups

1) *NatureServe ecologists present HCCVI results for subgroup of community types (Pat Comer, Marion Reid [phone], Keith Schulz [phone])*
2) *Discuss results for understanding by group; consider interactions among adjacent community types. Consider and describe any alternative climate-change scenarios relative to those used in the draft HCCVI analyses. (capture notes in each community abstract draft)*

12:30 Lunch

1:30 Resume Group Work

3) *List the key ecological stressors for each community*

4) *Identify and categorize where likely climate stress may intensify non-climate stressors (weak, moderate, strong interaction)*

3:15 Break

3:30 Resume Group Work

5) *Rank stressors by scope and severity, [i.e., by % of distribution effected vs. relative intensity of ecological disruption]*

Desired Day 1 outcome: *List of most important stressors for each community that will require action across the ecoregion.*

4:30 Report Back from Groups

5-10 min per group, share highlights & inspirations only, not entire results

4:55 Recap and Preview of Day 2, ***Bruce Young***

5:00 Adjourn

<u>Day 2: 2 August 2012</u>

8:00 Orientation to the day's activities, announcements, ***Pat Comer***

8:10 Overview of Conservation Adaptation Planning, ***Marcos Robles*** *(The Nature Conservancy)*

9:20 Charge for Breakout Groups, ***Bruce Young***

9:35 Initiate Work in Groups

1) *Review matrix developed on Day 1, making adjustments as needed according to any new insights by group members*
2) *Briefly characterize management goals for each community from each participants managing agency*

10:30 Break

10:45 Resume Group Work

3) *Brainstorm possible points of management intervention and strategies that could ameliorate stress (flip charts)*

4) For each community type, list and prioritize strategies as:

a. "No-regrets" actions to take within the next 5 years.

b. "Anticipated Actions" over the coming 5-15 years.

c. "Wait and Watch" or potential actions to anticipate over the 15-30 year timeframe, with indicators to monitor and inform those future decisions.

12:00 Lunch

1:00 Resume Group Work

6) Document strategies that would be logical and feasible to initiate or advance within each managed area represented in the breakout group.

3:00 Break

3:15 Resume Group Work

7) Prioritize research needs that have been documented throughout Day1 and 2.

8) Discuss desired workshop follow-up.

4:00 Report Back from Groups

10 min per group, share highlights & inspirations only, not entire results

4:30 Recap and Next Steps, ***Bruce Young***

5:00 Adjourn

Focal Natural Communities and Breakout Groups

	Breakout Group #
North American Warm Desert Riparian Woodland and Shrubland and Stream	1
North American Warm Desert Mesquite Bosque	1
Mojave-Sonoran Desert Springs and Seeps	1
Apacherian-Chihuahuan Semi-Desert Grassland and Steppe	2
Sonoran Paloverde-Mixed Cacti Desert Scrub	2
Sonora-Mojave Mixed Salt Desert Scrub	2&3
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	2&3
North American Warm Desert Active and Stabilized Dune	2&3
Mojave Mid-Elevation Mixed Desert Scrub	3
Great Basin Pinyon-Juniper Woodland	3

Breakout Groups

Group	***Facilitator***	***HCCVI Presenter***	***Notetaker***
1 – Riparian/Springs	*Carol Beardmore*	*Marion Reid (phone)*	*Bruce Young*
2 – Sonoran Desert uplands	*Pat Comer*	*Pat Comer*	*Marcos Robles*
3 – Mojave Desert uplands	*Jim Weigand*	*Keith Schulz (phone)*	*Laurie Simons*

Appendix 5. List of Workshop Participants

Attendee	Institution
Invitees	
Tom Anderson	Sonny Bono Salton Sea National Wildlife Refuge, Fish & Wildlife Service
John Arnett	DOD, Luke Air Force Base & Barry Goldwater Range
Cristi Baldino	Ash Meadows National Wildlife Refuge, Fish & Wildlife Service
Kathleen Blair	Bill Williams National Wildlife Refuge, Fish & Wildlife Service
David Braun (phone)	Sound Science
Sandee Dingman	Lake Mead National Recreation Area, NPS
Chris Gregory	Carlsbad Ecological Services Office, Fish & Wildlife Service
Kerry Griffis-Kyle	Texas Tech University
Jennifer Holmes	Northern Arizona University
Izar Izaguirre Pompa	Pinacate Biosphere Reserve, Comisión Nacional de Áreas Protegidas
Genevieve Johnson	Bureau of Reclamation, Phoenix
Janel Johnson	Nevada Natural Heritage Program
Mark Kaib	Fish & Wildlife Service Region 2
Sonja Kokos	Bureau of Reclamation, Las Vegas
Marty Lawrence	The Nature Conservancy
Yadid Antonio León Moreno	Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora
Alberto Macías	Centro de Estudios del Estado de Sonora, Hermosillo
Bernadine McCollum	The Nature Conservancy
Hector Munro	Pinacate Biosphere Reserve, Comisión Nacional de Áreas Protegidas
Alice Newton	Lake Mead National Recreation Area
Horacio Ortega Morales	Pinacate Biosphere Reserve, Comisión Nacional de Áreas Protegidas
Kris Randall	Arizona Field Office, Fish & Wildlife Service
Marion Reid (phone)	NatureServe
Keith Schulz (phone)	NatureServe
Sid Slone	Cabeza Prieta National Wildlife Refuge, Fish & Wildlife Service
Lindsay Smythe	Desert National Wildlife Refuge, Fish & Wildlife Service
Lisa Soo	BLM-Arizona
Bob Unnasch	Sound Science
Kim Veverka	Cabeza Prieta National Wildlife Refuge, Fish & Wildlife Service
Jim Weigand	BLM-California State Office
Brian Wooldridge	Arizona Field Office, Fish & Wildlife Service
Advisory Team Members	
Carol Beardmore	Fish & Wildlife Service Phoenix
Patrick Comer	NatureServe
Peter Holm	Organ Pipe Cactus National Monument, NPS
Elroy Masters	BLM, Arizona
Marcos Robles	The Nature Conservancy
Laurie Simons	Desert National Wildlife Refuge Complex, Fish & Wildlife Service
Sabra Tonn	Arizona Game and Fish Department
Bruce Young	NatureServe