

SOUTHWEST CLIMATE CHANGE INITIATIVE

The Four Forest Restoration Initiative: Implementing a Climate Change Adaptation Framework for Natural Resource Management and Planning

**Flagstaff, Arizona
7-8 April 2010**

Prepared by:

**Edward Smith (The Nature Conservancy)
Molly Cross (Wildlife Conservation Society)
Gregg Garfin (University of Arizona)
Patrick McCarthy (The Nature Conservancy)
Dave Gori (The Nature Conservancy)
Marcos Robles (The Nature Conservancy)
Carolyn Enquist (The Nature Conservancy)**

6 October 2010

**This work funded in part by the
Rodney Johnson – Katherine Ordway Stewardship Endowment Fund
and the Frankel Family Fund**

The Four Forest Restoration Initiative: Implementing a Climate Change Adaptation Framework for Natural Resource Management and Planning

Table of Contents

Table of Contents.....	1
List of Figures.....	3
List of Tables.....	4
Executive Summary.....	5
Introduction.....	1
Workshop Goal and Objectives.....	1
The Four Forest Restoration Initiative Landscape.....	1
Workshop Outcomes.....	2
Background Information for Development of Adaptation Strategies.....	3
Introduction to Adaptation Planning.....	11
Implementation of the Adaptation Planning Framework.....	12
Climate Change Adaptation Strategies for Conservation Targets.....	13
Climate Change Adaptation Strategies for Ponderosa Pine Fire Regime.....	13
Defining the Conservation Feature.....	14
Management Objectives.....	14
Conceptual Model and Impacts Assessment.....	15
Management Intervention Points and Adaptation Strategies.....	16
Priority Adaptation Strategies.....	16
Climate Change Adaptation Strategies for Maintaining Watershed Function in Ponderosa Pine Forests.....	17
Defining the Conservation Feature.....	17
Management Objectives.....	17
Conceptual Model and Impacts Assessment.....	18
Management Intervention Points and Adaptation Strategies.....	19
Priority Adaptation Strategies.....	20
Discussion and Next Steps.....	22
Climate Change Adaptation Strategies for the Mexican Spotted Owl.....	23

Defining the Conservation Feature	24
Management Objective	25
Conceptual Model.....	25
Climate Change Impacts Assessment	26
Management Intervention Points	27
Strategic Actions for Climate Adaptation.....	27
Research and Monitoring Needs for Mexican Spotted Owl.....	28
Priority Adaptation Strategies.....	29
Discussion and Next Steps.....	30
Synthesis of Priority Strategic Actions into Cross-Cutting Strategic Actions.....	31
Social and Economic Issues.....	31
Planning and Design of Treatments.....	31
Implementation and Monitoring of Treatments.....	32
Opportunities, Challenges, and Barriers to Strategic Action Implementation.....	32
Economics.....	32
Forest Management.....	33
Monitoring	34
Emerging Themes, Conclusions, and Next Steps	35
Closing Remarks	36
Acknowledgements.....	37
Literature Cited	38
Appendices.....	40
Appendix A Arizona Climate Change Adaptation Workshop Participant List	40
Appendix B Agenda for the Southwest Climate Change Initiative’s Arizona Workshop.....	42
Appendix C Future Climate Scenarios for Northern Arizona	46
Precipitation and Temperature	46
Moderate climate change scenario.....	47
Extreme climate change scenario.....	47
Sample results of a regional climate model scenario.....	48
Hydrological Scenarios.....	51
Overview of models and data used:	51
Appendix D1 Climate Change Impacts (Hypotheses of Change) for Ponderosa Pine Fire Regime	56
Appendix D2 Climate Change Impacts (Hypotheses of Change) for Ponderosa Pine Watershed Function	58

Appendix D3	Climate Change Impacts (Hypotheses of Change) for Mexican Spotted Owl	61
Appendix E	Arizona Climate Change Adaptation Workshop Definitions	64
Appendix F	Web Resources	67
Appendix G	Rocky Mountain Research Station Vulnerability Assessment for Mexican Spotted Owl	69

List of Figures

Figure 1	The analysis area of the workshop covered by the Four Forest Restoration Initiative area is depicted in this map. Map courtesy of Megan Friggens, Rocky Mountain Research Station. ...	2
Figure 2	Cross et al.'s (in review) iterative climate change adaptation framework for natural resource management and conservation. The left side represents the adaptation planning phase; the right side represents the action plan implementation.....	13
Figure 3	Conceptual model of ponderosa pine forest and associated fire regime.	15
Figure 4	Conceptual ecological model of ponderosa pine forest and associated watershed function.	18
Figure 5	Conceptual ecological model for Mexican spotted owl.	26
Figure 6	Annual time series of temperature for both the present period (1971-2000) and into the future (2041-2070) for roughly the Four Forest Restoration Initiative area of Arizona. A clear upward trend is exhibited in the current and future time periods, and the mean temperature increase in the future is about 2.7 °C (4.9°F).....	49
Figure 7	Annual time series of precipitation for the future period (2041-2070) minus the present period (1971-2000). Neither time series exhibits a distinct trend, but a mean annual decrease in precipitation in the future of 3% is found.	49
Figure 8	Graph shows changes in summer precipitation in the southwest US from the global model (CGCM3) and the change from the regional model (CRCM), which was nested in the global model. The same broad pattern of change is seen in both, but the regional model exhibits an intensification of the precipitation decreases in a more complex pattern.	50
Figure 9	Graph shows changes in summer precipitation in the southwest US from the global model (CGCM3). The same broad pattern of change is seen in both, but the regional model exhibits an intensification of the precipitation decreases in a more complex pattern.	50
Figure 10	The greenhouse gas emission scenario families as defined by IPCC in the Special Report on Emission Scenarios (SRES; IPCC, 2000).	51
Figure 11	Map of watersheds affected by climate change scenarios within the 4FRI area.....	53
Figure 12	Annual hydrograph of Salt River streamflow for the model-simulation of 1971-2000 (Sim Hist), 2009-2038 (Period 1), 2039-2068 (Period 2), and 2069-2098 (Period 3). The overall volume of annual flow declines with each successive future period, and the timing of peak runoff shifts to earlier months.....	54
Figure 13	Annual hydrograph of Verde River streamflow for the model-simulation of 1971-2000 (Sim Hist), 2009-2038 (Period 1), 2039-2068 (Period 2), and 2069-2098 (Period 3). The overall volume of annual flow declines with each successive future period; however, the timing of peak runoff remains in March.	55

List of Tables

Table 1 High priority strategic actions identified by participants for reducing climate change impacts on the Ponderosa Pine fire regime for two climate scenarios.	17
Table 2 Priority strategic actions identified by participants for reducing climate change impacts on Ponderosa pine-watershed function for two climate scenarios.....	21
Table 3 Total annual and seasonal changes in temperature and precipitation for all scenarios modeled as captured between the 25th and 75th quantiles from model runs to about 2060.	47
Table 4 Moderate climate scenario changes for temperature and precipitation.	47
Table 5 Extreme climate scenario changes for temperature and precipitation.	48
Table 6 ‘Alternate’ climate scenario changes for temperature and precipitation.	48
Table 7 Global Climate Models and simulation periods used for developing the hydrological scenarios for the workshop	51
Table 8 Mid-21st Century projections of Salt River streamflow change in percent change from the 1971-2000 mean. A1B, A2, and B1 refer to SRES emissions scenarios; the values in these columns are for the mean of 3 models described in the text (HadCM3, MPI ECHAM 5, NCAR CCSM3. Range refers to individual model runs.....	52
Table 9 Mid-21st Century projections of Verde River streamflow change in percent change from the 1971-2000 mean. A1B, A2, and B1 refer to SRES emissions scenarios; the values in these columns are for the mean of 3 models described in the text (HadCM3, MPI ECHAM 5, NCAR CCSM3). Range refers to individual model runs.....	52
Table 10 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on Ponderosa Pine Fire Regime Conservation Feature for two climate scenarios.....	56
Table 11 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on Ponderosa pine watershed function for two climate scenarios.....	58
Table 12 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on the Mexican Spotted Owl for two climate scenarios.....	61

The Four Forest Restoration Initiative: Implementing a Climate Change Adaptation Framework for Natural Resource Management and Planning

Executive Summary

Whether we call it climate change or long-term drought and warmer weather, people living in the deserts, grasslands, and forests of Arizona are noticing changes in the landscape.

*How would northern Arizona be if its forests were severely limited in extent?
What would it be like to have no snow in the mountains?*

On 7-8 April 2010, 44 representatives of 15 state and federal agencies, local governments and non-governmental organizations met in Flagstaff, Arizona to address these and other questions posed for forests, wildlife and communities within the Four Forest Restoration Initiative (4FRI) area. Participants learned about long-term drought and rising temperatures and their effects on forests, and then participated in identifying management strategies that will help native plants, animals and ecosystems adapt to a changing climate and lay the groundwork for strategy implementation.

Plausible scenarios of climate change over the next 40 to 60 years for northern Arizona include an average annual temperature increase of two to three degrees Celsius, and average annual precipitation changes ranging from an 18% decrease to a 3% increase. Potential hydrologic scenarios for the Verde and Salt Rivers range from an increase of 6.5% to a decrease of 27% of average flows over the 1971 to 2000 period. Ponderosa pine forests and the services they provide in habitat, water supply, recreation and others are highly vulnerable to these trends in temperature and precipitation. Speakers presented compelling stories that led participants to conclude that changes in local climate have contributed to increases in wildfire frequency and severity, tree mortality, and insect outbreaks, and declines in quality of wildlife habitat and watersheds. These trends are likely to continue. Participants used a formal decision-support framework to develop a set of strategic actions that can be implemented to promote resilience and realignment of ponderosa pine forests and their fire regimes, watershed function, and resident Mexican spotted owls. Some examples of strategic actions developed at the workshop include:

- Conduct large-scale risk assessment and planning to prioritize and sequence areas for treatment, taking into account geographic distribution of climate changes, fire risk, soil erosion potential, migration corridors, refugia and recruitment areas for rare species.
- Increase pace, scale and scope of restoration treatments including thinning, prescribed burning & use of resource benefit fires to reduce fire risk and drought induced tree mortality, increase herbaceous ground cover, and enhance infiltration, soil moisture and recharge.
- Encourage economic development, including markets for woody biomass for energy; design and implementation of large-scale contracts; development of other small diameter wood markets.

Participants concluded that the strategic actions developed at the workshop reinforce current management direction, and need further refinement to reduce the impacts to ponderosa pine forests, processes and wildlife, particularly under the extreme climate change scenario. The ecological changes that could occur under these scenarios likely require more extensive and intensive management intervention than the suite of strategies identified at the workshop, which will require further refinement.

Participants spent time discussing potential challenges, opportunities, and barriers to implementing strategies, and agreed that while a sense of urgency drives managers to reduce the impacts of climate change, the scale of change that has already occurred requires coordination of efforts across management units. Some of the barriers and opportunities include:

- There is an opportunity to better inform our understanding of forests' role in water delivery to communities
- Large scale project planning could be more efficient than current
- Large plans could also be a barrier because they are unprecedented, and could use an “all or nothing” approach
- Monitoring of treatment effectiveness and effects provides an opportunity to run efficient management experiments, demonstrating results for public investment.

Participants expressed the need for continued collaboration across the 4FRI landscape to plan for species and ecosystem adaptation to climate change in northern Arizona, and to continue exploration of new strategies as conditions shift. Recommended next steps include:

- Incorporate workshop strategies into 4FRI planning and analysis.
- Implement “no-regrets” strategies for the three conservation features, that is, strategies that have clear, beneficial effects with broad social acceptance.
- Convene a small group of key stakeholders, including federal and state land management agencies, county, scientists, and non-governmental organizations, to continue the climate adaptation dialogue and determine strategies for working together.
- Conduct further analyses of climate change and its ecological effects in northern Arizona, e.g., further interpretation of the moderate and extreme climate scenarios.
- Refine the identified strategic actions, especially for the more extreme scenario.
- Develop a communications plan related to these activities, emphasizing public outreach and education.
- Encourage research of priority needs to better understand the biological responses to climate change and to assist land managers in making land management decisions.

For SWCCI products, including the 4FRI workshop presentations and participant notebook materials, please visit:

http://nmconservation.org/downloads/data/flagstaff_climate_adaptation_workshop/.

The Four Forest Restoration Initiative: Implementing a Climate Change Adaptation Framework for Natural Resource Management and Planning

Introduction

The Nature Conservancy (TNC) in Arizona, working with the USDA Forest Service, TNC-New Mexico, University of Arizona, and Wildlife Conservation Society, convened a two-day workshop entitled *Climate Change Adaptation Workshop for Natural Resource Managers in the Four Forest Restoration Initiative* area on 7-8 April 2010 in Flagstaff, Arizona (See Appendix B, page 50 for the agenda). Forty-four representatives of 15 state and federal agencies, local governments and non-governmental organizations participated (See Appendix A, page 48 for the list of participants). This workshop was the third in a series of four workshops organized by the Southwest Climate Change Initiative (SWCCI), a collaborative effort to provide information and tools for climate change adaptation planning and implementation for conservation practitioners in the Four Corners states: Arizona, Colorado, New Mexico and Utah.

Workshop Goal and Objectives

The workshop goal was to identify management strategies that will help native plants, animals and ecosystems adapt to a changing climate and lay the groundwork for strategy implementation.

The objectives of the workshop were to:

1. Provide background information on climate change as it applies to northern Arizona.
2. Introduce a framework for landscape-scale climate change adaptation planning for use at this workshop and as a tool that can be used in other landscapes.
3. Assess the impacts of climate change on a set of high-priority species, ecosystems and natural processes selected by workshop organizers and participants.
4. Identify strategic actions that will reduce climate change impacts.
5. Identify opportunities for ongoing learning, collaboration, and implementation of on-the-ground climate change adaptation projects in northern Arizona.

The Four Forest Restoration Initiative Landscape

We selected the Four Forest Restoration Initiative (4-FRI) landscape for a case-study workshop in Arizona for a variety of reasons. First, the 4FRI is a community collaborative group dedicated to accelerating ecological restoration of 2.4 million acres of ponderosa pine (*Pinus ponderosa* var. *scopulorum*) forest across four National Forests in northern Arizona, affording an excellent opportunity to serve as a living laboratory for exploration of climate change adaptation strategies (Figure 1). Second, the 4-FRI collaborative members have acknowledged the importance of incorporating climate change into planning and management activities, and have recognized the importance of monitoring and an adaptive management framework to address research questions, reduce uncertainty, and continue to learn about the effects of management. The entire region is currently being assessed to determine the location, character, and sequencing of appropriate restoration treatments, followed by site-specific analysis of the first project landscape of 725,000 acres within the Coconino and Kaibab National Forests in 2010, with two other large analyses to follow in the coming years. The availability of large landscapes, willing partners, a commitment to using the best available science, and a receptive collaborative process all contribute to making the

4-FRI an excellent case study for planning, developing, and implementing climate change adaptation strategic actions.

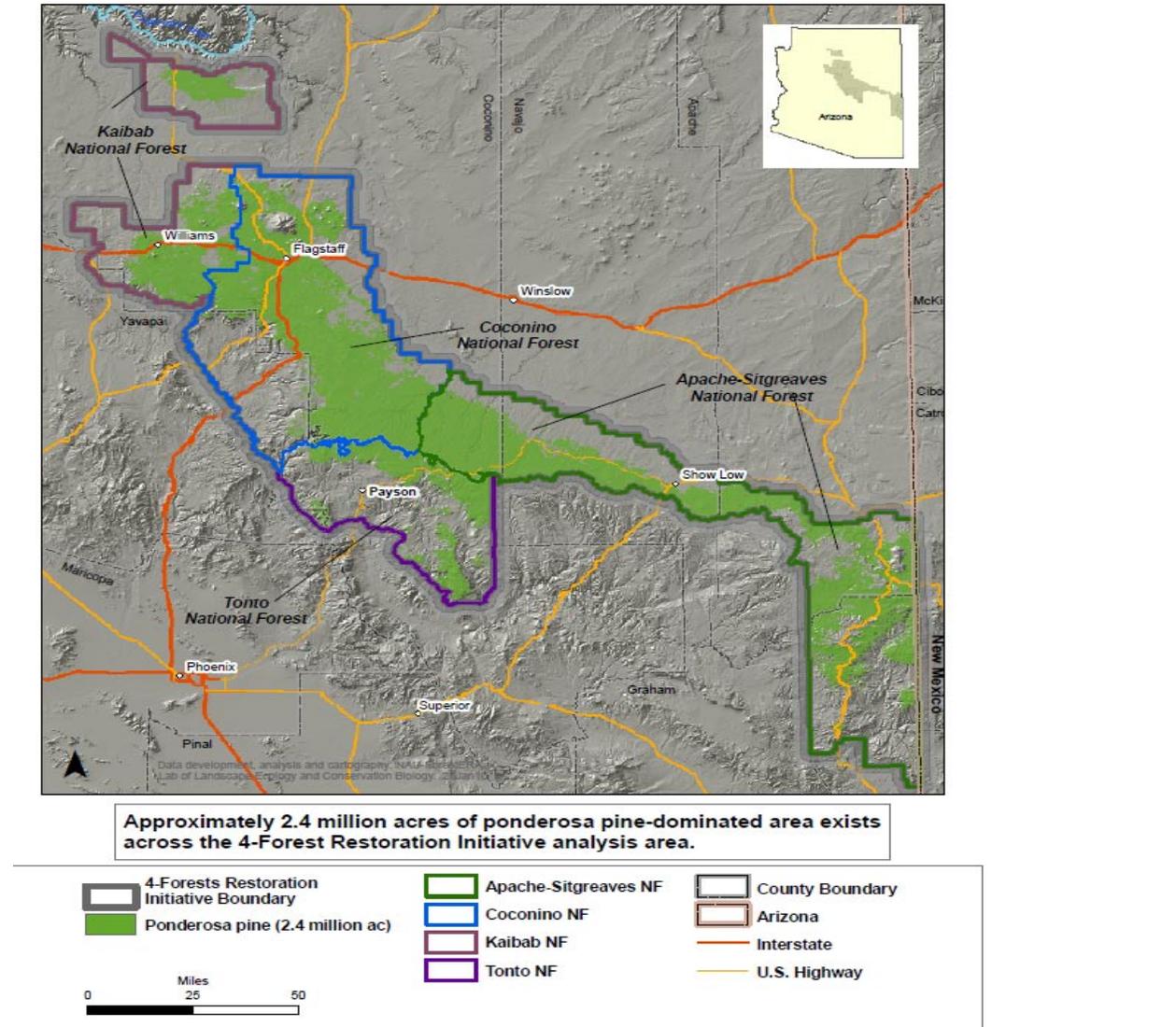


Figure 1 The analysis area of the workshop covered by the Four Forest Restoration Initiative area is depicted in this map. Map courtesy of Megan Friggens, Rocky Mountain Research Station.

Workshop Outcomes

Over the course of two days, participants worked through an interactive process to identify adaptation strategies under two climate change scenarios developed by Senior Scientist Linda Mearns of the National Center for Atmospheric Research and Research Scientist Seshadri Rajagopal of the University of Arizona’s Natural Resources Department. Workshop outcomes include:

1. Development of ecological descriptions and long-term management objectives for three conservation features, the ponderosa pine forest and associated fire regimes, ponderosa pine watershed function, and the Mexican Spotted Owl.

2. Review and interpretation of two climate change scenarios – moderate and extreme. Shared acknowledgement of uncertainties associated with projections, but recognition of the need to move forward.
3. Shared understanding of the known current and potential future effects of climate change, through development of conceptual models for the ponderosa pine forest and associated fire regimes, ponderosa pine watershed function, and the Mexican spotted owl. Conceptual models illustrate the climate, ecological, physical, and social factors that affect conservation features.
4. Identification of management intervention points (places in the system that we can influence through management and conservation actions) using conceptual models to help managers document the assumptions behind specific management actions for reducing negative impacts of climate change.
5. Identification of practical adaptation strategic actions that can be implemented by managers to promote resiliency and realignment of the ponderosa pine forest and associated fire regimes, ponderosa pine watershed function, and the Mexican Spotted Owl in the face of two climate scenarios. Many of the conservation strategies that are already being implemented in northern Arizona can be used to prepare for climate change. However, the scale, sequencing, priority and cost of these strategies will very likely need to be adjusted if management objectives are to be met under a changing climate.
6. Evaluation of opportunities to implement strategic climate adaptation actions.
7. Statement of research and monitoring needs for informing climate adaptation strategies in the northern Arizona.
8. Recognition that more work is needed to identify “no-regrets” strategic actions to reduce the impacts predicted for more extreme climate change scenarios. The ecological changes that could occur under these scenarios will require more in-depth climate analyses and more intensive and extensive management intervention – or perhaps even wholesale changes in management goals.
9. Recognition that cross-jurisdictional collaboration is needed to refine workshop products and implement the actions.
10. Recognition that effective climate change adaptation will require a great deal of communication and collaboration among stakeholders and policy makers.

See http://nmconservation.org/downloads/data/flagstaff_climate_adaptation_workshop/ for the 4FRI Adaptation Workshop presentations and participant notebook materials.

Background Information for Development of Adaptation Strategies

Pat Graham, state director of The Nature Conservancy in Arizona, set the stage for the workshop by welcoming everyone and providing opening remarks. In his talk, Pat

highlighted that collectively we have a good grasp of forest issues and how to manage them, but that actually doing the work is very challenging, and adding the dimension posed by a changing climate makes the work even more difficult. Public support for climate change as an issue has dropped dramatically, and some of the science is being discredited. The downturn in the economy hasn't made our work any easier, either. Pat told a story about how emotional the interface between scientists can get. In 2006, marine ecologist Boris Worm published a paper that predicted the world's commercial fish stocks would all collapse by 2048. Ray Hilborn, a fisheries biologist, called the forecasts "mind-bogglingly stupid" and accused Worm of putting social cause before scientific rigor. This "fish war" made for sensational science news, but that was not the interesting story. Instead of entrenching into diametrically opposed camps, Worm and Hilborn joined forces to re-examine the data and reconcile their different perspectives. The result was better science about both the risks of over-fishing and the ability of fisheries to be sustainably managed.

Pat went on to remark that climate change is such a monumental issue: when scientific conclusions affect major economic and social decisions it is important they take on an even greater level of transparency and high standards. Yet we all know with issues like climate change there will always be a degree of uncertainty. Near-term costs of action must be weighed against long-term risks of inaction, both of which will have profound economic, social, and ecological implications. People will inevitably take sides – even scientists. Only time will tell who was "right" and who was "wrong," yet everyone should agree that they want to take their positions based on the best possible science. For the current adaptation workshop, we acknowledge the uncertainty, and not whether the climate is changing. The evidence is overwhelming. The question is how much is manmade and how much is natural. To the environment the result will be the same. So while others will debate and study the reasons why, we are focused on an "adaptive management" approach.

At this workshop, participants are asked to apply their experience and knowledge to identify on-the-ground conservation actions that can increase the resiliency of our forests, aid in successful implementation of projects, and prioritize research needs. We cannot fully understand or anticipate all the implications of a changing climate. We can develop a process that is based on sound science, strong relationships, good communication and willingness to work and share ideas and resources across boundaries, across disciplines. We believe you are part of something special here. Because this is not the end, it is mapping out the future of our work together.

Pat ended his remarks by relating the following story. "A person recently wrote me to say he was becoming skeptical about climate change. I told him I hoped he was right because the future of our children depends on the answer. In the meantime the Conservancy will act in ways that minimize the risk to future generations and preserve that great resource that is our nation's forests."

Gregg Garfin of the University of Arizona (UA) was the overall facilitator of the two-day workshop. Dr. Garfin is an expert in Southwest climatology and is the UA's Deputy Director for

Science Translation and Outreach at the Institute of the Environment.
(<http://www.environment.arizona.edu/gregg-garfin>)

In his remarks, Garfin provided the rationale for the workshop, and discussed uncertainties associated with climate change. Key points from Garfin's presentation included the following:

- The goal of the workshop is to get from continental level to landscape level climate change projections, in order to identify strategies to address impacts.
- The rate at which emissions will rise – and thus, the extent to which the climate will change – is uncertain because of uncertainty about the future of global and national energy policy, future population estimates, adoption of green technologies, and the global economy.
- Preliminary lessons learned from other landscape adaptation workshops, including those convened by the USDA-Forest Service: adaptive management approaches are likely to be successful; managers need to lead the development of adaptation strategies; work in partnerships and leverage multi-agency resources; science-management collaboration will increase the likelihood of success; involve the public; and confront uncertainty.
- This workshop is a starting place for shared understanding of the Four Forests Restoration Initiative region and how climate affects its hydrology and its ecosystems.

Linda Mearns, Director of the Weather and Climate Impacts Assessment Science Program and Senior Scientist at the National Center for Atmospheric Research (NCAR), Boulder, Colorado (<http://www.isse.ucar.edu/staff/mearns/>), presented projections of future 4FRI region climate and scenarios for the workshop—*Future Regional Climate Change in Arizona: Concepts and Scenarios*. (Note: this presentation supplemented her March 26 and 31, 2010 webinars—*Overview of Regional Climate Change: The Known, the Unknown, and the Uncertain*, which focused on the science of the climate system, global climate projections, and sources of uncertainties). Key points from the April 7, 2010 workshop presentation include the following:

- Three key challenges to making realistic projections of future climate conditions, are (1) the varied topography of the 4FRI region, (2) the lack of adequate modern climate records in order to accurately know the current climate of the region, and (3) the relatively low resolution of climate models, in which regional topography is relatively coarse.
- The climate change projections for North America, from the IPCC (Intergovernmental Panel on Climate Change) are based on a moderate greenhouse gas emissions scenario – A1B: business as usual greenhouse gas emissions, no increase in globalization of sustainable practices, with global population increasing until the 2060s. These projections are based on 21 models, with typical geographic resolution of around 150 miles per side of a grid cell.
 - In addition to consensus among climate models that temperatures in the Southwest U.S. will increase over the course of the 21st century, IPCC North American projections suggest that annual average precipitation will decrease in the Southwest U.S. (67% probability), and that snow depth (67%

- probability) and snow season length (90% probability) will decrease in North America.
- The greatest uncertainty in precipitation projections for the 4FRI region is for summer season precipitation.
 - Dr. Mearns noted that some post-IPCC studies indicate a transition to a drier climate in the Southwest, due to (a) increased evaporation, and (b) changes in global atmospheric circulation that include a poleward expansion of subtropical high pressure over the Southwest. High pressure generates clear, dry conditions.
 - She also noted that recent research shows no change in the frequency of La Niña episodes, which cause dry winters in the Southwest; however, future La Niña episodes are likely to be much drier in the Southwest than during the historic climate record.
 - Dr. Mearns noted that global climate model (GCM; also known as general circulation models, when referring to atmospheric circulation) projections should not be interpreted as predictions of future climate, in the sense that we interpret daily weather forecasts. They should be used for insights into the types of changes that may occur, probable magnitudes of change, the mechanisms causing the changes, and for guidance in the development of scenarios and adaptation planning.
 - The special scenarios for the 4FRI region use regional climate model downscaling (so-called “dynamical downscaling”) to bring climate projections down to a resolution of about 30 miles per side of a grid cell. (These projections were extracted from NARCCAP, the North American Regional Climate Change Assessment Program). The special projections and scenarios for this workshop are based on a medium-high greenhouse gas emissions scenario – A2: close to business as usual emissions, with assumptions of no greenhouse gas mitigation and large increases in global population.
 - The scenarios depict moderate and extreme warming, and an alternate scenario, in which the temperature increases are somewhere between moderate and extreme. The scenarios for future 4FRI region temperature and precipitation, which can be found in Tables 3-6, Appendix C, pages 47-48, show decreases in annual precipitation, with differences in the seasonality and degree of precipitation decreases. The alternate scenario depicts an increase in summer precipitation.
 - Do we need to eliminate uncertainty to make decisions about climate change? No, it is better cope with current uncertainties, by making decisions that are robust and flexible that can be adjusted as we learn more about climate change in the future.

Seshadri Rajagopal, Graduate Research Scientist at the University of Arizona Department of Hydrology and Water Resources gave a presentation entitled *Assessing Impacts of Climate Change in a Semi-Arid Watershed Using Downscaled IPCC Climate Output*. (Mr. Rajagopal acknowledged Francina Dominguez, Hoshin Gupta, Peter Troch, and Christopher Castro, all of the University of Arizona, for their insights and contributions to the research). Gregg Garfin delivered Mr. Rajagopal’s presentation. Key points from his presentation include the following:

- Rajagopal noted that past records of hydrologic variation in the Verde and Salt River watersheds, reconstructed from tree rings, show a high degree of hydrologic variability, including low flow or drought periods more severe and more extended than severe drought of the 1950s.
- He showed how total annual streamflow in the Verde and Salt Rivers is highly dependent on winter precipitation and how, despite substantial summer precipitation totals, summer streamflow is relatively low – due to high temperatures and concomitantly high rates of evapotranspiration.
- Rajagopal’s method for generating hydrologic projections uses statistically downscaled output from GCMs as input to the Variable Infiltration Capacity (VIC) land surface/hydrologic model, developed at the University of Washington. VIC calculates changes in the energy balance at the surface, and its impacts on vegetation canopy, soils, and streams – in five elevation bands. Three GCMs were selected, based on their ability to capture seasonal temperature and precipitation variability for the Southwest U.S., and realistically represent El Niño-Southern Oscillation variability.
- In general, the hydrologic projections show
 - Decreased annual streamflow in both the Salt and Verde River basins, with decreases in winter streamflow, but increases in summer streamflow
 - An earlier peak in Salt River streamflow
 - Increased evapotranspiration in winter and summer
 - Decreased soil moisture
 - Decreased snow water equivalent
- See Tables 8 and 9, Appendix C, page 52 for 4FRI hydrologic scenarios developed by Mr. Rajagopal.

Dr. Kenneth Cole, Research Ecologist at the USGS Colorado Plateau Research Station, Southwest Biological Science Center (http://sbsc.wr.usgs.gov/about/contact/bio/cole_ken.aspx?id=214), presented information on past ecological changes in the 4FRI region—*Paleoclimate of the Southern Colorado Plateau: a Context for Future Change*. Key points from his April 7, 2010 workshop presentation include the following:

- Dr. Cole demonstrated widespread warming of the earth, following the last Ice Age, using records from ice cores. He pointed out sequences of rapid cooling and warming, known as the Bolling/Allerod and Younger Dryas (cool), as North America emerged from the Ice Age. Multiple lines of paleoclimatic, geological, and paleoecological evidence confirm the existence and wide extent of these event.
- Related to the aforementioned sequences, the Southwest U.S. experienced sudden warming of approximately 4°C (~7°F) over less than 100 years at around 11,700, 14,700, and 16,800 years ago. These warming episodes were similar in pace and magnitude to temperature changes projected by climate models for the 21st Century.
- Cole then used a series of diagrams to demonstrate vegetation changes associated with these warming episodes. He showed that early successional species, such as ponderosa pine, increased in abundance on the Colorado Plateau, in the warming following the Younger Dryas cold period, and the cold-loving species, such as *Picea* and *Artemisia*

declined in abundance as the region warmed. Overall, he noted that widely distributed plant species have survived many prior warming events.

- He also demonstrated, using records from packrat midden macrofossils, that during and immediately following rapid warming periods, early successional/rapidly dispersing species, and species from directly downhill, dominate plant associations for several thousand years following the event. He noted that plant *associations* change dramatically in character; thus monitoring early successional species is very important to gauge temperature-affected changes in plant distribution.
- Cole mentioned that in the warming following the Younger Dryas period, ponderosa pine migrated at a rate of 500 m/year or 50 km/century – **extremely rapid migration**.
- Most importantly, with regard to future vegetation changes in response to warming, Cole noted that **vegetation associations within plant communities are re-shuffled following warming episodes, due to differential migration and differential shifts in climate variables**. He noted that 5,000 years or more are usually required for them to re-associate in semi-arid habitats, and he concluded that resources are better spent monitoring and modeling individual species migration and abundance, rather than community-level vegetation associations.

Kirsten Ironside, Research Specialist, Merriam Powell Center for Environmental Research, Northern Arizona University, presented information on projected changes of ponderosa pine habitat in the 4FRI region— *Plausible Future Effects of Climate Change on Ponderosa Pine*. Key points from her April 7, 2010 workshop presentation include the following:

- Ms. Ironside discussed climate-genetic relationships for varieties of ponderosa pine. Based on her recent research evaluating the statistical relationships between monthly climate values and species geographic ranges to establish the most critical values limiting ponderosa pine distribution, the Colorado Plateau variety of ponderosa pine is
 - Susceptible to winter and spring frosts
 - Tolerant of high temperatures, and
 - Adapted to the arid, bimodal precipitation pattern in the Southwest
- Through further research, she determined that the distribution of ponderosa pine is more limited by precipitation than temperature.
- Ironside used output from 5 GCMs, representing a range of future climates under the SRES A1B emission scenario, downscaled to a 4-km grid spacing for the western U.S., as input to a vegetation change model. She examined the ponderosa pine change projections individually and in ensemble, and determined that:
 - The only locations that will contain a climate suitable for ponderosa pine within the 4-FRI study area will be the San Francisco Peaks on the Coconino National Forest, and the Springerville and Alpine Ranger Districts in the Apache-Sitgreaves National Forests, looking across different model projections, and over the course of the 21st Century
 - Other portions of the study area vary substantially between GCM scenarios and over time as to the suitability of climate to support the occurrence of ponderosa pine

Dr. Peter Fulé, Associate Professor, School of Forestry, and Director of Research and Development, Ecological Restoration Institute, Northern Arizona University, (<http://www.for.nau.edu/cms/content/view/18/40/>) presented information on fire and its impacts in ponderosa pine forests in the 4FRI region— *Interactions of Climate Change, Fire Regimes, and Hydrologic Regimes*. Key points from his April 7, 2010 workshop presentation include the following:

- Dr. Fulé noted that in the 4FRI area, a region with fire-adapted ecosystems, climate is a top-down factor synchronizing fire activity, fuels are a bottom-up factor with site-specific variability, and during the 20th century, changes in both climate and fuels supported larger and more severe fires.
 - Climate factors leading to larger and more intense fires include reduced snowpack, earlier snowmelt, decreased fuel moisture, and longer fire seasons.
- The upshot of larger, more severe and often stand-replacing fires in ponderosa pine forests is an increase in erosion potential, such that
 - the loss of forest protective cover exposes soils, leading to increased runoff and sediment transport during hydrologic events, especially in the first year post-fire
 - increased runoff leads to higher streamflows and channel erosion, which can lead to intensive erosion and mass wasting, such as following the Missionary Ridge fire (Colorado)
 - peak flows can increase by an order of magnitude
 - and channel downcutting can occur
- Fulé noted that following large fires forest ecosystem productivity declines, arid region soil formation is exceedingly slow, and alternative ecosystems may form, such as grasslands or shrublands.
 - Soil water retention declines, infiltration of water into soils declines, and flooding potential increases – which can lead to downstream impacts to fish, water quality, and infrastructure.
- Fulé briefly mentioned the wide-scale tree mortality in western North America, which is associated with significantly warmer and also drier conditions. He noted that an increase in such conditions is predicted to support more burning, but if fuels decline – due to a warmer climate – then there may eventually be a trade-off between increased fire (driven by changing climatology) and less fuel for fire (also driven by changing climate factors).

Dr. Megan Friggens, Ecologist, USFS Rocky Mountain Research Station (<http://www.fs.fed.us/rm/albuq/mfriggens.php?last=Friggens&first=Megan%20MacKellar>), presented information on the Mexican spotted owl (MSO), listed as a threatened species, and an iconic dweller in northern Arizona old growth ponderosa pine forests—*Mexican Spotted Owl: Results of a Vulnerability to Climate Change Assessment*. Dr. Friggens' co-authors are Deborah Finch, Karen Bagne, and Sharon Coe. Key points from her April 7, 2010 workshop presentation include the following:

- The climate change vulnerability assessment described by Dr. Friggens is based on a detailed questionnaire, in which regional experts rate species vulnerability in terms of

future climate, habitat, physiology, phenology, and biotic interactions. She reported on the results of MSO case studies in Arizona and New Mexico. Climate changes for the 4FRI region, used in the study, are similar to those described by the previous workshop speakers, and include: greater exposure to higher temperatures, drought, habitat changes, fire, loss of ephemeral streams, changes in streamflow, changes in disturbance and in plant and insect activity.

- Friggens described MSO ecology, including these important characteristics:
 - MSO is an “old growth” resident that prefers complex forest structure, and needs large roosts (snags, cliff crevices).
 - MSO has strong fidelity to roosting sites, is long-lived, nocturnal, produces a single clutch of 1-3 eggs/year, and does not migrate.
 - MSO population declines are chiefly due to habitat loss and conversion.
 - It preys on small mammals, and its primary predators in the 4-FRI area include the great-horned owl and northern goshawk
- According to the vulnerability assessment, the MSO is moderately sensitive to predicted climate changes and impacts. Key vulnerability considerations, by category:
 - Habitat: sensitivity to reduced conifer forest habitat and loss of nesting sites;
 - Physiology: a somewhat high sensitivity to heat and lack of food storage (which may be counteracted by its long life span);
 - Phenology: highly sensitive, due to the fact that it does not migrate; therefore, MSO doesn’t respond well to changing temperature and precipitation cues
 - Interactions: highly sensitive to potential starvation and if other predator species, such as the barred owl, become established
- In conclusion, starvation is a major issue for this owl. Though difficult to predict at this time, the potential limiting nature of this sensitivity warrants further research and careful monitoring of prey populations and prey-owl interactions. Another limiting variable is the presence of suitable foraging areas and roost sites. Habitat loss projected to occur as a result of warming trends and increased fire is likely to be detrimental to the Mexican Spotted Owl. See Appendix F, page 62 for the detailed analysis.

Dr. Joseph L. Ganey, Research Wildlife Biologist, USFS Rocky Mountain Research Station, (<http://www.rmrs.nau.edu/lab/people/jganey/>) presented information on tree mortality in 4FRI region forests—*Tree Mortality in Drought-stressed Mixed-conifer and Ponderosa Pine Forests, Arizona*. Key points from his April 7, 2010 workshop presentation include the following:

- Dr. Ganey noted that in the 4FRI area, during the 1997-2007 period, most mortality was attributable to a suite of forest insects, in combination with severe drought stress.
- He showed that when contrasting two five year periods, 1997-2002, with 2002-2007, mixed conifer forest mortality increased by 200% and ponderosa pine mortality increased by 74%. He noted that mortality rates depended little on stand density, but the relative proportion of mortality was greater in large-sized tree classes than in small-sized trees.
 - In mixed-conifer forests aspen and white fir mortality was particularly high. These species are not drought tolerant, and they are important to forest and species biodiversity. He mentioned that MSO nests most often in mixed-conifer forests.

- Ganey noted huge spatial variability in tree mortality, and that change has been exceedingly rapid. He noted that current forests are not resilient to projected climate changes, but cautioned that the magnitude of changes will depend on interactions between climate and disturbance regime.

Introduction to Adaptation Planning

Molly Cross, Climate Change Ecologist and Adaptation Coordinator with the Wildlife Conservation Society (WCS), provided an overview of climate change adaptation concepts and approaches, including a new adaptation planning framework in her presentation, *Place-based Climate Change Planning: Overcoming the Paralysis of Uncertainty*. Key points:

- There are many challenges to incorporating climate change into natural resource management, including how to make broad understanding of impacts applicable to specific systems, how to deal with the uncertainty and complexity of climate change, how to know where to begin planning for the impacts of climate change, and how to determine what it is we're trying to manage for in a time of change.
- General principles of adaptation and approaches to reframing management goals such as the "5Rs+1" (Box 1) are useful at a conceptual level, but more specific solutions are needed by managers working at landscape and site levels; the lack of specific direction is causing *uncertainty paralysis*, preventing managers from taking action in the near term.
- The Wildlife Conservation Society, the Center for Large Landscape Conservation, and the National Center for Ecological Analysis and Synthesis convened a working group of scientists and managers from multiple institutions and agencies to develop the Adaptation for Conservation Targets (ACT) Framework designed to translate general recommendations on climate change adaptation strategies into practical, specific actions for a given landscape, set of species, or ecosystems using a

Box 1. General concepts for thinking about climate change adaptation and natural resource management.

The "5-R's + 1" Framework (adapted from Millar et al. 2007):

- Resistance – hold back the tide
- Resilience – decrease stressors
- Response – conserve for all extremes
- Realign – conserve for new reality
- Reduce – mitigate greenhouse gases
- Triage – prioritize action (medical triage = address the most sick first; military triage = address those that are most likely to get back onto the battlefield).

Question: Will promoting resistance and resilience be feasible in light of the magnitude of projected changes?

General Principles of Adaptation (adapted from Glick et al. 2009):

- Reduce non-climate stressors
- Manage for ecological function and protection of biodiversity
- Establish buffer zones and connectivity
- Implement proactive strategies
- Increase monitoring

Challenges: How to deal with complexity and uncertainty? How do principles, concepts apply to particular systems?

transparent and participatory process (Cross et al. *in review*). This framework was modified slightly for the purposes of this workshop, to include components of TNC's conservation action planning methodology for addressing climate change (TNC 2009a).

The ACT Framework has been applied at climate change adaptation workshops in the Jemez Mountains, New Mexico (Enquist et al. 2009) and the Gunnison Basin, Colorado (Neely et al. 2010), and at a workshop organized by WCS and the U.S. Fish and Wildlife Service on adaptation planning for grizzly bears and wolverine in the Northern U.S. Rockies (contact mcross@wcs.org for details). The TNC climate framework has been applied to 20 sites across the globe at a workshop held in Utah in September 2009. (See The Nature Conservancy's Climate Adaptation workspace on ConserveOnline for more information).

Implementation of the Adaptation Planning Framework

The climate change adaptation framework is designed for collaborative application in a given landscape by a multidisciplinary group of managers, conservation practitioners and scientists, and includes the following steps:

1. Select feature targeted for conservation (e.g., species, ecological processes, or ecosystems) and specify an explicit, measurable management objective for that feature.
2. Build a conceptual model that illustrates the climatic, physical, ecological, and socio-economic drivers that affect the selected feature.
3. Assess impacts of plausible future climate scenarios: a. Use the conceptual model to assess climate change impacts (i.e., develop hypotheses of change) by examining how specific changes in climate variables might directly or indirectly influence the selected feature, for each scenario of future climate conditions being considered.
 - a. Consider how human responses to climate change (e.g., solar and wind power development, geothermal exploration, construction of dams for increased water storage, etc.) may influence the selected feature.
 - b. Assess the likely impact of climate change relative to other known impacts or threats, and identify which climate-induced impacts are most critical to address to achieve the stated management objective.
4. Identify potential strategic actions in light of climate change: a. Identify intervention points—those places in the system that we can influence through management and conservation actions.
 - a. Brainstorm potential strategic actions that can be taken at those intervention points to achieve the stated objective under each climate scenario.
 - b. Determine whether the management objective or the selection of the feature needs to be revisited: Does climate change fundamentally change the landscape? Do the management objectives for that feature need to change? Will the feature even be found in the same location in the future? Does our view of the landscape and boundaries need to change?
5. Evaluate feasibility of potential strategic actions and prioritize according to factors such as: cost; social and political feasibility; potential for positive effects or risk of unintended negative consequences for other features or objectives; and robustness to uncertainty in future climate.
6. Develop action plan outlining priority strategic actions to be implemented.
7. Implement action plan.

8. Monitor and evaluate action effectiveness and progress toward objectives—adjust or reevaluate actions if needed to address system changes or ineffective actions.

For the purposes of this workshop, breakout groups focused on completing the first five steps of the *planning phase* (left-hand side of Figure1). Workshop facilitators divided the participants into three groups, each with a different conservation feature: 1) Ponderosa pine fire regime; 2) Ponderosa pine hydrological regime; and 3) the Mexican spotted owl.

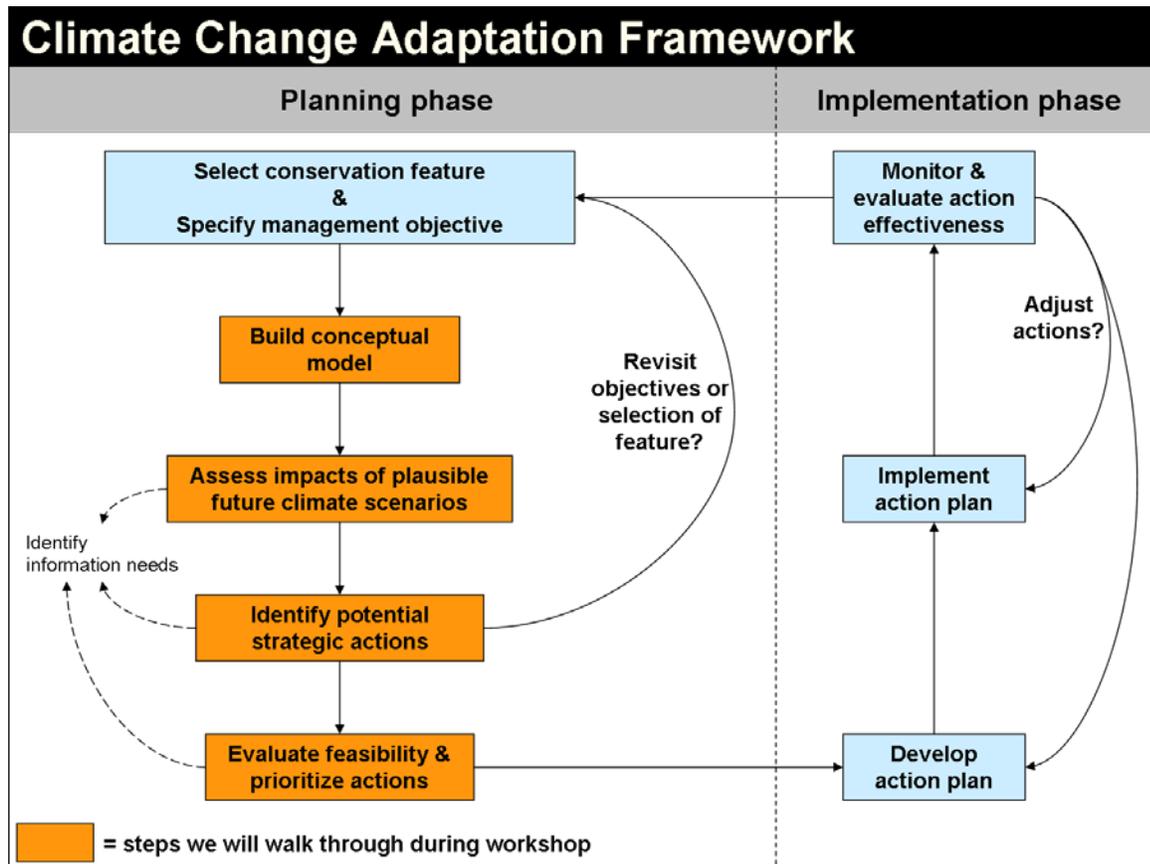


Figure 2 Cross et al.’s (in review) iterative climate change adaptation framework for natural resource management and conservation. The left side represents the adaptation planning phase; the right side represents the action plan implementation.

Climate Change Adaptation Strategies for Conservation Targets

Climate Change Adaptation Strategies for Ponderosa Pine Fire Regime

The Ponderosa pine fire regime breakout group consisted of 12 participants with expertise in forest and fire management, plant and wildlife ecology, and/or climate science representing state and federal agencies, non-governmental organizations, and academic institutions. This group was facilitated by Molly Cross and Edward Smith.

Defining the Conservation Feature

Breakout session participants were focused on the ponderosa pine forest ecosystem in the 4FRI area, and related fire dynamics. Within Arizona and New Mexico, there are 19 different ponderosa pine dominated vegetation associations or habitat types delineated by site conditions, elevation and aspect, and understory vegetation (USFS 1997). Ponderosa pine forests throughout the Southwest formerly experienced widespread, low-intensity surface fires of frequent return intervals (Weaver 1951, 1952, Cooper 1960, Dieterich 1980, Covington and Moore 1994, Swetnam and Baisan 1996). Analysis of a comprehensive network of fire scar sites and their fire chronologies indicates that for 53 sites in Arizona and New Mexico where ponderosa pine dominates or co-dominates, mean fire return intervals were 2 to 17 years for fires scarring one or more trees, and 4 to 36 years for fires scarring between 10% and 25% of trees between the years of 1700 and 1900 (Swetnam and Baisan 1996). For the same network of sites, Swetnam and Baisan (1996) reported a range of Weibull Median Probability Interval (WMPI) values of 1.74 to 13.83 years. For a smaller subset of 31 pure ponderosa pine sites, the FRI ranged from 5.6 to 31.9 years for fires scarring more than 25% of trees, with an average of 18.8 years (Smith 2006).

Management Objectives

A set of objectives for the recently created Four Forest Restoration Initiative (4FRI) have already been identified:

- Reduce hazardous fuels and risk of large-scale uncharacteristic fire;
- Reintroduce fire as a natural process;
- Restore forest composition, structure, and species;
- Provide sufficient certainty in biomass flow to invite appropriately scaled industry (economic sustainability).

Participants decided that during the workshop we would examine what management and conservation strategies (or adaptation actions) would be necessary to achieve these objectives in light of the two climate scenarios being considered. However, participants noted early on that several aspects of these objectives may need to be revisited given the projected impacts of climate change on ponderosa pine (PIPO) distribution and abundance. In particular, the desire to “restore” PIPO forest composition and structure may be incompatible with the influence that climate change might have on species assemblages in the region. Other sub-objectives that could eventually be included in the overall management objective for this system include:

- Maintain native understory by preventing the take-over by invasive species
- Build social acceptance around fire/smoke
- Promote current native plant community in the short-term and provide a smooth transition to a desirable alternate state in the longer-term.

While subsequent discussions did not explore these additional or alternate sub-objectives in detail, participants noted that future discussions might try to flesh these ideas out further.

Conceptual Model and Impacts Assessment

The group created a graphical conceptual model of important direct and indirect physical, ecological, climatic, social and economic drivers affecting PIPO forests and wildfire frequency, intensity and severity (Figure 3). The group then used the conceptual model to guide their discussions of observed and predicted impacts of Climate Scenarios 1 and 2 on PIPO distribution and abundance, and fire dynamics (Table 10, Appendix D1, pages 56-57).

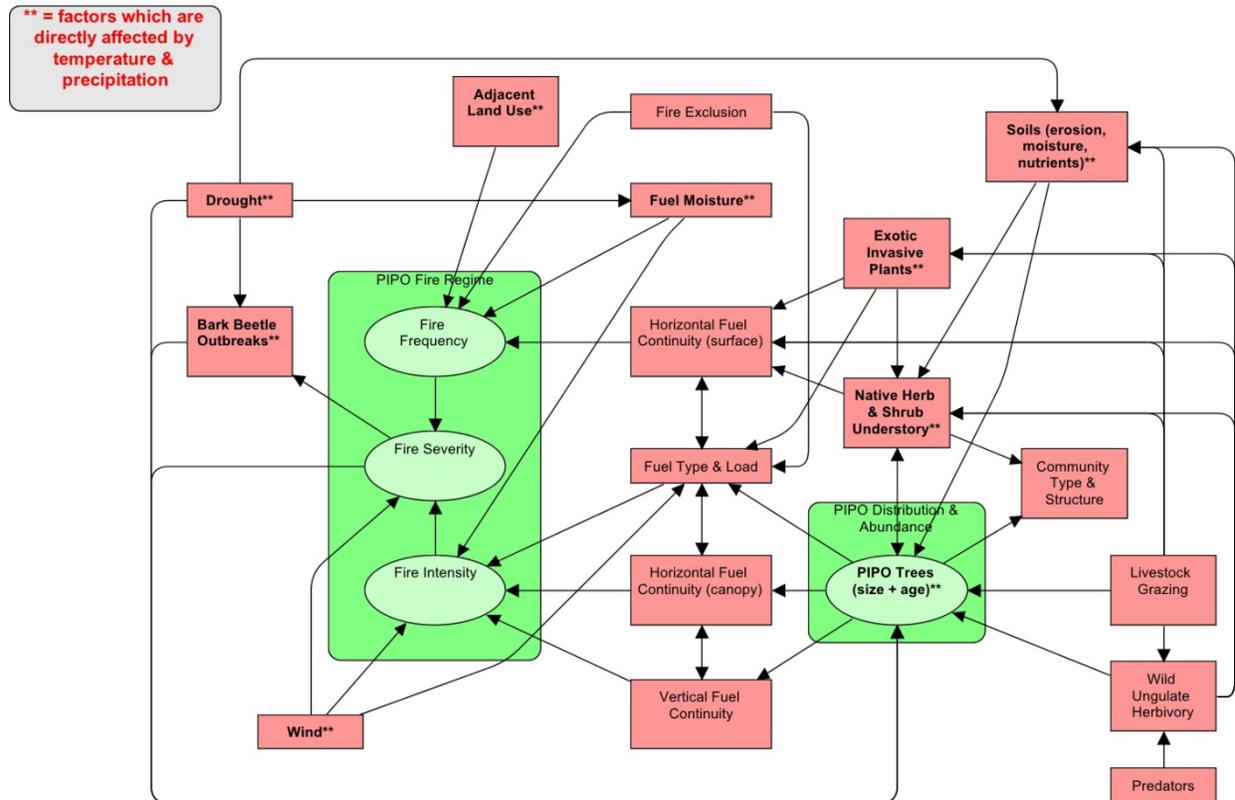


Figure 3 Conceptual model of ponderosa pine forest and associated fire regime.

Under both climate scenarios, the group expects to see an increase in wildfire frequency, intensity and severity due to a longer fire season, drier fuels, and changes in fuel loads and types, with conditions being further exacerbated under the more extreme Climate Scenario 2. Under Climate Scenario 1, participants felt that overall we might expect to see a reduction in the abundance and distribution of PIPO forests—although not a complete loss—in the 4FRI area. These changes primarily result from how decreased precipitation in winter and summer might lead to increased drought- and bark beetle-related PIPO mortality, increased risk of uncharacteristically high severity fire, decreased productivity of native understory plants, and increased success of early successional and drought- and fire-adapted native and exotic invasive understory plants. Under the more extreme Climate Scenario 2, it is possible that a significant portion of the 4FRI area might experience climate conditions outside of the survival threshold (i.e., climate envelope) for PIPO, leading to more dramatic declines in PIPO acreage. Participants also expect to see a stronger transition towards a system more dominated by shrubs and other drought- and fire-prone vegetation types and species. Cattle and wild ungulate grazing

and browsing were discussed as important stressors in the system, with both climate scenarios making grazing and ungulate management more complicated.

Management Intervention Points and Adaptation Strategies

After discussing the potential impacts of the two climate scenarios, the group identified intervention points in the conceptual model where management actions could be taken to lessen the negative impacts of climate change and provide progress toward the management objective. The group then brainstormed specific adaptation actions that might be considered at each of these intervention points (See Table 1 for strategic actions for PIPO fire). Many management actions were centered on reducing hazardous fuel loads, reducing the risk of uncharacteristically severe fire, and on increasing our ability to prevent and suppress fires. Other actions were focused on minimizing the effects of the two climate change scenarios on PIPO mortality and regeneration, maintaining healthy native understory vegetation, and educating the public and managers on the importance of fuel load treatments and fire suppression and prevention. While many of these actions are in-line with management actions that are currently being implemented or encouraged, there were some ways that the group discussed applying these familiar tools in specific ways to cope with the impacts of climate change. For example, the group discussed the importance of integrating climate forecasts (e.g., El Nino-Southern Oscillation seasonal forecasts, or multi-annual drought forecasts) into decisions about when and where to apply prescribed burns.

This brainstorming session was intended to generate a diverse range of potential actions that could be considered, and the resulting list (Table 10) does not necessarily represent actions that people agree should be implemented, nor is it exhaustive. It is an initial list of actions that might be considered, some of which are more outside-the-box or controversial than others.

Unless otherwise noted, all of the strategic actions identified for Scenario 1 were also recommended under Scenario 2. The main differences across scenarios were that under Scenario 2, actions to maintain large PIPO trees and reduce dangerous fuel loads become even more of an imperative, and it is necessary to focus a greater amount of attention on how to manage shifts in tree and understory vegetation species composition. In general, the group indicated that we might not want to invest as much in maintaining PIPO in low elevation areas, but rather concentrating actions to foster PIPO growth in high elevation and wetter areas.

Priority Adaptation Strategies

After a long list of potential management actions was developed (Table 10), the group highlighted five high priority adaptation actions (Table 1, below) that address fuels management, education, and vegetation management. These high priority actions were then shared with the larger workshop group during a full plenary report-back session.

Table 1 High priority strategic actions identified by participants for reducing climate change impacts on the Ponderosa Pine fire regime for two climate scenarios.

Observed & Projected Climate Change Impact (Hypotheses of Change)	Intervention Point	High Priority Strategic Actions (Planning Horizon: 2040-2060) <i>(note: these apply to both Scenarios 1 and 2)</i>
Fire frequency, intensity and severity: Longer fire season, drier fuels, and changes in fuel loads and type will increase wildfire frequency, intensity and severity.	Fuels management	<ul style="list-style-type: none"> • Thin to create a mosaic of clumpy, groupy tree distribution and openings. • Treat more acres with prescribed burns. • Allow more wildland fire to burn.
Vegetation changes: Reduced abundance and distribution of PIPO forests in the 4FRI area due to increased drought- and bark beetle-related PIPO mortality, increased risk of uncharacteristically high severity fire, decreased productivity of native understory plants, and increased success of early successional and drought- and fire-adapted native and exotic invasive understory plants.	Vegetation management	<ul style="list-style-type: none"> • Management actions that encourage recruitment of drought- and fire-prone species.
Fire frequency, intensity and severity: Longer fire season, drier fuels, and changes in fuel loads and type will increase wildfire frequency, intensity and severity.	Education of public and managers	<ul style="list-style-type: none"> • Increase social acceptance/capital for appropriate forest management (including thinning, prescribed fire and wildland fires for resource benefit) in light of climate change.

Climate Change Adaptation Strategies for Maintaining Watershed Function in Ponderosa Pine Forests

Facilitated by Dave Gori and Carolyn Enquist, the Ponderosa pine-watershed function breakout group included 13 workshop participants with a broad range of experience in forest, watershed, wildlife and water management, hydrology and climatology.

Defining the Conservation Feature

The ponderosa pine forests of northern Arizona serve as the headwaters or watersheds for several important Arizona rivers, including the Salt, the Verde, and many of their tributaries. Key attributes of watershed function include evapotranspiration, infiltration, runoff, soil erosion, and groundwater recharge. These attributes sustain watershed vegetation, including ponderosa pine and associated plant species, and determine water quality, quantity and timing of flow for surface water and groundwater. Forest thinning can increase water yield and enhance groundwater recharge due to reduced sublimation and evapotranspiration (Brewer 2008, Dore et al. 2010). Future low-severity fires occurring in treated areas would likely result in surface fires that do not eliminate ground cover or mineralize soil organic matter, protecting soil nutrient cycling and watershed function.

Management Objectives

The group agreed to the following overarching management objective: *Maintain or improve watershed function in ponderosa pine-dominated systems.*

To achieve this objective, the following outcomes or sub-objectives were also identified:

- Maintain or improve water quality, quantity and timing of flow for surface and ground water;
- Maintain or improve soil productivity; and
- Promote adequate soil moisture and recharge by maintaining or improving the recharge-to-runoff ratio.

In the course of developing these objectives, the group discussed whether they should target current conditions or frame the objective in a way that explicitly considers resilience or realignment of watershed vegetation and hydrological processes. The group decided to start with current conditions (and management objectives), assuming that in attempting to maintain or improve soil productivity, recharge-to-runoff ratios, depth-to-groundwater and key components of the surface flow regime that increased resilience or realignment would occur or be facilitated over time.

Conceptual Model and Impacts Assessment

Participants started with a baseline conceptual model of the ponderosa pine-hydrological system developed by University of Arizona and Northern Arizona University (NAU) scientists, Don Falk, Peter Troch and John Vankat, and reviewed by Forest Service and NAU hydrologists, Rory Steinke and Sharon Masek Lopez, before the workshop. The group added *carbon dynamics* and *flooding* as physical drivers to the model as well as a number of human drivers including groundwater pumping, surface water withdrawals (diversions), impoundments, roads and culverts, impermeable surfaces, OHV/dispersed camping, timber harvest, forest and shrubland management, residential development, energy development, fragmentation, procurement of water rights, and dust (Figure 4, below). The group edited and added arrows linking these drivers with other climatic, ecological and physical drivers in the conceptual model.

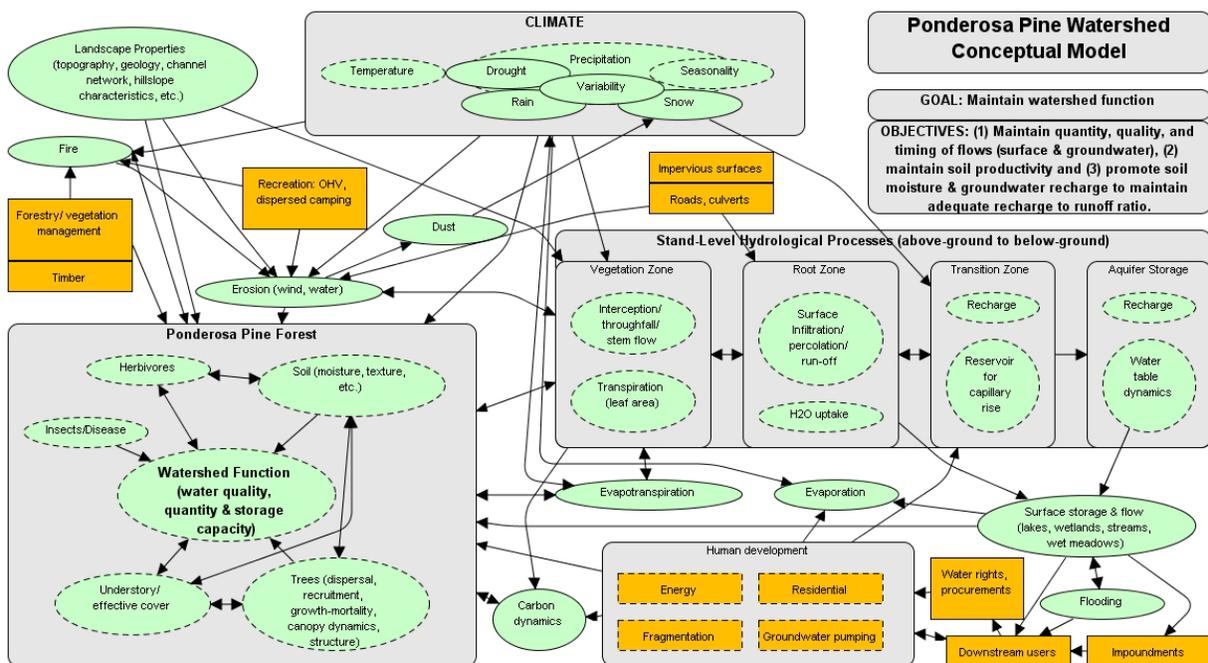


Figure 4 Conceptual ecological model of ponderosa pine forest and associated watershed function.

The group discussed the potential direction of change in the drivers under the moderate and extreme climate change scenarios, using the relationships summarized in the conceptual model and carefully considering alternative lines of reasoning. Considering the moderate scenario (S1) first, participants identified a number of climate change impacts and proposed hypotheses of change whereby direct and indirect effects of changes in temperature and precipitation resulted in cascading ecosystem impacts and management challenges (See Table 11, Appendix D2, pages 58-60). The group also estimated the likelihood of impacts. The major lines of reasoning focused on climate-induced changes to evapotranspiration, snowpack dynamics, human water demands and development patterns and their effects on watershed vegetation, runoff, base flows, groundwater recharge and flood regimes. Other important lines of reasoning emphasized changes to vegetation disturbance regimes (fire, drought and insect/disease outbreaks) with cascading impacts on tree density, herbaceous vegetation cover, groundwater recharge, runoff, soil erosion and water quality.

Before diving into a parallel exercise for the extreme scenario (S2), the group discussed an ‘alternate’ moderate scenario proposed by Linda Mearns in her morning presentation where annual precipitation decreased by 6% and summer precipitation increased by 13%, compensating, in part, for the decreased winter precipitation under Scenario #1; temperature increases were similar under both moderate scenarios. The question framed by participants was whether the increased summer precipitation would be sufficient to compensate for the impacts of increased temperatures and reduced winter precipitation on vegetation and watershed hydrological processes? The group decided that increased summer precipitation would increase water availability to vegetation, resulting in less drought- and insect-induced mortality of trees; have no effect on groundwater recharge; and perhaps lead to a small increase in summer and fall baseflows compared to Scenario #1 as a result of increased runoff and enhanced floodplain aquifer recharge associated with larger, more frequent summer floods. In considering Scenario #2, participants decided that the impacts would be in a similar direction but more severe than for Scenario #1 since both project a warmer and drier future. Together, the discussion helped the group understand that from the standpoint of a qualitative impacts and management response, there wasn’t a significant difference between the two alternative moderate and the extreme scenarios.

Management Intervention Points and Adaptation Strategies

The group identified seven management intervention points for climate adaptation, including:

1. Fire management
2. Forest and vegetation management
3. Grazing management (livestock, native herbivores)
4. Roads management
5. Recreation management
6. Snowpack management
7. Water management

The group then devised a series of strategies that addressed the overall need of coping with less water in Ponderosa pine watersheds as well as with changes in ecosystem disturbance regimes under moderate and extreme climate change scenarios.

Adaptation Strategies for Climate Scenario #1—“Warmer and drier, Moderate Change”

The group identified a diverse mix of adaptation strategies (Table 11). These included current riparian and forest management practices, such as thinning, prescribed burns, resource benefit fires,

maintenance of streamside management zones to mitigate sedimentation and filter/control runoff, recreation management and grazing management, the latter emphasizing flexible stocking numbers and monitoring so that herbivore densities are more closely aligned with annual forage production. Legal and policy strategies, such as procuring in-stream flow water rights and legally recognizing the connection between surface and groundwater, were also identified as strategies as were road closures and restoration, enforcement of OHV restrictions, and infrastructure improvements including culverts, enhanced road drainage measures, and hardened stream crossings to reduce runoff and erosion. More innovative ideas included managing forest structure through selective thinning to maximize snowpack accumulation and minimize sublimation losses (which current research estimates at approximately 50% of total snowfall); installation of snow fences and planting trees as natural snow fences.

Adaptation Strategies for Climate Scenario #2—“Even Warmer and Drier, Extreme Change”

The group considered more extreme approaches in response to Scenario #2 noting that the substantial temperature increases and precipitation decreases may lead to even more significant declines in snow-melt driven runoff, soil moisture and recharge. The group’s thinking seem somewhat constrained by the uncertainty of whether some important ecological threshold would be crossed such that much of the 4-FRI area would become climatically unsuitable for ponderosa pine establishment and, if so, what vegetation type and plant species they should be managing for. Nonetheless, strategies to encourage as much infiltration and groundwater recharge as possible were identified, including (1) more aggressive use of restoration treatments to maximize snowpack accumulation and retention and to reduce the risk of fire and insect outbreaks; (2) focusing these restoration treatments on the mid- to upper-elevation limits of Ponderosa pine distribution; (3) more drastic adjustments in herbivore numbers and use to maintain herbaceous ground cover in the face of reduced water availability; and (4) purchasing (and transporting) alternative water supplies, for example, from Lake Powell, to augment existing water sources.

Priority Adaptation Strategies

The group selected four priority strategies, or groups of strategies, for adaptation in Ponderosa pine watersheds (Table 2, below). The first is to apply restoration treatments, like thinning or prescribed burning, to reduce fire risk and drought-induced tree mortality, increase herbaceous ground cover, and improve watershed health, in this way enhancing infiltration, soil moisture and groundwater recharge. In order to prioritize areas for treatment, participants identified the need for a landscape-scale risk assessment that considered fuel loads, erosion potential and potential moisture stress on vegetation related to elevation and soils. Treatments should be monitored and adjusted with observed and projected changes in the vegetation so that lessons-learned can be applied to other parts of the landscape.

The second adaptation priority involves actions related to travel management to address the expected increased erosion in watersheds; these include optimizing road density for multiple uses, decommissioning and restoring unnecessary roads, and upgrading existing roads with enhanced drainage measures, culverts and hardened stream crossings.

The third adaptation priority also uses forest and vegetation management as an intervention point, but this time with the goal of maximizing snowpack accumulation and minimizing sublimation losses. As above, treatments include thinning, prescribed burning and use of naturally-ignited fires for resource benefit. In order to implement these strategies with confidence, research is needed to reduce uncertainties in future climate changes, especially the shifts in the timing of precipitation, and to

quantitatively analyze the effectiveness of restoration treatments on snowpack, soil moisture, groundwater recharge and base flow using hydrological models and field measurements.

Finally, the fourth adaptation priority involves purchase or lease of in-stream flow water rights and other surface water rights to ensure adequate stream flows in the face of increasing human water demands and reduced future supply. An important component of this strategy is a policy change to recognize the connection between surface and ground water so that increased groundwater pumping (to meet human demands) does not negate management actions taken to improve watershed health, infiltration and recharge. In anticipation of extreme change, the group identified obtaining additional water supplies from Lake Powell, although competition for declining regional supplies will make implementation of this action difficult.

Table 2 Priority strategic actions identified by participants for reducing climate change impacts on Ponderosa pine-watershed function for two climate scenarios.

Observed & Projected Climate Change Impact (Hypotheses of Change)	Intervention Point	Scenario #1 Strategic Action (Planning Horizon: 10-15 years)	Scenario #2 Strategic Action (Planning Horizon: 10-15 years)
<p>More frequent & severe fire. (S1&S2)</p> <p>Increased drought-induced tree mortality due to soil moisture stress and stress caused by insects and disease. This will lead to decreased canopy cover, reduced tree density of trees & changes in the understory. In short-term, increased herbaceous cover & reduction in tree water use leads to greater fraction of <i>available</i> water going to recharge. Also expect reduced baseflows and increased water temperatures. (S1)</p> <p>More widespread effects in species composition that are amplified in time & space (S2)</p> <p>Increased temperature leads to increased potential-ET (PET) and thus decreased recharge. This leads to increase moisture stress for plants across system. In riparian systems this will translate to increase in actual-ET (AET) for plants with access to water, decreasing baseflow (S1 and Alternative moderate scenario)</p> <p>If overstory and understory cover reduced, may have decreased ET as result of reduced transpiration.</p>	<p>Fire management</p> <p>Forest/vegetation management</p>	<p>1st Priority Strategic Actions.</p> <p>Apply restoration treatments including thinning, prescribed burns & resource benefit fires to reduce fire risk & drought induced tree mortality, increase herbaceous ground cover, and enhance infiltration, soil moisture and recharge. Plan for 6-year fire rotation around landscape (HRV) to maintain water yield benefits (maintenance burning)</p> <p>Conduct landscape risk assessment to prioritize areas for treatment; take into account fire risk, soil erosion potential and increased climate-stress levels at lower elevation sites; learn from treatment effects so that lessons may be applied to other parts of landscape; adjust treatments relative to expected changes in vegetation (see research needs).</p> <p>Develop economic uses/markets for wood fiber (biomass, pellets)</p>	<p>More aggressively apply restoration treatments & technologies, focusing them on mid- to upper-elevation limits in PIPO</p>

(S2)			
Short-term reductions in vegetation cover due to extreme events leaves soil more vulnerable to erosion --especially after flashier runoff events. Expect decreased soil water capacity, sedimentation of streams, and, ultimately, reduced water quality (S1 & S2)	Roads management	2nd Priority Strategic Actions. To mitigate for increased erosion potential in the watershed, optimize road density for fire, recreation, timber & other resource uses; decommission & restore roads as necessary. Maintain and upgrade existing roads including installation of culverts and hardened stream crossings to reduce runoff, erosion.	
More precipitation delivered as rain than snow. Expect decreased snowpack from rain on snow events, sublimation, & snow melt. Peak stream flows from snowmelt will be earlier and smaller, yet runoff can be variable (& more flashy) depending on rate of snowmelt and rain to snow ratio. This could lead to reduced recharge & lower baseflows; water supply may be lowered in stock tanks & reservoirs. (S1&S2) Effect on downstream users: earlier peak flows (or floods) may force earlier release of water from reservoirs exacerbating already lowered water availability. (S1&S2)	Snowpack management	3rd Priority Strategic Action. Optimize water quantity & quality by managing forests through selective thinning to increase snowpack accumulation and shading reduce sublimation; install snow fences & plant new trees as living snow fences, as needed.	
Temperature changes may lead to change in development patterns (urban refugia?). Changing energy policies lead to increased pressure for energy development (including renewable sources such as wind). Reduced water availability can lead to increased impoundments, increased ground water pumping, water importation, more conflicts over water rights. (S1&S2)	Water management (water rights, groundwater pumping, impoundments, policy)	4th Priority Strategic Actions. To mitigate for increasing water demand and reduced supply, procure in-stream flow water rights & other surface water rights. Monitor water quality, quantity w/ groundwater wells, stream gages. Change water policy to recognize connections between surface & ground water	Obtain additional water supplies from Lake Powell to augment existing ones (CO Water Advisory)

Discussion and Next Steps

Participants recommended a mix of climate change resistance strategies including procurement of in-stream flow water rights to maintain base flows, and resilience and realignment strategies, including

restoration treatments to increase infiltration, groundwater recharge and base flow and respond to climate-induced changes in disturbance regimes. Discussion about impacts and strategic response generated many research questions which deal primarily with getting a more precise, quantitative understanding of: 1) the multi-directional interactions between climate change, vegetation change and hydrological processes and parameters; and 2) the effects of forest/shrubland treatments on herbaceous cover, altered disturbance regimes (e.g. fire, pests, drought), snowpack accumulation and other hydrological processes. For example, in order to improve the ability to address climate change concerns through management actions, participants require better information on the relationships between projected climate changes, including seasonal shifts in precipitation, and vegetation changes, including succession, forest structure, canopy cover and herbaceous cover, and how these, in turn, impact hydrological processes.

The group noted that the implementation of the recommended strategies will require an understanding of the moderate and extreme climate change scenarios developed by the workshop's climate experts as well as other potential climate scenarios; more in-depth discussion, testing and confirmation of the group's conclusions and recommendations; a commitment to research and system-wide monitoring to determine the effects of adaptation strategies; and dedicated efforts to raise funds and rally managers around a shared program of work.

Climate Change Adaptation Strategies for the Mexican Spotted Owl

Facilitated by Patrick McCarthy and Marcos Robles of The Nature Conservancy, the Mexican Spotted Owl (MSO) breakout group included nine participants with a broad range of experience in wildlife, forest, and landscape ecology and management:

- Christine Dawe – US Forest Service, Southwestern Region
- Valerie Foster – US Forest Service, Coconino National Forest
- Joe Ganey – US Forest Service, Rocky Mountain Research Station
- Shaula Hedwall – US Fish and Wildlife Service
- Bill Noble – US Forest Service, Four Forest Restoration Initiative
- Sarah Reif – Arizona Department of Game and Fish
- Courtney Schultz – US Forest Service, Four Forest Restoration Initiative
- Sarah Hurteau – The Nature Conservancy in Arizona
- Sue Sitko – The Nature Conservancy in Arizona

Sarah Hurteau and Sue Sitko of TNC also recorded the proceedings. TNC policy specialist Magill Weber sat in for much of the two sessions.

The MSO break-out group used the process laid out in the Adaptation for Conservation Targets framework described earlier in the workshop by Molly Cross. The group's charge was to complete the following in two half-day sessions:

- Define a specific, measurable, attainable and time-bound management objective for the MSO.
- Develop a conceptual model for the MSO and its habitat.
- Describe known or likely impacts of climate change under two scenarios: moderate and severe.

- Identify management intervention points: activities that might exacerbate, mitigate or reduce the effects of climate change on the MSO.
- Identify strategic actions that could help the MSO adapt to moderate and/or severe climate change.

Defining the Conservation Feature

MEXICAN SPOTTED OWL (*Strix occidentalis lucida*)

(This information is from the USFWS website)

STATUS: Threatened (58 FR 14248, March 16, 1993) with critical habitat (69 FR 53182, August 31, 2004).

SPECIES DESCRIPTION: Medium-sized owl with large dark eyes and no ear tufts. Plumage is brown with numerous white spots and posterior underparts have short, horizontal bars or spots. Length is about 0.4 m (17 in) and wingspan is 1.0 m (3.3 ft).

HABITAT: Occurs in varied habitat, consisting of mature montane forest and woodland, shady wooded canyons, and steep canyons. In forested habitat, uneven-aged stands with a high canopy closure, high tree density, and a sloped terrain appear to be key habitat components. They can also be found in mixed conifer and pine-oak vegetation types. Generally nests in older forests of mixed conifer or ponderosa pine/Gambel oak. Nests are found in live trees in natural platforms (e.g., dwarf mistletoe brooms), snags, and on canyon walls. Elevation ranges from 1,249 to 2,743 m (4,100 to 9,000 ft).

RANGE: Historical: Range extended from the southern Rocky mountains in Colorado and the Colorado Plateau in southern Utah southward through Arizona, New Mexico, and far western Texas, through the Sierra Madre Occidental and Oriental, to the mountains at the southern end of the Mexican Plateau.

Current: Present range is thought to be similar to the historical range. Populations in Arizona are patchily distributed and occur where appropriate habitat is present throughout all but the arid southwestern portion of the state.

REASONS FOR DECLINE/VULNERABILITY: Threatened because of destruction and modification of nesting habitat. The primary threat is believed to be unnatural fuel loadings and the resultant threat of high-severity, stand replacing wildfire.

LAND MANAGEMENT/OWNERSHIP: The majority of the owls are found on National Forests lands, also found on tribal lands, National Parks Service lands, and on Bureau of Land Management lands.

NOTES: The Recovery Plan for the Mexican Spotted Owl was completed in December 1995 and is available online at:

<http://www.fws.gov/southwest/es/arizona/Documents/RecoveryPlans/MexicanSpottedOwl.pdf>.

The plan is currently being revised and a draft is expected for public release in spring 2008.

Listed as a Species of Special Concern by the State of Arizona.

Critical habitat is designated in Apache, Cochise, Coconino, Gila, Graham, Greenlee, Maricopa, Mohave, Navajo, Pima, Pinal, Santa Cruz, and Yavapai counties in Arizona (August 31, 2004).

Critical habitat also occurs in New Mexico, Utah, and Colorado. Tribal lands within Arizona are excluded from Mexican spotted owl critical habitat designation under Section 4(b)(2) of the Act.

Management Objective

The group's charge in this portion of the breakout sessions was to establish a five- to ten-year management objective for the MSO in the 4FRI region. The purpose of setting an objective was to provide a foundation for identifying climate change impacts, and developing strategies for reducing these impacts. Another purpose of establishing an objective is to determine whether, in the face of ongoing and future climate change, it should be retained, revised or discarded.

After reviewing what is known of the status of MSO populations and habitat in the Four Forests Restoration Initiative area (remarkably little, due to funding shortfalls for research and monitoring), the most recent (1995) recovery plan for the bird; and the ongoing recovery plan revision process, the group agreed to the following 5-10 year management objective for MSO in the 4FRI:

Maintain and/or enhance existing (restricted/protected) habitat and foster development of new habitat such that the total amount of habitat is stable or increasing.

The group noted that establishment of a measurable, quantifiable objective is problematic, if not impossible, at present, because of the paucity of data describing the location, numbers and movement of MSO in the 4FRI area. Moreover, wildlife biologists and managers will not be able to determine whether an objective – even one as qualitative as the one proposed by this group – has been met without much more comprehensive and extensive description and monitoring of MSO habitat. While MSO habitat has been reasonably well described by biologists since the species was federally listed, we still cannot predict the number of animals that are supported by habitat of a particular size or kind.

It is critically important for managers to know actual numbers and locations of MSO individuals and nesting pairs, but, given current priorities and funding for the 4FRI landscape, it is not realistic to expect that we will be able to determine population size and distribution for the foreseeable future. The group concluded that, in the absence of definitive knowledge about MSO population dynamics within the 4FRI area, it is best to establish a habitat-focused objective. With more and better characterization, mapping and monitoring of owl habitat – focusing on the establishment of baseline numbers for roosting/nesting habitat and foraging habitat – it will be possible to determine whether the proposed management has been achieved. One suggestion from the group was to develop a habitat model based on known MSO occurrences and Forest Inventory and Analysis plots, then estimate the number and distribution of owls across the entire 4FRI area from existing FIA data for the four National Forests.

Conceptual Model

Participants began with a first-draft conceptual model of the Mexican spotted owl and its habitat that was developed just before the workshop by scientists Joe Ganey and Shaula Hedwall, experienced biologists and longtime members of the interagency MSO Recovery Team.

Starting with a fairly simple model containing a small number of boxes and arrows representing ecological pieces, pattern and processes, the group discussed and expanded the diagram considerably by reorganizing and adding habitat elements and ecological drivers (Figure 5, below). The group also added seven drivers associated with human management, including

silviculture, fire management, livestock management, game management, fuelwood gathering, recreation, and infrastructure development.

The final version of the conceptual model centers on the quality, condition and spatial distribution of two types of pine-oak habitat that are critical to the bird's viability: nesting and roosting habitat, and foraging habitat. The experts also called out the importance of connectivity, fragmentation, dispersion and patch size, grouping these under a driver they called *landscape configuration*. In recognition of the role played by climate variability and change in shaping the ecosystems that support MSO (cf. Seamans et al. 2002) the group added drivers for temperature and precipitation.

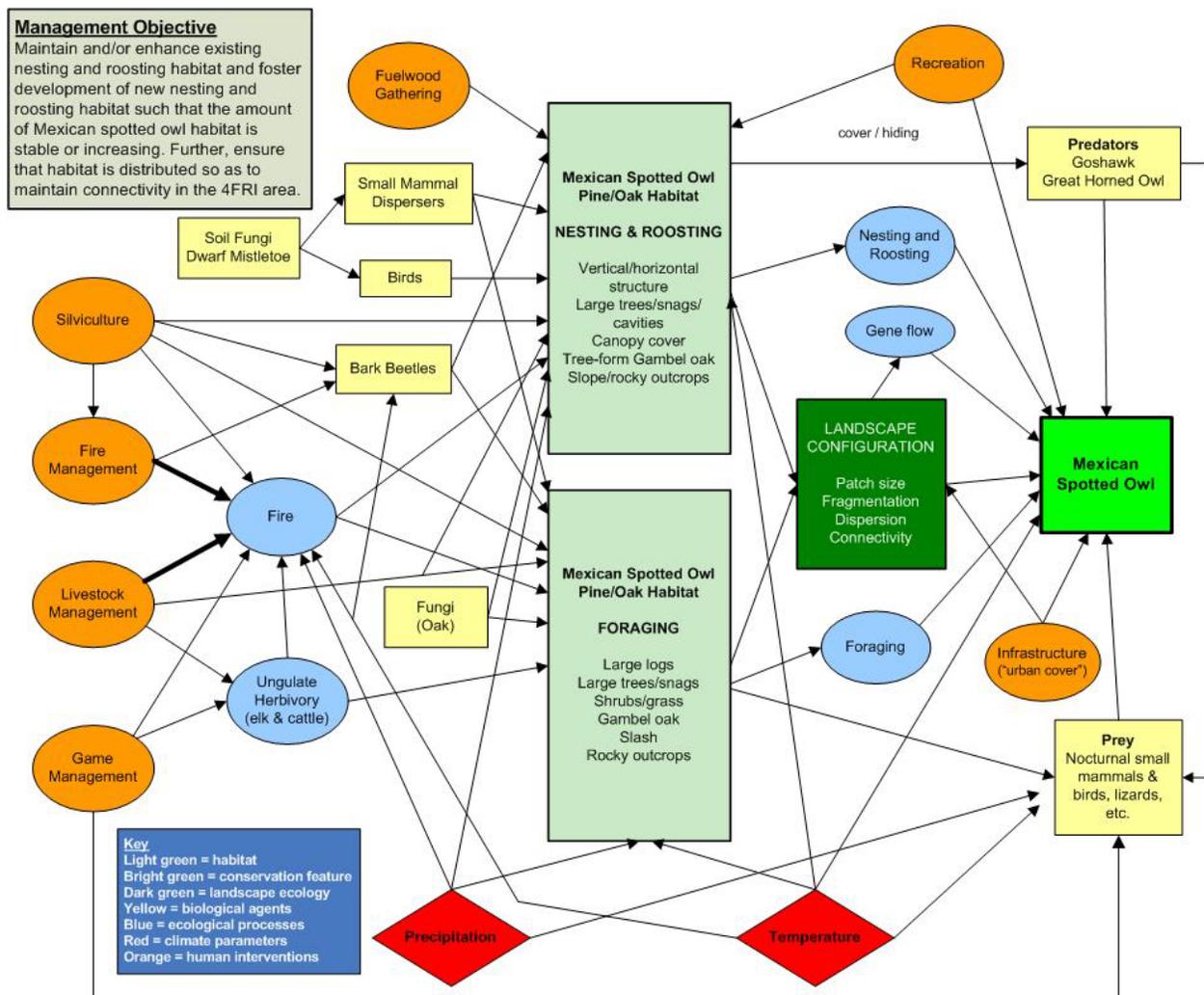


Figure 5 Conceptual ecological model for Mexican spotted owl.

Climate Change Impacts Assessment

After completing the conceptual model, the group delved into whether and how the moderate and extreme climate change scenarios developed by Dr. Mearns and Dr. Rajagopal would influence the ecological drivers. The participants considered the moderate scenario (S1) first, using the

relationships summarized in the conceptual model – and their own personal and professional knowledge – to identify known and projected climate change impacts. Symbols indicating increase, decrease or change (+, - or Δ) were drawn directly onto the model so that participants could keep track of – and later summarize – the many anticipated interacting effects of climate change. The experts then proposed and discussed hypotheses of change whereby direct and indirect effects of changes in temperature and precipitation result in cascading ecosystem impacts and management challenges (See Table 12, Appendix D3, page 61-63). The most significant known or likely impacts identified by the group included changes in fire regime (frequency, severity and size of fire in pine-oak habitats), increased frequency and extent of bark beetle outbreaks, and changes in landscape configuration (patch size, fragmentation, dispersion and connectivity of habitats that support the owl). The group hypothesized that these changes in pattern and process would lead to changes in the spatial distribution, areal extent, composition and structure of nesting/roosting and foraging habitat. These would lead, in turn, to decreases in the amount of available habitat, change in prey abundance, increases in predation (by northern goshawk and great horned owl), and consequently an increased risk of extirpation of the Mexican spotted owl across the 4FRI region. Several participants emphasized the uncertainty inherent in these hypotheses of change, and called for research and monitoring as a foundation for adaptive management as the regional climate changes.

The group’s lengthy deliberations on Scenario 1 left little time for discussion of the impacts of the more extreme (hotter, drier) Scenario 2. But, after an inconclusive discussion of ecological thresholds, the group agreed that the hypothesized changes to ecological drivers noted for Scenario 1 would likely increase in amplitude and pace under Scenario 2. In summary, the group concluded that “neither Scenario would lead to good outcomes for the owl” but, under Scenario 2, we managers might be more willing to take on more risky and expensive management interventions to increase the viability of the Mexican spotted owl.

Management Intervention Points

As a starting point for identifying strategic actions could help the MSO adapt to a changing climate, the group identified ten management intervention points:

1. Forest management policy
2. Outreach and education
3. Recreation management
4. Infrastructure design
5. Fuelwood collection management
6. Game management
7. Livestock management
8. Fire management
9. Silviculture
10. Strategic landscape planning

Strategic Actions for Climate Adaptation

The group then brainstormed strategic actions that might help the Mexican spotted owl survive in the 4FRI area in the warmer, drier climates of Scenarios 1 and 2. Table 12 presents a list of these

strategic actions, organized by hypothesis of change. We also noted, for each strategic action, the management intervention point, urgency/priority, and opportunities for implementation.

The group identified a wide-ranging and comprehensive list of strategies. The proposed strategies addressed nine of the ten management intervention points listed above, and ranged from climate change science outreach to protecting MSO habitats through infrastructure development planning.

Group emphasized the need for landscape-scale, multi-jurisdictional landscape planning and management that integrate forest restoration, MSO habitat conservation, economic development and other community natural resource values. The dramatic changes in the ponderosa pine forest that are projected for the next several decades, they felt, will put these values at great risk. If we are to conserve the owl and the forests in depends on, the natural resources management community must work together across ownership and disciplinary boundaries toward shared goals. To be effective, MSO management must be integrated into landscape planning for multiple conservation features. Indeed, the group felt that only a regional (or landscape-scale) plan that is holistic and inclusive – that is, one that integrates landscape ecology with forest restoration treatments, economic development, infrastructure planning, fire management, outreach and education, and other management interventions – will be successful in building resilience of the MSO and other key ecosystem components.

After considerable discussion of the likely future isolation of owl habitat in a forest subjected to more frequent and more intense droughts and warm periods, the group concluded that a “habitat linkage design” will be necessary to ensure that the landscape configuration (as described in the conceptual model) will be sufficient to support the MSO. In simpler terms, the MSO will be viable in a warmer and drier world only if habitat patches – which will grow smaller and more isolated over time – are individually protected and linked to each other by habitat corridors. The group agreed that much more information is needed – through research and monitoring – about current population distribution, habitat distribution, and projected changes in habitat to devise a rigorous, science-based landscape conservation plan.

Nonetheless, the group also observed that the 4FRI presents many excellent opportunities for conservation of the MSO and other conservation features through landscape strategic planning. A large and strong partnership is already in place, there is much scientific information already available, and the 4FRI has begun a regional strategic planning process.

The group also noted that, for many species and habitats, but especially for the MSO, there is a critical need for research and monitoring. In spite of the 1993 federal listing of the owl and the short-term burst of funding that it brought for scientific inquiry, there has been little monitoring of the northern Arizona populations and even less research. We do not have a defensible estimate of the number of owls in the 4FRI area, nor do we know very much about their population dynamics or distribution, with the exception of occupied habitat in or near Forest Service project sites – the only sites that have been systematically surveyed for owls.

Research and Monitoring Needs for Mexican Spotted Owl

Specific research needs that the group identified:

- Identification of minimum patch size for nesting and roosting habitat.
- Determination of effects of fuels treatments on MSO occupancy, reproduction and survival in Protected Activity Centers.
- Identification of current owl habitat locations.
- Models that explain how the structure, composition and distribution of these habitat might be altered through climate change.
- Spatially-explicit models that project the future distribution and population dynamics of the bird.
- Infrastructure build-out analyses that determine how future development in the 4FRI area might change the distribution of MSO and its habitat.

After identifying research and monitoring needs, the group revisited the management objective that it developed at the beginning of the breakout session in light of projected climate change impacts. The group's final, revised, management objective:

Maintain and/or enhance existing nesting and roosting habitat and foster development of new nesting and roosting habitat such that the amount of Mexican spotted owl habitat is stable or increasing. Further, ensure that habitat is distributed so as to maintain connectivity in the 4FRI area.

Priority Adaptation Strategies

The facilitators asked the group to identify the strategies most likely to increase the viability of the MSO in the face of moderate and extreme climate change. The group rapidly reached consensus in selecting the following four adaptation strategies (really groups of strategies), in priority order:

1. Landscape strategic planning that:
 - Integrates objectives for MSO survival and viability
 - specifically identifies priority areas for forest restoration treatment (in a spatially-explicit way)
 - Evaluates trade-offs and sets priorities
 - Shares draft maps and plans with the public to garner support
 - Identifies key linkages and proposes a patch linkage design to provide landscape connectivity.

The group agreed that, under the more extreme change change scenario (#2), strategic planning, which normally requires years, must be more rapid and aggressive (with respect to restoration or resilience-building forest treatments).

The group also recognized that landscape strategic planning is already underway through the 4FRI, and that the information generated in this workshop could be integrated into the new plan. In fact, the 4FRI presents an excellent opportunity for building climate adaptation into agency planning and implementation.

2. Forest thinning and ecological restoration that includes:

- Developing and maintaining large trees
- Identifying refugia microclimates (fire, north facing slopes, soil types) for management of MSO nesting/roosting habitat
- Identifying, managing & maintaining key linkages across the landscape to assist and provide landscape connectivity

Under the more extreme climate change scenario, the group felt it would be necessary to take extra, more aggressive, measures, including creation of strategically placed fire breaks across the landscape to reduce risk of large uncharacteristic fires

3. Economic development, including:

- Developing markets for woody biomass for energy
- Design and implementation of large-scale contracts
- Development of other small diameter wood markets

The best current opportunity for implementation of this strategy is to partner with the Department of Defense, Drake Cement, and interested organizations to use woody biomass to meet their renewable energy standards. Another important opportunity is to develop partnerships with the small- and large-diameter wood product industry.

4. Fire management, including:

- Conducting low intensity planned fires to reduce fuels, increase understory vegetation, restore natural fire regimes, and break up fuel continuity.
- Reducing suppression by using unplanned fires where feasible to meet resource objectives. Design resource objectives that incorporate MSO habitat considerations

Discussion and Next Steps

The group's four top priorities point to a strategic approach to landscape management that integrates multiple natural resources values – Mexican spotted owl, forest resilience, water provision, energy development, economic development – and uses several different management tools to sustain them. The group discussed the similarity between the climate adaptation strategies identified they identified and the strategies that the US Forest Service and other organizations have already adopted for forest restoration and biodiversity conservation. But the you noted that the location, pace and scale of these activities should be adjusted in the face of rapid climate change.

Moreover, the ultimate goals of landscape strategic planning – and the management interventions that we use, including silviculture, and fire management – should be adjusted for rapid climate change. The goals and objectives that we have established through forest plan revision and landscape strategic planning for a presumably stable environment may become irrelevant,

unattainable or impractical across the rapidly warming Colorado Plateau. Accordingly, the group called for more study and broader understanding of the plausible climate change scenarios presented by Dr. Linda Mearns and Dr. Seth Rajagopal, and a deeper consideration of assumptions and goals than the short duration of this workshop allowed.

Participants also pointed out that research and monitoring are essential management tools as the climate changes. To manage for MSO viability, not only do we need to know more about basic biological variables such as MSO locations, movement, habitat use, and reproductive success – we need to know much more about how the owl, and the habitat that supports it, are responding to climate change. Moreover, we will need to track and understand how our interventions are affecting local habitats and the regional landscape, thereby testing our assumptions about how we can reduce the impacts of climate change on species, habitats and ecosystems.

As did the ponderosa pine/hydrology group, the MSO group noted that the implementation of the recommended strategies will require an understanding of the moderate and extreme climate change scenarios developed by the workshop’s climate experts as well as other potential climate scenarios; more in-depth discussion, testing and confirmation of the group’s conclusions and recommendations; a commitment to research; system-wide monitoring to determine the effects of adaptation strategies; and dedicated efforts to raise funds and rally managers around a shared program of work.

Synthesis of Priority Strategic Actions into Cross-Cutting Strategic Actions

As the three breakout groups reported back to each other their top priority strategic actions, some common themes emerged that cut across all three conservation features, and those are reported here as ‘no regrets’ strategies that could be used and implemented by the 4FRI stakeholders and team, some of which already fit into ongoing projects and plans:

Social and Economic Issues

1. Develop economic uses and markets for wood fiber. Encourage economic development for woody biomass; establishment of sustainable forest industries is a key, top priority. Acknowledge low value-added characteristic of restoration products and provide certainty of supply and incentives to encourage investment.
2. Increase social acceptance and capital for appropriate forest management in light of climate change. Provide high quality information to the public in a digestible format, demonstrating relevance to resource management and human needs, disclosing uncertainties and assumptions to build confidence.

Planning and Design of Treatments

1. More aggressive and rapid strategic planning is a top priority with an emphasis on strategic placement of treatments to meet multiple objectives. Different parts of the landscape should be treated differently, e.g. ecotones, riparian areas, and habitat types within ponderosa pine: a variety of different ecological goals should be identified based on site variability, ecological potential, local climatology, and described in terms of what the areas should look like in the future and how thinning and fire management in these zones will achieve ecological goals.

2. Through the planning process, design and adequately fund a series of management experiments to inform management decisions related to species composition, structure and function. Link performance measures of the monitoring of treatment effects to the ability to conduct further treatments.
3. Conduct landscape risk assessment: use collaborative process to decide exactly what treatments and Best Management Practices (BMPs) to implement while meeting operational goals: minimizing/optimizing road placement and rehabilitation for fire management, recreation, and mechanical treatments; meeting fuels reduction goals; meeting ecological goals (see #4 below).

Implementation and Monitoring of Treatments

1. Use thinning and burning treatments to create a mosaic of ‘clumpy-groupy’, uneven aged trees and openings to promote herbaceous understory and to provide effective crown-fire fuel breaks. Maintain large, old, pre-settlement trees as highest priority but also maintain a range of all age/size classes of trees to ensure resilience and sustainability of forests, including riparian forests, into the future.
2. Treat more acres with prescribed burning and allow more unplanned ignitions of wildland fires to burn for resource benefit. Make short-term fire planning more responsive to our understanding of current weather events like El Nino-Southern Oscillation events, and incorporate the best available climate data into longer term forecasting, fire management, wildlife management, and other actions.
3. Implement management actions that encourage retention and recruitment of drought and fire adapted plant and animal species to encourage resilience and realignment to the changing climate. For example, instead of only identifying where the best MSO habitat is currently, also identify where owl habitat will be able to persist into the future. Ensure that high quality habitat patches are sufficiently large and connected to allow owls to forage, nest, breed, and recruit young into breeding adults.
4. Implement essential monitoring to track the effects of treatments on ecosystems and progress toward meeting goals. Provide adequate human, financial, and timing resources to analyze and use results of monitoring, including reporting, storing, and archiving of data, and incorporation of results into subsequent planning efforts.

Opportunities, Challenges, and Barriers to Strategic Action Implementation

Participants divided themselves into three, new groups to discuss opportunities and barriers that apply to the strategic actions identified in the breakout groups. Some of the opportunities and barriers applied to all three groups, which consisted of water management, forest management, and monitoring.

Economics

We discussed the opportunity for 4FRI stakeholders and scientists to build and refine information and case studies that link forest management to water yield and water quality. More complete information would help all interested parties engage in elevated dialogue about the

values protected and the costs incurred in managing our forests. The challenge will be in clearly demonstrating a direct connection between forest conditions and water quality and quantity, as well as the importance of forests to urban sustainability. There is a good example and precedent of forest treatment cost offsets by water ratepayers, by both residential and commercial customers in the Santa Fe, New Mexico watershed who have agreed to a surcharge on water bills that helps pay for forest conservation activities. In several Latin American countries, Water Trusts are growing in importance for protecting urban water supplies by conserving upland watersheds.

Participants also discussed that within 4FRI, there is an industry engagement working group consisting of several industry representatives and other stakeholders who are working with the US Forest Service to help design creative contracting mechanisms that may improve the economic opportunities afforded industries that are interested in investing in infrastructure development in the 4FRI area, through incentives, long-term contracts, hybrid timber sales, and other mechanisms. Stewardship Contracting was recently reviewed in several reports, and its authority will be reviewed and new policy developed in 2013.

Forest Management

There is an opportunity through 4FRI to increase efficiency of many aspects of analysis, planning, contracting and implementing because of the high degree of mutual understanding and stakeholder agreement and the social license that affords. Also, because of its large geographic scope, and long temporal scale, 4FRI could gain efficiency through analysis, planning, and operations that take advantage of the large scale by decreasing the amount of time expended per unit area. This is also perceived as a potential barrier, as there are few precedents in public land management that have operated at this large scale. Such issues as National Environmental Policy Act (NEPA) compliance, strategic planning, prescribed burning, mechanical thinning, roads analysis and management, wildlife management, and others have rarely been addressed at this scale, and participants expressed concerns about being able to conduct all these processes well at this scale. However, a team of experts has been organized by USFS to focus on large scale NEPA. Participants did feel that stakeholders and USFS have the capacity to continue this work.

Other barriers included public acceptance or approval of thinning and burning at large scale, and that the public is unfamiliar with providing input through NEPA analysis as large as 4FRI is proposing. Ongoing funding will be an issue, as will the fact that although industry partners are in the stakeholder group, existing industry is small compared to the potential volume of material that could be generated by 4FRI-designed mechanical treatments, and so the timing of industry infrastructure build-up will be critical to their success. There may be regulatory limits on how much area may be burned in any time period due to air quality concerns, and there may be limits to how many acres can be burned due to logistics, availability of trained personnel, and capacity. Some parts of the USA have legislated approval of fire management through 'right to burn' laws (e.g., Florida).

Another barrier relates to the increasing size of the Wildland Urban Interface (WUI) through human development, which continues to expand even as land managers struggle to keep up with management of current priority acres. While plenty of land use planning occurs throughout the area, participants are unsure of whether or not planning efforts hinder land management efforts, and doubt that fire managers' opinions, ideas and insights are incorporated into planning efforts.

Another set of barriers stymies effective road management efforts, which are critical not only because comprehensive ecological restoration necessitates that some poorly designed or maintained roads be obliterated or rehabilitated to reduce erosion and restore altered hydrology in many areas, but also because functional roads are required in areas where mechanical thinning is the preferred tool of forest restoration. Travel Management Rules have been litigated, and those that have been decided are difficult to enforce due to capacity and an unwilling public. Clearly, this issue will need to be addressed, and a rational, sequential solution designed, implemented, enforced, monitored, and adapted for the 4FRI to be successful.

Monitoring

There is a tremendous opportunity for 4FRI to effectively and efficiently track the effects of its treatments, but to be effective it needs to be well designed, focused on essential elements rather than comprehensive, and adequately funded. The 4FRI Science and Monitoring working group provides an excellent opportunity for its stakeholders to meet these needs in developing monitoring plans and protocols ahead of project implementation. High quality monitoring needs to focus on three areas: designing monitoring plans and protocols, implementing those plans and protocols, and analyzing and using the results in development of new projects through formal adaptive management.

Some of the barriers to good monitoring include the lack of a targeted design that meets explicit management needs, and inconsistency in timing between when projects are implemented and when funding is available for the monitoring. These barriers can be avoided by including managers in the conversation that identifies monitoring objectives and appropriate, targeted protocols that are designed to inform those objectives. The funding issue could be avoided by including estimates of costs throughout the design phase of the monitoring program or framework. Opportunities exist within both the Stewardship Contracting mechanism, which stipulates a percentage of implementation costs be allocated for monitoring (e.g., White Mountains Stewardship Contract [WMSC], 5-year report [here](#)), and the Collaborative Forest Landscape Restoration Program (CFLRP), which requires monitoring as an element of the program, and provides funds for monitoring. 4FRI has been awarded funds from the CFLRP, and is likely to receive resources from this program for the next ten years, and several 4FRI stakeholders have direct experience with the WMSC and they are using lessons learned from the 5-year report in development of their own monitoring program.

Participants in the adaptation workshop recommended that the implementing agency, or US Forest Service be the lead agency for implementing the monitoring, but not necessarily responsible for conducting all the monitoring, which could be accomplished by several stakeholder groups, individuals, and agencies. This is important not only to have a single entity that is held accountable for accomplishing the monitoring, but also to ensure that there is adequate funding that is dedicated to monitoring and not just part of another budget item. It was also discussed whether or not execution of monitoring, analysis of data, and incorporation of results into subsequent planning efforts might be used as performance measures that unless they are achieved, new projects could not proceed. There is an opportunity for 4FRI to use its collaborative structure to engender a sense of responsibility and commitment to use monitoring data in subsequent planning efforts. Also, monitoring data can be used to demonstrate to the

public that they are ‘getting what they pay for’ through their taxes and other support of forest restoration activities.

Emerging Themes, Conclusions, and Next Steps

Rob Marshall facilitated the last session of the workshop through a series of questions posed to the participants. Rob noted that participants have a good grasp of, and are working to reduce the effects of multiple stressors or threats that affect Arizona’s forests. The list includes fire suppression, changes in horizontal and vertical structure, ex-urban development, drought, insects and diseases, too many ladder fuels, too few fine fuels, altered hydrology, and others. With an acknowledgment of the effects of climate change, the issue is trying to build more resiliency into the ecosystems we manage.

Q1. Does the workshop process confirm what you are already doing?

Answers back from participants included that yes, the strategies we are already using were reassured, but we may not be doing enough to account for potential species shifts under the more extreme scenario – that is, allowing for realignment of species. Also, the workshop provided for a greater sense of urgency, and inspired an interest in finding ways that action can take place more quickly. Another participant appreciated knowing just how bad conditions are in the SW, but also that there is plenty of variability within ecosystems – especially within ecotones or transition zones – that necessitates treating different areas differently. When someone noted that we (as managers) don’t take sufficient advantage of ENSO conditions for short-term planning, Gregg Garfin indicated that information is available from the Southwest Coordination Center predictive services ([SWCC](#)) that may be useful for several applications beyond the firefighting community for which it is designed.

Q2. Were there any new ideas generated by the workshop?

Responses included that the workshop encouraged managers to try something unconscionable previously: [assisted migration](#) through management experiments, putting resources into other strategies besides running chainsaws, like planting Mexican pines or other species from the Southern Sky Islands that are better adapted to drought and higher temperatures – in terms of Ken Cole’s talk, pushing the clock forward for some species. Participants agreed that this was worth exploring as a good next step that would require its own workshop. Another response was that thinking out 40-60 years was OK, but that using a longer planning horizon of 100 years might be more relevant to determining what would be a good investment of resources, rather than spending too much time working on potentially short-term solutions. A related concern was that there is less certainty about projections further into the future: How do I act, what do I do? One participant noted that the workshop helped them from feeling like a ‘deer in the headlights’, and that we don’t have to know or understand everything before trying to do something about climate change. Another participant who has been involved with 4FRI since the beginning has been asked and asked herself how 4FRI is incorporating climate change into its goals, and now realizes that everything we are planning on doing is probably going to help habitat trend in the right direction. A wildlife biologist said that he never has enough information, and has to compromise decisions because of this, but that when you wait on decisions, there is a potentially serious cost. Information provided during the first ½-day plenary session helped move his understanding level in the right direction. The concept of using forests as snow fences was fascinating, and demonstrated promise of using forest structure to enhance watershed function.

Q3 The more extreme scenario was harder for the breakout groups to tackle. But would you prioritize your strategic actions differently if you used this scenario?

The MSO group did re-prioritize their strategies, and agreed that their focus would be on both protecting known inhabited areas, but would also focus on putting fuel-breaks in to protect potential future refugia. Strategic placement of treatments can focus on different objectives that might give different solutions, and will generate tradeoffs by leaving some areas untreated. The use of scenario planning allows you to see how the landscape looks when you emphasize different objectives (e.g., focus on MSO refugia vs. community protection through fuels reduction).

Q4 What wasn't covered in this workshop that should have been?

Somebody could talk about big patterns of insects and disease, and the role of plant and animal genetics on climate change adaptation. Having a landscape ecologist talk about abruptness of change, and how this leads to large-scale fragmentation would be helpful. We don't really know how to deal with invasive species (plants and animals), but if restoration and fuels reduction leads to an increase in invasives, we may win the battle but lose the war (e.g., Mt. Trumbull restoration and cheatgrass invasion). It's unclear how to downscale climate change data to the project level. While doing nothing is not an option, it's better to get people together, use projections of temperature change as focal process because there is less uncertainty, and utilize local knowledge of microtopography and other factors to speculate on what areas are more likely to be resilient. You don't have to know exact data to get a better sense of the climate sensitivity of different species, one can rely on collective knowledge and existing tools (like RMRS Vulnerability Tool) to help prioritize your work. 4FRI has tremendous bench strength that will help in making progress. There are rules of thumb that can help with adaptation planning: for the Colorado River basin area, for every one degree Celsius change in temperature, expect stream runoff to change by about 6-11%; and a 1% change in precipitation translates to about a 2% change in stream runoff.

Q5 What are the next steps?

- Participants thought that they needed to start having more discussions in the office about climate change adaptation.
- Incorporate workshop information into 4FRI planning and implementation processes.
- Follow-up discussions by webinar, or coupling face-to-face with webinar.
- From priority research questions, could bring in experts to clarify data gaps, re-prioritize, and pursue those that rise to the surface.

Closing Remarks

Edward Smith related a story from earlier in the week, recognizing that the reason there weren't any insect and disease experts in the adaptation workshop was because they were attending an annual meeting across town in another venue. Flagstaff is famous for its spring winds, but in recent years, those winds have kicked up dust storms severe enough to close Interstate 40 near Winslow east of Flagstaff multiple times each year. A couple of entomologists called Ed's house Monday night because they were stopped by the I-40 closure, and wanted some advice on what to do, as they had a hotel reservation and meeting to get to, and had limited information and

resources. Should they wait out the storm? Should they pay extra and stay the night in Winslow? Was there another route they could take? Ed and his wife scrambled to gather some information to answer their questions, and provided some possible scenarios of what to do, even though they didn't have complete information or necessarily accurate predictions.

This story is a microcosm of the adaptation workshop: We may not have all the information to address knowing exactly how to proceed with absolute confidence. But by sharing the information we do have about where climate is changing and by how much, and by gathering high quality data on species' habitat requirements and likely response to changes, and by having conversations in which we ask ourselves the relevant questions that explore different scenarios – their benefits and tradeoffs – we can get to a better position of collectively developing a robust approach and reasonable, strategic actions to begin addressing climate change adaptation.

Acknowledgements

We would like to acknowledge the eight months' worth of phone calls and webinars it took to organize this workshop that were donated by the Adaptation Workshop Planning Team, consisting of Gregg Garfin (UA); Molly Cross (WCS); Heather Green and Yewah Lau (Coconino NF); Neil Cobb (NAU); Patrick McCarthy, Dave Gori, and Carolyn Enquist (TNC New Mexico); and Sue Sitko and Edward Smith (TNC AZ).

We would also like to thank our speakers, including Pat Graham for his inspirational opening remarks, Gregg Garfin for his excellent work as overall workshop facilitator and fill-in for Seshandri Rajagopal (UA), Linda Mearns (NCAR), Ken Cole (USGS), Megan Friggens (RMRS), Pete Fule (NAU), Kirsten Ironside (NAU), and Joe Ganey (RMRS) for plenary talks.

We would like to thank Sarah Hurteau (TNC-AZ) for her tireless assistance in printing and assembling the participant notebooks, and for designing and printing the wall posters used in the breakout groups.

Thanks also to our breakout session facilitators, Patrick McCarthy and Marcos Robles (TNC-AZ) (Owl Group), Dave Gori and Carrie Enquist (Hydrology Group), and Molly Cross and Edward Smith (Fire Group). Kudos and thanks also to Rob Marshall (TNC-AZ) for facilitating the home stretch sessions on Emerging Themes and Next Steps.

Many thanks also to our note-takers and recorders: Louise Misztal (Sky Island Alliance), Sarah Hurteau, Sue Sitko, Gita Bodner (TNC-AZ), and Magill Weber (TNC-AZ).

Literature Cited

Brewer, D. 2008. Accounting for watershed and other resource values -- consideration in the NEPA analysis. Ecological Restoration Institute Fact Sheet. 4pp.

Christensen, J. B. Hewitson, and 15 co-authors including L. O. Mearns 2007: Regional Climate Projections. In *IPCC WG1, Fourth Assessment Report, The Physical Science Basis*. Solomon *et al.* (eds.). Chapter 11. Cambridge U. Press, pp. 847-940.

Christensen, N. S., and D. P. Lettenmaier, 2007: A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. *Hydrology and Earth System Sciences*, 11, 1417-1434.

Cooper, Charles F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs*. 30(2): 129-164.

Covington, W. W.; Moore, M. M. 1994. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. *Journal of Sustainable Forestry*. 2(1/2): 153-181.

Cross, M. S., E. S. Zavaleta, D. Bachelet, M. L. Brooks, C. A. F. Enquist, E. Fleishman, L. Graumlich, C. R. Groves, L. Hannah, L. Hansen, G. Hayward, M. Koopman, J. J. Lawler, J. Malcolm, J. Nordgren, B. Petersen, D. Scott, S. L. Shafer, M. R. Shaw, and G. M. Tabor. (In review). Adaptation for Conservation Targets (ACT) Framework: A tool for incorporating climate change into natural resource conservation and management. *Environmental Management*.

Dieterich, John H. 1980. Chimney Springs forest fire history. USDA Forest Service Research Paper RM-220:1-8.

Dore, S., T.E. Kolb, M. Montes-Helu, S.E. Eckert, B.W. Sullivan, B.A. Hungate, J.P. Kaye, S.C. Hart, G.W. Koch, and A. Finkral. 2010. Carbon and water fluxes from ponderosa pine forests disturbed by wildfire and thinning. *Ecological Applications* (in press).

Hamlet, A. F., P. W. Mote, M. P. Clark, and D. P. Lettenmaier, 2005: Effects of temperature and precipitation variability on snowpack trends in the western United States. *Journal of Climate*, 18, 4545-4561.

Mearns, L. O., et al., 2009: A regional climate change assessment program for North America. *EOS* 90: 311-312.

Seager et al. 2007: Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316:1181-1184.

Smith, Edward B. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Ponderosa Pine of the Southwestern U.S.

Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 43 pp. Report online at www.AZConservation.org.

Swetnam, Thomas W., Baisan, Christopher H. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. In: Allen, Craig D., ed. Fire effects in Southwestern forests: Proceedings, 2nd La Mesa fire symposium; 1994 March 29-31; Los Alamos, NM. RM-GTR-286. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 11-32.

Tebaldi, C., L. O. Mearns, R. Smith, D. Nychka, 2004: Regional probabilities of precipitation change: A Bayesian approach. *Geophys. Res. Lett.* 31:L24213, doi:10.1029/2004GL021276.

Tebaldi, C., R. Smith, D. Nychka, and L. O. Mearns, 2005: Quantifying uncertainty in projections of regional climate change: A Bayesian approach to the analysis of multi-model ensembles. *J. Climate* 18:1524-1540.

Weaver, Harold. 1951. Fire as an ecological factor in the Southwestern ponderosa pine forests. *Journal of Forestry*. 49(2): 93-98.

Weaver, Harold. 1952. A preliminary report on prescribed burning in virgin ponderosa pine. *Journal of Forestry*. 50: 662-667.

United States Forest Service 1997. Plant associations of Arizona and New Mexico, ed. 3, Volume 1:Forests. USDA Forest Service, Southwestern Region, July 1997.

Appendices

Appendix A Arizona Climate Change Adaptation Workshop Participant List

Name	Email	Target Group
Abe Springer	Abe.springer@nau.edu	Water
Al Hendricks	alhendricks@azstatefire.org	Fire
Bill Noble	bnoble@fs.fed.us	MSO
Brenda Smith	Brenda_Smith@fws.gov	Fire
Carolyn Enquist	cenquist@tnc.org	Water
Charles Schelz	Charles_Schelz@nps.gov	Water
Christina Vojta	cvojta@fs.fed.us	Fire
Christine Dawe	cdawe@fs.fed.us	MSO
Courtney Schultz	caschultz@fs.fed.us	MSO
Daniel Laughlin	Daniel.mclaughlin@nau.edu	Water
Diane Vosick	Diane.vosick@nau.edu	Fire
Dave Gori	dgori@tnc.org	Water
Earl Stewart	estewart@fs.fed.us	MSO
Edward Smith	esmith@tnc.org	Fire
Ethan Aumack	eaumack@grandcanyontrust.org	Fire
Evan Girvetz	egirvetz@tnc.org	Water
Gen Johnson	grjohnson@fs.fed.us	Water
Gita Bodner	gbodner@tnc.org	Water
Gregg Garfin	gmgarfin@email.arizona.edu	ROVER
Heather Green	hgreen@fs.fed.us	Water
Henry Provencio	hprovencio@fs.fed.us	MSO
Joan Degiorgio	jdegiorgio@tnc.org	Water
Joe Ganey	jganey@fs.fed.us	MSO
Joyce Francis	JFrancis@azgfd.gov	Water
Ken Cole	Kenneth.Cole@nau.edu	Fire
Kirsten Ironside	Kirsten.Ironside@nau.edu	Fire
Linda Jackson	lljackson@fs.fed.us	Water
Linda Mearns	lindam@ucar.edu	MSO
Louise Misztal	Louise@skyislandalliance.org	Fire
Magill Weber	mweber@tnc.org	MSO
Marcos Robles	mrobles@tnc.org	MSO
Megan Friggens	mfriggens@fs.fed.us	MSO
Mike Chaveas	mchaveas@fs.fed.us	Water
Mitchel White	mwhite04@fs.fed.us	Fire
Molly Cross	mcross@wcs.org	Fire
Neil McCusker	NMcCusker@fs.fed.us	Fire
Pat Graham	pgraham@tnc.org	Water

Patrick McCarthy	pmccarthy@tnc.org	MSO
Peter Fulé	Pete.Fule@nau.edu	Fire
Rob Marshall	rmarshall@tnc.org	ROVER
Rory Steinke	rsteinke@fs.fed.us	Water
Sarah Hurteau	shurteau@tnc.org	MSO
Sarah Reif	SReif@azgfd.gov	MSO
Seshadri Rajagopal	seshadri@email.arizona.edu	Water
Sharon Masek Lopez	sharon.masek_lopez@nau.edu	Water
Shaula Hedwall	Shaula_Hedwall@fws.gov	MSO
Sue Sitko	ssitko@TNC.ORG	MSO
Valerie K Stein	vkstein@fs.fed.us	MSO
Vicki Christiansen	victoria@azstatefire.org	Fire
Yewah Lau	ylau@fs.fed.us	Fire

Appendix B Agenda for the Southwest Climate Change Initiative's Arizona Workshop

ARIZONA CLIMATE CHANGE ADAPTATION WORKSHOP FOR NATURAL RESOURCE MANAGERS OF THE FOUR FORESTS RESTORATION INITIATIVE AREA

7-8 April 2010

Radisson Woodlands Hotel, Flagstaff, Arizona

1175 W Route 66 928-773-8888

WORKSHOP GOAL:

Identify management strategies that will help native plants, animals and ecosystems adapt to a changing climate and lay the groundwork for their implementation.

WORKSHOP OBJECTIVES:

1. Provide background information on climate change as it applies to the forests of northern Arizona.
2. Introduce a framework for landscape-scale climate change adaptation for use at this workshop and as a tool that can be used in other landscapes.
3. Assess the impacts of climate change on ponderosa pine forests and related species and processes.
4. Identify strategic management actions that will reduce climate change impacts.
5. Identify opportunities for ongoing learning, collaboration, and implementation of on-the-ground climate change adaptation projects in the Four Forest Restoration Initiative (4FRI) area.

DESIRED OUTCOMES:

1. Shared understanding of the known current and potential future effects of climate change, through development of conceptual models for ponderosa pine forests and embedded species and ecological processes.
2. Set of strategic actions to promote conservation resilience and realignment of ponderosa pine ecosystems, Mexican spotted owls, and forest fire and hydrologic regimes in the face of climate change.
3. Set of opportunities to facilitate successful implementation of strategic actions.
4. Priority list of research and monitoring needs for climate adaptation in the 4FRI area.
5. Set of recommended next steps to be taken by natural resource managers of the 4FRI area.

7 APRIL 2010: 8:30 AM -11:45 PM

- 7:30-8:30 Registration & Continental Breakfast in Canyon Room (Provided)
8:30- 8:40 Welcome & Southwest Climate Change Initiative (SWCCI) Overview in the Kaibab Room
- Pat Graham, *State Director, The Nature Conservancy, AZ*

- 8:40-9:10 Rationale for this Workshop - Gregg Garfin, *Director of Science Translation and Outreach, University of Arizona (Workshop Facilitator)*
- 9:10-10:00 Overview of Regional Climate Change Impacts: the Known, the Unknown, and the Uncertain
- Dr. Linda Mearns, Senior *Scientist, National Center for Atmospheric Research*
 - Sesh Rajagopal, *Department of Hydrology and Water Resources, University of Arizona*
- 10:00-10:30 Effects of past, present and future climate change on biota of the SW, Part I:
- The Paleoclimate of the Southwest as Context for Current Climate Change - Dr. Kenneth Cole, USGS and NAU
 - Plausible future effects of climate change on ponderosa pine – Kirsten Ironside, Merriam-Powell Center for Environmental Research at NAU

BREAK: 10:30 - 10:45 AM

- 10:45-11:30 Effects of past, present and future climate change on biota of the SW, Part II:
- Interactions of climate change, fire regimes, and hydrologic regimes - Dr. Peter Fule, Ecological Restoration Institute at NAU)
 - Results of Rocky Mountain Research Station (RMRS) Vulnerability Tool for Mexican spotted owl - Megan Friggens, Ecologist RMRS
 - Effects of Drought Stress on Tree Mortality - Dr. Joseph L. Ganey, Research Scientist RMRS
- 11:30-11:45 Overview of Conservation Adaptation Planning
- Molly Cross, *Climate Scientist & Adaptation Specialist, Wildlife Conservation Society*
- 11:45-12:00 Implementing a Framework for Adaptation Planning: Future Climate Scenarios, Goals & Logistics for Remainder of the Workshop
- Gregg Garfin & Molly Cross

LUNCH: 12:00 – 12:45 PM (BUFFET LUNCH PROVIDED IN CANYON ROOM)

1:00 – 5:15 PM, WITH BREAK FROM 3:00 – 3:15 PM

- 12:45-4:30 Break-out groups assemble in separate rooms; introductions
- Ponderosa Pine and Fire Regime group facilitators: Molly Cross and Ed Smith (Humphreys Room)
 - Mexican spotted owl group facilitators: Patrick McCarthy and Marcos Robles (Mt. Elden Room)

- Ponderosa Pine and Watershed Hydrology group facilitators: Carrie Enquist and Dave Gori (Kachina Room)

Objectives for the three groups include:

- *Identify/refine management objectives*
- *Develop a conceptual model*
- *Assess impacts of two future climate change scenarios*
- *Complete Table 1: Climate Change Impacts (in participant packet)*

BREAK 4:30-4:45 FEEL FREE TO FIND A REFRESHMENT AND BRING IT BACK TO THE KAIBAB

4:45 -5:15 BACK IN KAIBAB ROOM - OPTIONAL DEMONSTRATION OF CLIMATEWIZARD

THIS IS AN ONLINE TOOL FOR ANALYZING LOCAL CLIMATE CHANGE BY EVAN GIRVETZ, SENIOR SCIENTIST FOR THE NATURE CONSERVANCY'S GLOBAL CLIMATE CHANGE PROGRAM

DAY ONE ADJOURN: 5:15 PM

HAPPY HOUR: 5:15-6 PM CASH BAR IN HOTEL LOUNGE

APRIL 8TH 2010, 8:30 AM -11:30 AM w/ BREAK FROM 10:15 – 10:30 AM

7:30-8:30 Breakfast in Canyon Room (Provided)
 8:30-11:30 Re-assemble into three break-out groups and designated rooms:
 Ponderosa Pine & Fire: Humphreys Room
 Mexican Spotted Owl: Mt. Elden Room
 Ponderosa Pine & Hydrology: Kachina

Objectives for three groups include:

- *Identify strategic actions by building on the work of the previous day*
- *Complete Table 2: Identification of Strategic Actions (in participant packet)*
- *Review management objectives*
- *Begin to evaluate level of urgency/priority and identify opportunities for implementation*
- *List research and monitoring needs*

LUNCH: 11:30 – 12:30 PM (PROVIDED IN CANYON ROOM)

12:30 – 4:30 PM

12:30-2:00 Break-out Groups Re-assemble in Kaibab Room and Report Back (Gregg)

- All three groups present/review their priority strategic actions
- Facilitated summary and discussion

2:00-3:00 Opportunities for Strategic Action Implementation: Integrate and evaluate top priority actions considering barriers and key uncertainties, e.g., cost, social, political, regulatory, lack of knowledge, and opportunities for implementation. Mini-breakout groups meet for 10 minutes to discuss barriers and opportunities, followed by report-out and whole-group discussion.

Facilitator: Gregg Garfin

- Outcomes:
 - *Barriers to implementing strategic actions*
 - *Opportunities for overcoming barriers to implement the actions*
 - *If time is available, include lead agency and timeline*

BREAK: 3:00 – 3:15 PM

3:15-4:00 Facilitated Discussion on Emerging Themes, Implementation & Next Steps
Facilitator: Rob Marshall

Outcomes:

- *What strategies might apply to all targets?*
- *What work planned or underway will be affected by climate change?*

4:10-4:20 Workshop Summary, Outcomes and Next Steps: Patrick McCarthy

4:20-4:30 Closing Remarks: Edward Smith, Workshop Organizer

PLEASE COMPLETE EVALUATION FORM!! THANK YOU!!

WORKSHOP ADJOURNS: 4:30 PM

Appendix C Future Climate Scenarios for Northern Arizona

To frame the workshop discussions on the impacts of climate change and to guide development of adaptation strategies, Linda Mearns of the National Center for Atmospheric Research (NCAR) developed two scenarios of climate change, and Seshadri Rajagopal of the University of Arizona developed two scenarios of related hydrological change.

Precipitation and Temperature

Sources of information for constructing the climate change scenarios include: probabilistic information generated using the CMIP3 suite of global climate model results analyzed in the IPCC Fourth Assessment Report (based on Tebaldi et al. 2004, 2005 methods), results from Chapter 11 (Regional Climate Projections) of the IPCC WG1 2007 Report (Christensen et al., 2007), a paper specifically on climate change in the southwest US (Seager et al., 2007) and some results from the NARCCAP Regional Climate Model Simulations (Mearns et al., 2009). The emissions scenario considered in the probabilistic information and in NARCCAP simulations is the A2, a medium high scenario, but for Chapter 11 of IPCC it is the A1B scenario, a lower (middle) emissions scenario. The time period for the future is roughly 2041-2070, compared to 30 years in the current period (1971-2000) for NARCCAP but further out in the century for the CIMIP3 climate model results in IPCC Chapter 11.

The area of Arizona under consideration falls within the area of the Southwest for which qualitative probability statements of changes in precipitation were made in Chapter 11 of the IPCC WG1 Report. These kinds of statements were made only for areas of the world where there were various sources of evidence that pointed to the same kinds of changes. Those sources included: global climate model simulations, regional climate model simulations, trends in observations, and physical understanding of processes governing regional responses. All these sources indicate likely annual mean decreases in precipitation in the 21st century for this region. This is the case regardless of the emissions scenario considered, and the decreases become more severe further out in the 21st century one goes. Seager et al., (2007) provides a detailed analysis of this mean precipitation decrease from the CMIP3 models analyzed in the IPCC Fourth Assessment Report. In general terms it is likely for Arizona that annual precipitation will decrease on the order of 15%. However, how this would be distributed seasonally remains somewhat unclear. From the IPCC global climate model results, decreases appear to commonly occur in winter and spring, but there is less model agreement about change in summer. Temperature change in summer would likely be larger than in winter, about 2.5 °C in winter and 3.5 °C in summer.

The general framework for the two detailed scenarios presented below are quantiles of the probability distributions for temperature change (°C) and precipitation change (%) for annual and seasonal values for an area covering all of Arizona for the A2 emissions scenario. The quantiles are developed from probabilistic summaries of all the global climate model results used in the IPCC Fourth Assessment Report. However, input from the other sources cited above is also taken into consideration. The 25th and 75th quantiles from these distributions are presented below to give the reader a sense of the spread across the model simulations.

Table 3 Total annual and seasonal changes in temperature and precipitation for all scenarios modeled as captured between the 25th and 75th quantiles from model runs to about 2060.

Quantiles	25 th	75 th
Annual Changes		
Temperature °C (°F):	2.1 (3.8)	3.0 (5.4)
Precipitation (% change)	-18	+3
Winter		
Temperature	1.6 (2.8)	2.6 (4.7)
Precipitation (% change)	-12	+10
Spring		
Temperature	2.2 (4.0),	3.2 (4.3)
Precipitation (% change)	-35	-15
Summer		
Temperature	2.4 (4.3)	3.4 (6.1)
Precipitation (% change)	-15	+17
Fall		
Temperature	2.4 (4.3)	3.2 (5.8)
Precipitation (% change)	-18	+9

Moderate climate change scenario

For the moderate climate change scenario, annual precipitation decreases by 14 % and annual temperature increases by 2° C by about 2060. These values are based on results from the Japanese MRI and Australian CSIRO global climate models, which tend to fall around the 50th percentile of the changes in temperature and precipitation.

Seasonal changes are the following:

Table 4 Moderate climate scenario changes for temperature and precipitation.

	Temperature (°C)	Precipitation (% Change)
Winter	1.3	-13
Spring	1.8	-16
Summer	2.5	- 8
Fall	2.5	-24

Extreme climate change scenario

In the extreme scenario the decreases in precipitation are much more pronounced, and temperature changes are larger. On an annual basis precipitation decreases by 25% and temperature increases by 3.4 °C. Decreases in precipitation in spring and summer are on the order of 35%, while temperature increases are around 4.0 °C in summer and 3.0 °C in spring. Precipitation decreases by 25% in fall when temperatures increase by 2.8 °C. In winter precipitation decreases by 14% as temperatures rise by 3.5°C. The combined higher temperatures and large precipitation decreases in critical seasons makes for a very difficult future climate. The details of this scenario are based on the French IPSL global climate model simulations. The results of this model fall around the 90th percentile of the probability

distribution for change in temperature (large increase) and the 10th percentile for change in precipitation (large decrease).

Table 5 Extreme climate scenario changes for temperature and precipitation.

	Temperature (°C)	Precipitation (% Change)
Annual	3.4	-25
Winter	3.5	-14
Spring	3.0	-35
Summer	4.0	-35
Fall	2.5	-25

Table 6 ‘Alternate’ climate scenario changes for temperature and precipitation.

	Temperature (°C)	Precipitation (% Change)
Annual	2.5	-6
Winter	2.1	-18
Spring	2.6	-17
Summer	2.6	+13
Fall	2.5	-22

Sample results of a regional climate model scenario

The four plots presented here show sample results from one regional climate model (the Canadian RCM, CRCM), run at 50 km resolution, nested in one global climate model (the Canadian global model, CGCM3) with a horizontal resolution of about 250 km. The emissions scenario used is the A2. Thirty years of the present (1971-2000) and thirty years in the future (2041-2070) were simulated. The Figure 3 shows the annual time series of temperature for both time periods for roughly the Four Forest Restoration Initiative area of Arizona. A clear upward trend is exhibited in the current and future time periods, and the mean temperature increase in the future is about 2.7 °C (4.9°F). Figure 4 shows the same results for simulated annual precipitation for the current and future periods. Neither time series exhibits a distinct trend, but a mean annual decrease in precipitation in the future of 3% is found. The last two figures (Figure 5 and Figure 6) show changes in summer precipitation in the southwest US from the global model (CGCM3) and the change from the regional model (CRCM), which was nested in the global model. The same broad pattern of change is seen in both, but the regional model exhibits an intensification of the precipitation decreases in a more complex pattern. The changes in the global model are naturally coarser but less intense. In the North American Regional Climate Change Assessment Program (NARCCAP) we are working to determine which results (here the global vs. the regional model) are more credible. This is important since adapting to a climate with about a 20 % decrease in precipitation would be rather different from adapting to a more extreme climate change of around a 40% decrease in precipitation in central/northern Arizona in summer.

CRCM+CGCM3 Spatial Avg, Arizona Region

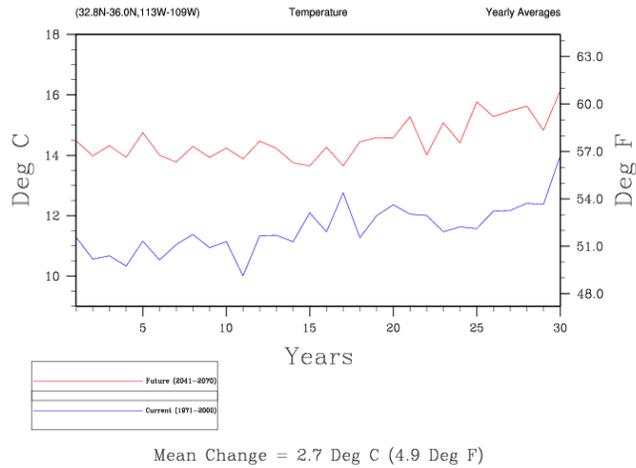


Figure 6 Annual time series of temperature for both the present period (1971-2000) and into the future (2041-2070) for roughly the Four Forest Restoration Initiative area of Arizona. A clear upward trend is exhibited in the current and future time periods, and the mean temperature increase in the future is about 2.7 °C (4.9°F).

CRCM+CGCM3 Change in Seasonal Avg Precip

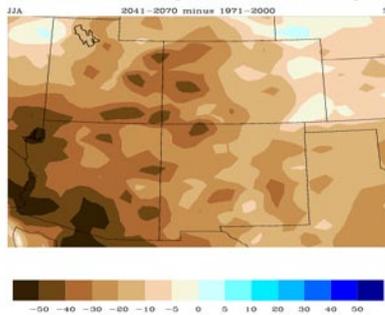


Figure 7 Annual time series of precipitation for the future period (2041-2070) minus the present period (1971-2000). Neither time series exhibits a distinct trend, but a mean annual decrease in precipitation in the future of 3% is found.

CRCM+CGCM3 Spatial Avg, Arizona Region

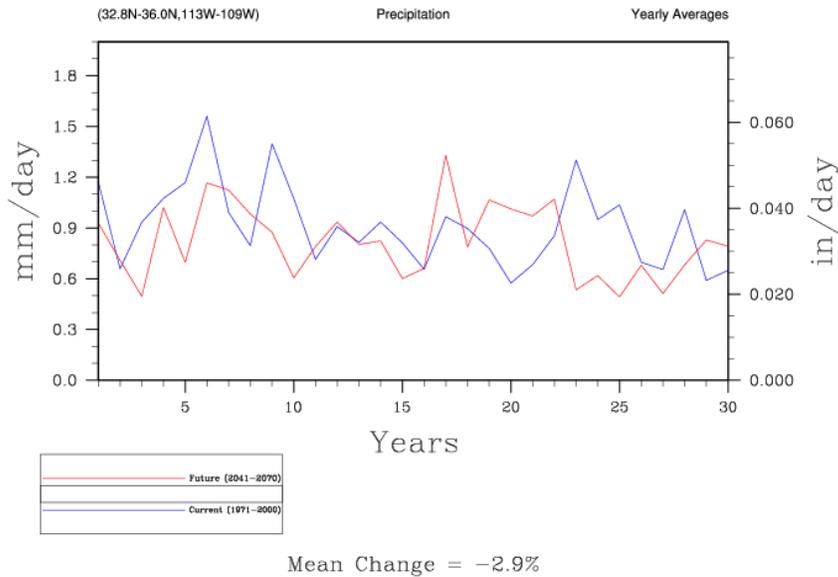


Figure 8 Graph shows changes in summer precipitation in the southwest US from the global model (CGCM3) and the change from the regional model (CRCM), which was nested in the global model. The same broad pattern of change is seen in both, but the regional model exhibits an intensification of the precipitation decreases in a more complex pattern.

CGCM3 Change In Seasonal Avg Precip

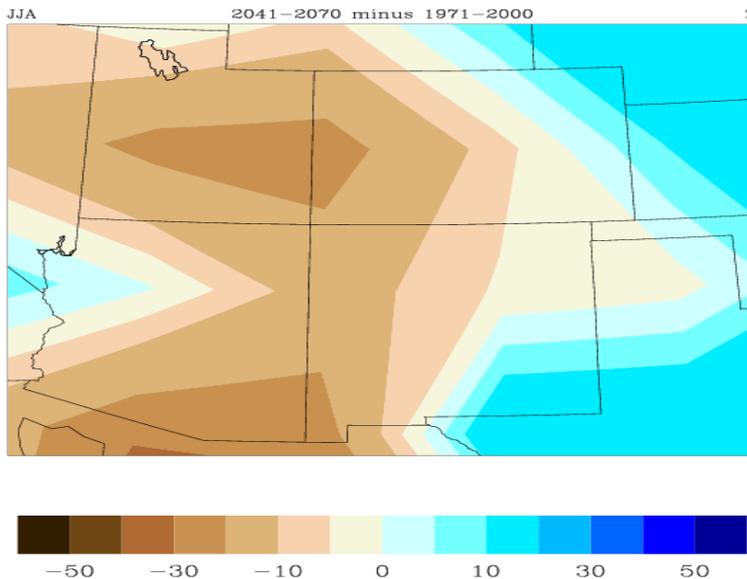


Figure 9 Graph shows changes in summer precipitation in the southwest US from the global model (CGCM3). The same broad pattern of change is seen in both, but the regional model exhibits an intensification of the precipitation decreases in a more complex pattern.

Hydrological Scenarios

The emissions scenarios used for generation of model outputs are circled below:

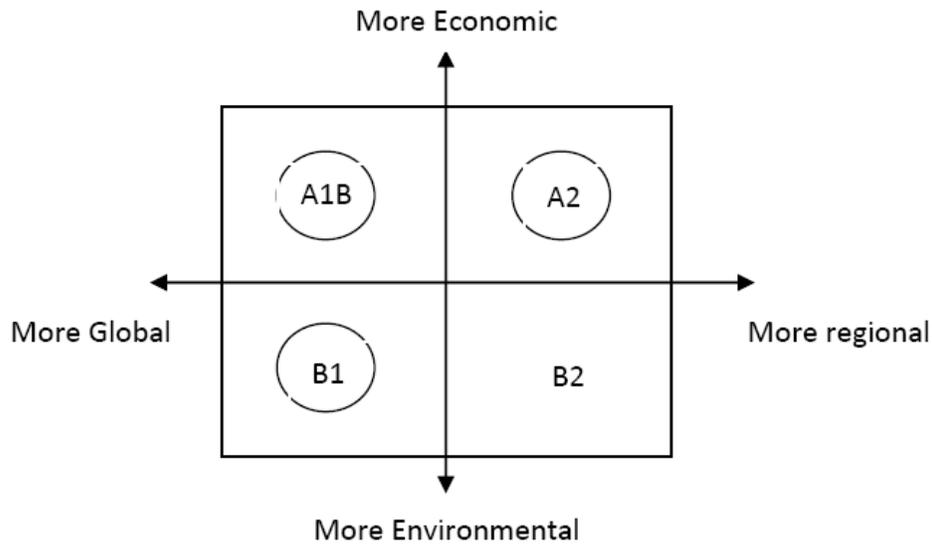


Figure 10 The greenhouse gas emission scenario families as defined by IPCC in the Special Report on Emission Scenarios (SRES; IPCC, 2000).

Overview of models and data used:

Table 7 Global Climate Models and simulation periods used for developing the hydrological scenarios for the workshop

Driving Data (past and future)	Simulation Period	Analysis Period
Observations	1961-2000	1971-2000 (30 years)
UK-HADCM3	1961-2098	2009-2038, 2039-2068, 2069-2098
NCAR-CCSM3	1961-2098	2009-2038, 2039-2068, 2069-2098
MPI-ECHAM5	1961-2098	2009-2038, 2039-2068, 2069-2098

Table 8 Mid-21st Century projections of Salt River streamflow change in percent change from the 1971-2000 mean. A1B, A2, and B1 refer to SRES emissions scenarios; the values in these columns are for the mean of 3 models described in the text (HadCM3, MPI ECHAM 5, NCAR CCSM3). Range refers to individual model runs.

	A1B	A2	B1	Range
Annual	-23.5	-14.5	-9.3	-27.0 to +5.9
Winter	-28.9	-22.9	-13.8	-32.8 to -6.1
Summer	3.6	13.5	4.4	-8.0 to +16.5

Table 9 Mid-21st Century projections of Verde River streamflow change in percent change from the 1971-2000 mean. A1B, A2, and B1 refer to SRES emissions scenarios; the values in these columns are for the mean of 3 models described in the text (HadCM3, MPI ECHAM 5, NCAR CCSM3). Range refers to individual model runs.

	A1B	A2	B1	Range
Annual	-21.3	-7.2	-5.5	-21.3 to +6.5
Winter	-27.3	-18.9	-9.4	-29.6 to +3.7
Summer	8.3	33.7	10.0	-6.6 to +37.0

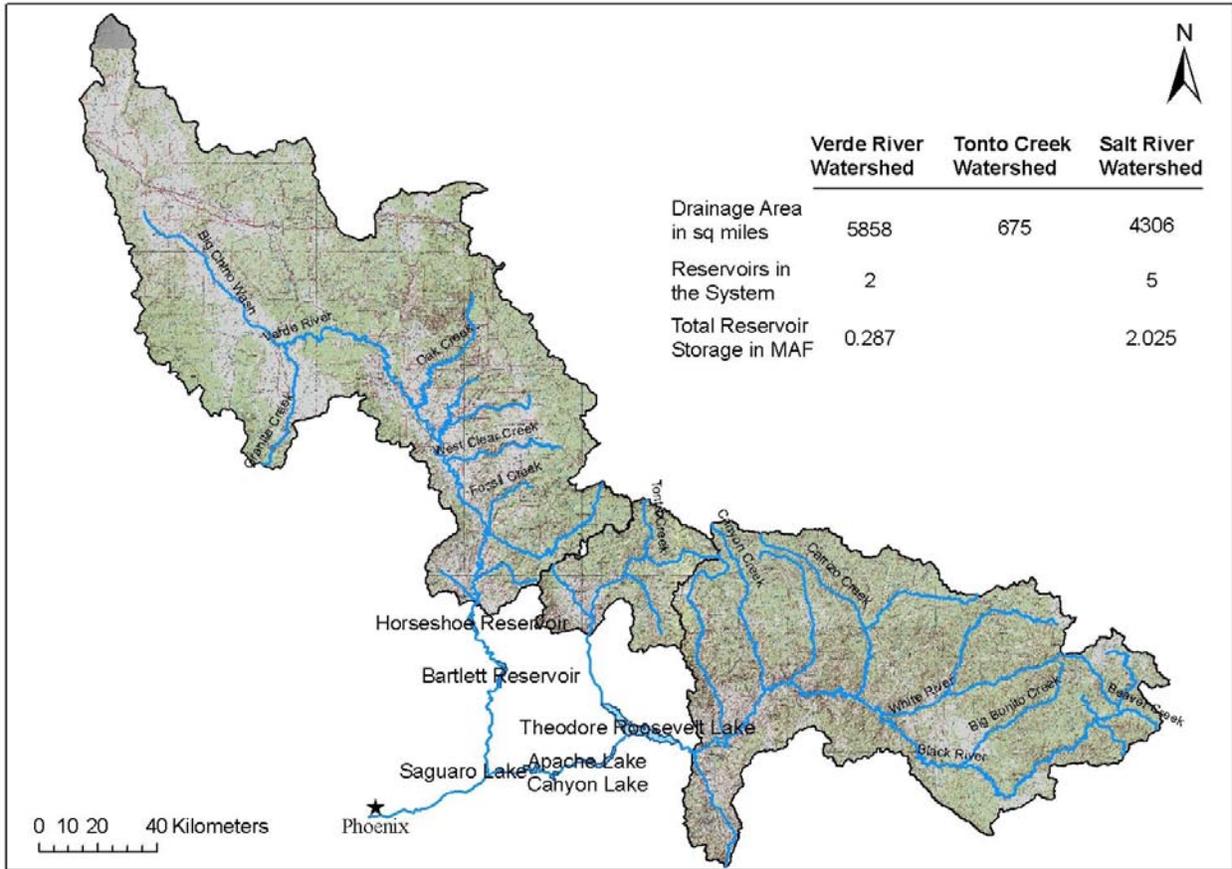


Figure 11 Map of watersheds affected by climate change scenarios within the 4FRI area.

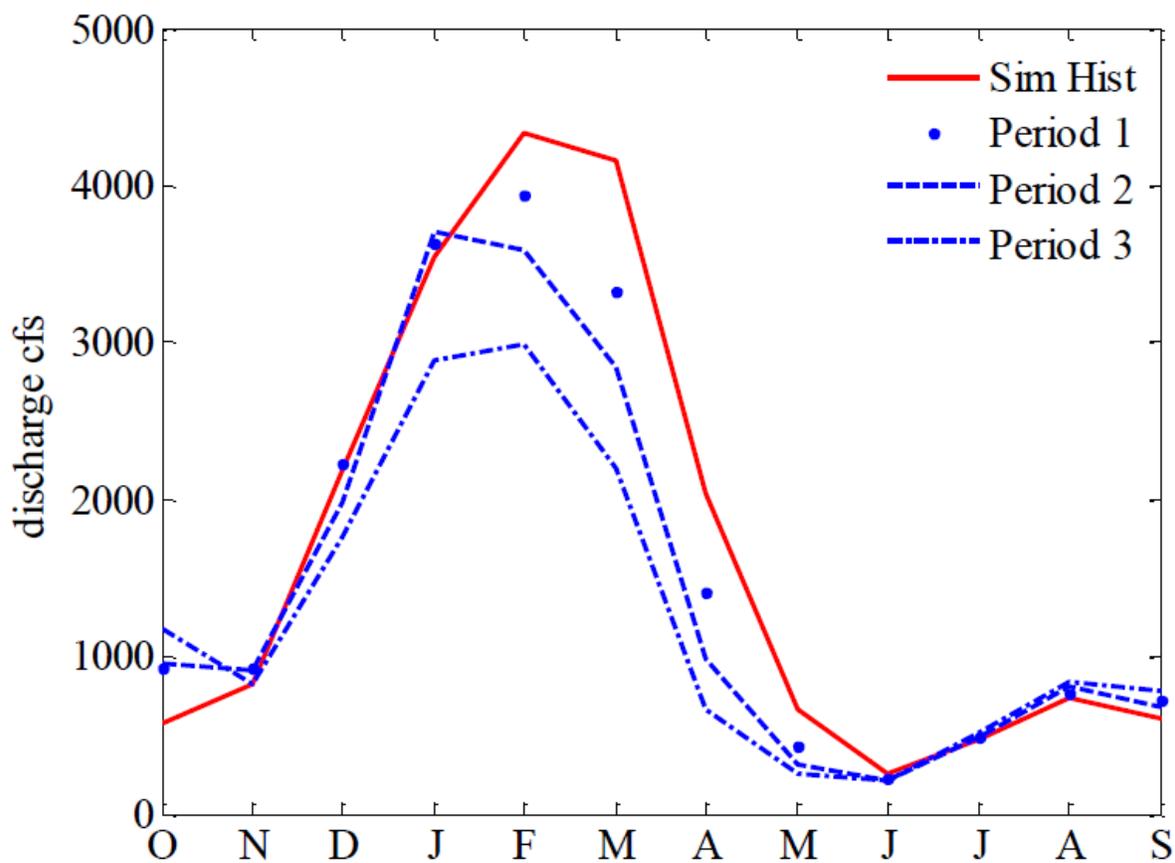


Figure 12 Annual hydrograph of Salt River streamflow for the model-simulation of 1971-2000 (Sim Hist), 2009-2038 (Period 1), 2039-2068 (Period 2), and 2069-2098 (Period 3). The overall volume of annual flow declines with each successive future period, and the timing of peak runoff shifts to earlier months.

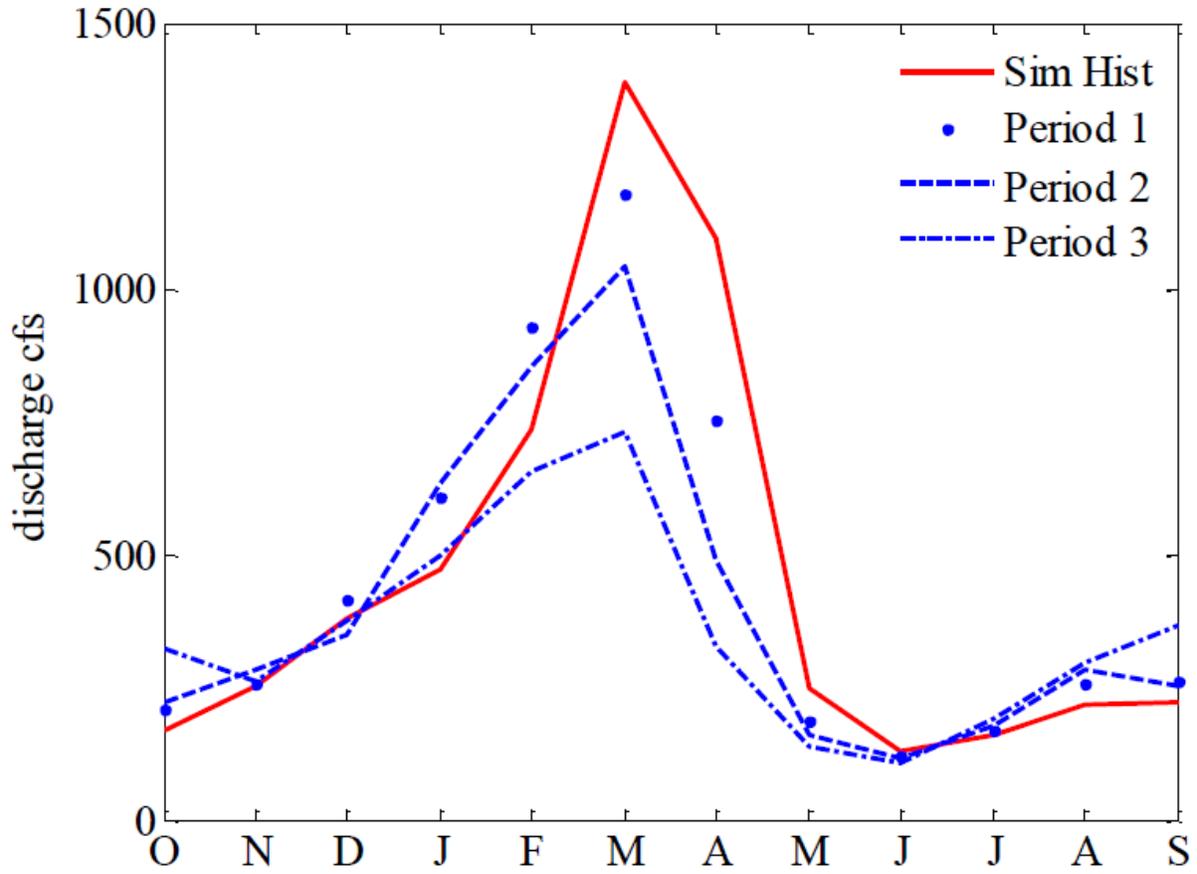


Figure 13 Annual hydrograph of Verde River streamflow for the model-simulation of 1971-2000 (Sim Hist), 2009-2038 (Period 1), 2039-2068 (Period 2), and 2069-2098 (Period 3). The overall volume of annual flow declines with each successive future period; however, the timing of peak runoff remains in March.

Appendix D1 Climate Change Impacts (Hypotheses of Change) for Ponderosa Pine Fire Regime

Table 10 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on Ponderosa Pine Fire Regime Conservation Feature for two climate scenarios.

Key Climate-Influenced Drivers/Effects (e.g., Physical, Ecological, Social, Economic)	Observed & Projected Climate Change Impact ¹ (i.e., Hypotheses of Change)	Likelihood ² /Severity ³ of Climate Change Impact		Comments, Notes, Sources
		Scenario #1: Moderate Change	Scenario #2: Extreme Change	
Drought	Warmer temperatures and decreased precipitation will increase drought frequency, duration and severity. (S1&S2)	Very likely/moderate severity	Virtually certain/high severity	
Drought-induced changes in coarse woody debris (CWD) and canopy fuel loads	Increased drought will increase PIPO mortality, leading to a near-term (next few decades) increase in CWD fuel loads, and a decrease in currently high canopy fuel loads. Longer term changes in CWD and canopy fuel loads depend on fire recurrence and intensity (S1&S2)	Likely/Moderate severity	Likely/Moderate severity	
Drought-induced changes in fine fuels	Increased drought will decrease the productivity of understory vegetation which will decrease the availability of fine fuels in the near term (next few decades); in the longer term, decreased PIPO canopy cover will likely lead to increased understory and increased fine fuel loads. (S1&S2) Under Scenario 2, fine fuels may be dominated by early successional, fire-adapted species (e.g., exotic invasives). (S2)	Likely/Moderate severity	Likely/Moderate severity	
Bark beetle-induced changes in fuel loads	Warmer temperatures and increased drought will likely increase bark beetle outbreaks because they will be able to reproduce multiple times in a year and PIPO hosts will be drought-stressed. Increased bark beetle outbreak will likely have similar effects on fuel loads as drought-induced PIPO mortality (see above), although in the longer-term there may be a sufficient decrease in the availability of PIPO hosts to begin to reduce the risk of bark beetle outbreaks. (S1&S2)	Likely/Moderate severity	Likely/Moderate severity	
Risk of uncharacteristic (high severity) wildfire in PIPO	Warmer temperatures and decreased precipitation will increase the risk of uncharacteristically severe fires, even if ENSO frequency does not change. (S1&S2)	Likely/High severity	Very likely/High severity	

Fire season length	Decreased precipitation in winter and spring will shift fire season earlier, and lead to a longer fire season (this shift is already being observed). (S1&S2). Under Scenario 2, a greatly reduced monsoon will lead to a much longer fire season. (S2)	Very likely/high severity	Very Likely/Very high severity	
Fuel moisture	Increased drought, warmer temperatures and decreased precipitation will lead to drier fuels, thereby increasing fire frequency, intensity and severity. (S1&S2)	Very likely/High severity	Virtually certain/High severity	
Wind	It is unknown how wind will change under either of the scenarios, but if wind were to increase it would exacerbate the other effects of changing climate on fire frequency, intensity and severity (by increasing the chance that fires will spread once started and drying out fuels). If wind were to decrease, it would somewhat lessen the effect of warmer and drier conditions on fire, but it is not likely that it would decrease enough to reverse the effects of the scenarios on fire. (S1&S2)	Uncertain/Potentially high severity if winds were to increase	Uncertain/Potentially high severity if winds were to increase	Linda Mearns has volunteered to look into existing projects that are trying to estimate how wind may differ under various climate change scenarios.
Native understory vegetation	Decreased precipitation in both the winter and summer will negatively affect both cool-season C3 plants and warm-season C4 plants, although early successional and drought- and fire-adapted native species may increase. (S1) Under Scenario 2, we expect big changes to the understory plant community -- decreased productivity of non-drought tolerate species, changes in species assemblages, potential increases in drought- and fire-adapted species. (S2)	Likely/Moderate severity	Likely/High severity	
Exotic invasive plants	We expect many drought- and fire-adapted exotic invasive species to increase. (S1) Even greater invasion of exotics under Scenario 2 (S2).	Uncertain/Potentially moderate severity	Uncertain/Potentially high severity	Need more information on the impacts of these scenarios on specific exotic invasive species.
Cattle grazing effects on understory vegetation and fuel loads	Decreased precipitation makes managing cattle grazing impacts on understory vegetation and fuels more complicated since there may be changes to forage quantity and quality. (S1) Under Scenario 2, impacts of drought on understory vegetation may influence grazing management. (S2)	Uncertain/Low severity	Uncertain/Moderate severity	
Wild ungulate (e.g., elk, deer) grazing and browsing effects on understory vegetation and PIPO	Decreased precipitation makes managing wild ungulate impacts on understory vegetation and PIPO trees more complicated since there may be changes to forage quantity and quality. (S1) Under Scenario 2, impacts of drought on understory vegetation will likely influence grazing/browsing wildlife abundances and distributions. (S2)	Uncertain/Low severity	Uncertain/Moderate severity	

¹ Indicate Scenario (see description in heading) the impact applies to: “S1” = Scenario #1 only, “S2” = Scenario #2 only, or “S1+S2” = both.

² Likelihood of Impact: Virtually Certain, Very Likely, Likely, and Uncertain (see “Definitions” document in packet).

³ Severity of Impact: Very High, High, Medium, Low (estimates based on expert knowledge).

Appendix D2 Climate Change Impacts (Hypotheses of Change) for Ponderosa Pine Watershed Function

Table 11 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on Ponderosa pine watershed function for two climate scenarios.

Observed & Projected Climate Change Impact (Hypotheses of Change)	Intervention Point	Scenario #1 Strategic Action (Planning Horizon: 10-15 years)	Scenario #2 Strategic Action (Planning Horizon: 10-15 years)
<p>More frequent & severe fire. (S1&S2)</p> <p>Increased drought-induced tree mortality due to soil moisture stress and stress caused by insects and disease. This will lead to decreased canopy cover, reduced tree density of trees & changes in the understory. In short-term, increased herbaceous cover & reduction in tree water use leads to greater fraction of <i>available</i> water going to recharge. Also expect reduced baseflows and increased water temperatures. (S1)</p> <p>More widespread effects in species composition that are amplified in time & space (S2)</p> <p>Increased temperature leads to increased potential-ET (PET) and thus decreased recharge. This leads to increase moisture stress for plants across system. In riparian systems this will translate</p>	<p>Fire management</p> <p>Forest/vegetation management</p>	<p>1st Priority Strategic Actions.</p> <p>Apply restoration treatments including thinning, prescribed burns & resource benefit fires to reduce fire risk & drought induced tree mortality, increase herbaceous ground cover, and enhance infiltration, soil moisture and recharge. Plan for 6-year fire rotation around landscape (HRV) to maintain water yield benefits (maintenance burning)</p> <p>Conduct landscape risk assessment to prioritize areas for treatment; take into account fire risk, soil erosion potential and increased climate-stress levels at lower elevation sites; learn from treatment effects so that lessons may be applied to other parts of landscape; adjust treatments relative to expected changes in vegetation (see research needs).</p>	<p>More aggressively apply restoration treatments & technologies, focusing them on mid- to upper-elevation limits in PIPO</p>

<p>to increase in actual-ET (AET) for plants with access to water, decreasing baseflow (S1 and Alternative moderate scenario)</p> <p>If overstory and understory cover reduced, may have decreased ET as result of reduced transpiration. (S2)</p>		<p>Develop economic uses/markets for wood fiber (biomass, pellets)</p>	
<p>Short-term reductions in vegetation cover due to extreme events leaves soil more vulnerable to erosion --especially after flashier runoff events. Expect decreased soil water capacity, sedimentation of streams, and, ultimately, reduced water quality (S1 & S2)</p>	<p>Roads management</p>	<p>2nd Priority Strategic Actions. To mitigate for increased erosion potential in the watershed, optimize road density for fire, recreation, timber & other resource uses; decommission & restore roads as necessary. Maintain and upgrade existing roads including installation of culverts and hardened stream crossings to reduce runoff, erosion.</p>	
<p>More precipitation delivered as rain than snow. Expect decreased snowpack from rain on snow events, sublimation, & snow melt. Peak stream flows from snowmelt will be earlier and smaller, yet runoff can be variable (& more flashy) depending on rate of snowmelt and rain to snow ratio. This could lead to reduced recharge & lower baseflows; water supply may be lowered in stock tanks & reservoirs. (S1&S2)</p> <p>Effect on downstream users: earlier peak flows (or floods) may force earlier release of water from reservoirs exacerbating already</p>	<p>Snowpack management</p>	<p>3rd Priority Strategic Action. Optimize water quantity & quality by managing forests through selective thinning to increase snowpack accumulation and shading reduce sublimation; install snow fences & plant new trees as living snow fences, as needed.</p>	

lowered water availability. (S1&S2)			
<p>Temperature changes may lead to change in development patterns (urban refugia?).</p> <p>Changing energy policies lead to increased pressure for energy development (including renewable sources such as wind).</p> <p>Reduced water availability can lead to increased impoundments, increased ground water pumping, water importation, more conflicts over water rights. (S1&S2)</p>	<p>Water management (water rights, groundwater pumping, impoundments, policy)</p>	<p>4th Priority Strategic Actions.</p> <p>To mitigate for increasing water demand and reduced supply, procure in-stream flow water rights & other surface water rights. Monitor water quality, quantity w/ groundwater wells, stream gages. Change water policy to recognize connections between surface & ground water</p>	<p>Obtain additional water supplies from Lake Powell to augment existing ones (CO Water Advisory)</p>

Appendix D3 Climate Change Impacts (Hypotheses of Change) for Mexican Spotted Owl

Table 12 Observed and projected climate change impacts (Hypotheses of Change), intervention points, and priority strategic actions identified by participants for reducing climate change impacts on the Mexican Spotted Owl for two climate scenarios.

Key Climate-Influenced Drivers/Effects (e.g., Physical, Ecological, Social, Economic)	Observed & Projected Climate Change Impact ¹ (i.e., Hypotheses of Change)	Likelihood ² /Severity ³ of Climate Change Impact		Comments, Notes, Sources
		Scenario #1: Moderate Change	Scenario #2: Extreme Change	
Change in vegetation type and landscape configuration	Decrease in pine-oak habitat; pine shifting up, and unknown impact on oak; decrease in mixed conifer	High likelihood, high severity	For all projected impacts, no new patterns under Scenario 2, but impacts will carry through model pathways faster and with greater amplification. No agreement on climate-related thresholds of change; if there are climate-mediated ecological thresholds, we are unprepared to identify them at this time.	
Decrease in large live trees; leads to decrease in canopy cover and vertical structure	Decline in roosting and nesting habitat	Very Likely, high severity		
Increase in temperature causes change in understory composition and diversity	Affects foraging habitat, but unsure as to which direction	Likely, but severity level unknown		
Increase in temperature leads to increase in bark beetle outbreaks and tree mortality. Short-term increase in snags and logs. Decrease in vertical structure; decrease in canopy cover, amplifies fire conceptual model pathways. Increase in shrubs and grass.	Overall impact is decline in nesting/roosting habitat	Very likely, high severity		At some unknown point in the future, bark beetle infestations & associated tree mortality may actually decrease because of

				reduction in fuel loads
Size, frequency, and severity of fire will increase	Decrease in nesting/roosting habitat features and structure	Very likely, high severity		At some unknown point in the future, fire size & severity may actually decrease because of reduction in fuel loads
Shifting mosaic of landscape configuration: reduction in patch size, increased distance between patches, and reduction in quality. Declining patch size, increasing fragmentation, reduced connectivity, unknown dispersion.	Overall impact is decline in quality and size of nesting/roosting habitat. decreased MSO demography, increased isolation, increased bottlenecks, and reduction in gene flow	Likely, high severity		
Reduced ungulate populations lead to reduced herbivory	Potential increase in groundcover vegetation for prey and potential release of shrub-form oak to tree-form	Unknown likelihood; other factors could overshadow this impact. Severity level unknown		May be impacting foraging habitat, but that is not the limiting factor for MSO
Reduction in hiding cover and increase in predation from reduction in nesting/roosting habitat characteristics	Direct reduction in population			Increase in Great Horned Owl and Red-Tail Hawk, reduction in Northern Goshawk. Currently is habitat separation between GHO and MSO (40% CC), future unknown

Infrastructure Development (roads, power lines, interstate expansion, wind farms)	Fragments nesting/roosting habitat	Certain; already happening and likely to continue		Several project planned or in development that will impact MSO habitat
Increase in competition of nest/roost sites with a decrease in this habitat type.	Increase predation by Corvids on juveniles. Decline of nesting habitat for MSO			

¹ Indicate Scenario (see description in heading) the impact applies to: “S1” = Scenario #1 only, “S2” = Scenario #2 only, or “S1+S2” = both.

² Likelihood of Impact: Virtually Certain, Very Likely, Likely, and Uncertain (see “Definitions” document in packet).

³ Severity of Impact: Very High, High, Medium, Low (estimates based on expert knowledge).

Appendix E Arizona Climate Change Adaptation Workshop Definitions

1. **Adaptation to climate change:** An adjustment in natural systems in response to a changing climate in order to moderate adverse impacts or capitalize on novel opportunities (IPCC 2007). Adaptation involves anticipating the influence of climate change and using this information to make proactive choices to achieve objectives.
2. **Adaptive capacity:** The ability of a system to adjust, to moderate, to take advantage of, or cope with novel conditions (IPCC 2000). Enhancement of an ecosystem's adaptive capacity reduces the system's vulnerability and/or strengthens its ecological resilience through management or mitigation.
3. **Adaptive strategies:** Actions to take to build resistance build resilience or facilitate the response of natural features to change. For example, improvement in habitat connectivity enables species populations to move to more suitable habitats as the climate changes.
4. **Climate change impacts (hypotheses of change):** Hypotheses or assumptions about how climate change will affect conservation features and their ecological attributes (e.g., *significantly reduced snow pack will alter the spring and summer hydrologic flow regime for a riparian ecosystem*).
5. **Climate projection:** A *projection* of the response of the *climate system* to *emission or concentration scenarios* of *greenhouse gases* and *aerosols*, or *radiative forcing scenarios*, often based upon simulations by *climate models*. Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the emission/concentration/ radiative forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial *uncertainty* (IPCC 2007).
6. **Climate system:** The climate system is the highly complex system consisting of five major components: the *atmosphere*, the *hydrosphere*, the *cryosphere*, the land surface and the *biosphere*, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of *external forcings* such as volcanic eruptions, solar variations and *anthropogenic forcings* such as the changing composition of the atmosphere and *land use change*. (IPCC 2007).
7. **Conceptual ecological model:** Illustration of the climatic, ecological, social and economic factors that affect a selected species or ecosystem. It is a box and arrow diagram that represents relationships, helping planners and managers to understand and communicate impacts of climate change on conservation features.
8. **Downscaling:** Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses. Two main methods are distinguished: *dynamical downscaling* and *empirical/statistical downscaling*. The dynamical method uses the output of regional *climate models*, global models with variable spatial resolution or high-resolution global models. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. The quality of the downscaled product depends on the quality of the driving model (IPCC 2007).

9. **Driver:** An environmental factor that causes a change in an organism, community, ecosystem, or other ecological component of the landscape.
10. **Ensemble:** A group of parallel model simulations used for *climate projections*. Variation of the results across the ensemble members gives an estimate of *uncertainty*. Ensembles made with the same model but different initial conditions only characterize the uncertainty associated with internal *climate variability*, whereas multi-model ensembles including simulations by several models also include the impact of model differences. (IPCC, 2007)
11. **Exposure:** The degree, duration, and/or extent to which a system is in contact with a climatic or other environmental perturbation, often depicted by analysis of historic climate or climate projection data (such as changes in temperature and precipitation).
12. **Feasibility:** Capability of a strategy being implemented, considering ease of implementation, availability of an experienced lead person, institutional support, ability to motivate key constituencies, and ability to secure necessary funds.
13. **Intervention points:** Places in the system that we can influence through management and conservation actions, e.g., *grazing management or invasive species management*.
14. **Mitigation:** A human intervention to reduce the *sources* or enhance the *sinks* of *greenhouse gases* (IPCC 2007).
15. **Objective:** Biological outcomes we are trying to achieve. Quantitative and measurable statement of success for a conservation feature based on its viability or threat reduction, e.g.: *By 2025 ensure good base-flows in summer so that no sections of the Blue River go dry (50-75 CFS) in dry years*.
16. **Realignment:** Used in lieu of restoration; facilitate the establishment of conditions that are outside the Natural Range of Variation (NRV).
17. **Refugia:** Physical environments that are less affected by climate change than other areas and thus offer a refuge from climate change.
18. **Resilience:** Degree to which a system rebounds, recoups or recovers from a disturbance or stimulus. An example of a resilience strategy is to restore riparian areas along streams experiencing increased intensity of drought, helping to maintain water quantity and quality.
19. **Resistance:** Degree to which an ecosystem can resist the influence of climate change and forestall its undesirable effects (adapted from Millar et al. 2007), e.g., *reduce effects of climate change for animals by improving their ability to migrate by creating large management units and broad corridors* (Joyce et al. 2009).
20. **Sensitivity:** Degree to which a system or species is affected by or responsive to climate change.
21. **Strategic actions:** Actions necessary to address the most important impacts of climate change or human responses, e.g., *aggressively manage snowpack with snow fences, cover and shade of snowpack/drifts, or windbreaks*.

22. **Uncertainty:** The degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain *projections* of human behavior. Where uncertainty in specific outcomes is expressed (as in Table 1), the following likelihood ranges are used to express the assessed probability of occurrence (IPCC 2007):

- virtually certain >99%;
- extremely likely >95%;
- very likely >90%;
- likely >66%;
- more likely than not > 50%;
- about as likely as not 33% to 66%;
- unlikely <33%;
- very unlikely <10%;
- extremely unlikely <5%;
- exceptionally unlikely <1%.

Where uncertainty is assessed more quantitatively then the following scale of confidence levels is used to express the assessed chance of a finding being correct:

- very high confidence at least 9 out of 10;
- high confidence about 8 out of 10;
- medium confidence about 5 out of 10;
- low confidence about 2 out of 10; and
- very low confidence less than 1 out of 10.

23. **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 (IPCC 2007). Vulnerability is a function of exposure, sensitivity, and adaptive capacity.

Appendix F Web Resources

ARIZONA CLIMATE CHANGE ADAPTATION WORKSHOP FOR NATURAL RESOURCE MANAGERS OF THE FOUR FORESTS RESTORATION INITIATIVE AREA

Climate Wizard: <http://www.climatewizard.org/>

Southwest Climate Change Initiative:
http://nmconservation.org/projects/new_mexico_climate_change/

The Nature Conservancy in Arizona's Conservation Science Webpage:
<http://www.azconservation.org/>

Southwest Climate Change Initiative Webinar Recordings:
Webinar #1 on 3/26/10
<https://nethope.webex.com/nethope/lsr.php?AT=pb&SP=MC&rID=59197182&rKey=3e874d288e8931a9>

Webinar #2 on 3/31/10:
<https://nethope.webex.com/nethope/lsr.php?AT=pb&SP=MC&rID=59224397&rKey=af8c323b3eb1d398>

Molly Cross' Webinar on the Adaptation Framework:
<https://nethope.webex.com/nethope/ldr.php?AT=pb&SP=MC&rID=59234182&rKey=4a5c701542b307f3>

National Center for Atmospheric Research: <http://www.ncar.ucar.edu/>

USDA Forest Service Research and Development has released an interactive short course that presents current scientific knowledge on adapting to climate variability in wildland management. Titled "Adapting to Climate Change: A Short Course for Land Managers", the course is available as a DVD or online at the Climate Change Resource Center. Please see <http://www.fs.fed.us/ccrc>

CLIMAS was established to assess the impacts of climate variability and longer-term climate change on human and natural systems in the Southwest. Our mission is to improve the ability of the region to respond sufficiently and appropriately to climatic events and climate changes. <http://www.climas.arizona.edu/>.

Arizona Climate Action Initiative (Results of the Arizona Climate Change Advisory Group (created by AZ Executive Order in 2005) Exec Summary and full report has many recommendations. <http://www.azclimatechange.gov/index.html>
Exec Summary: <http://www.azclimatechange.gov/download/O40F9299.pdf>
Agriculture and Forestry Appendix: <http://www.azclimatechange.gov/download/O40F9289.pdf>

Global Change Research Program: <http://www.globalchange.gov/>

Interagency reports (include Dept of Ag, Dept of Interior, and many others)

Regional sections include fact sheets and fuller reports – including connections to other identified issues like Biodiversity, Fire, Economics, etc.

Southwest page:

<http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climatechange-impacts/southwest>

Southwest Report:

<http://www.globalchange.gov/images/cir/pdf/southwest.pdf>

<http://www.epa.gov/climatechange/effects/forests.html>

The Nature Conservancy's Global Climate Change Program:

<http://www.nature.org/initiatives/climatechange/>

The Council of Western State Foresters has a webpage with many climate change resources:

<http://www.wflccenter.org/climate.php>

USFS strategy (primarily about research)

<http://www.fs.fed.us/climatechange/documents/global-change-strategy.pdf>

Educational Toolkit (multi agency educational materials)

<http://www.globalchange.gov/resources/educators/toolkit>

Appendix G Rocky Mountain Research Station Vulnerability Assessment for Mexican Spotted Owl



Vulnerability of the Mexican Spotted Owl to Climate Change

Megan Friggens, Deborah Finch, Karen Bagne and Sharon Coe

Background: The RMRS has developed a method for assessing the relative risk to persistence of individual species under projected changes in temperature, precipitation, and related climate phenomena. The RMRS assessment consists of a scoring system focused on simple predictive criteria for terrestrial vertebrate species and was specifically designed to be applied by managers. The assessment is based upon 25 species traits that are believed to reflect the potential impacts of climate change on the ability of individual species to survive and reproduce. We used the RMRS assessment tool to identify the potential threats of climate change to Mexican Spotted Owl populations in the Four Forest focus area.

Climate Projections: The southwestern United States is expected to experience relatively large temperature increases and specific predictions for the region include an increase in the severity and duration of drought periods, more heat waves, greater variation in precipitation, increased wildfires and insect outbreaks, and increased evapotranspiration and salinization. Within the Four Forest focus area, vegetation models predict a loss of Montane mixed conifer forest and woodland habitat and a substantial increase in desert scrub habitat over the next 50 years.

Table 1. Vulnerability Scores for the Mexican Spotted Owl.

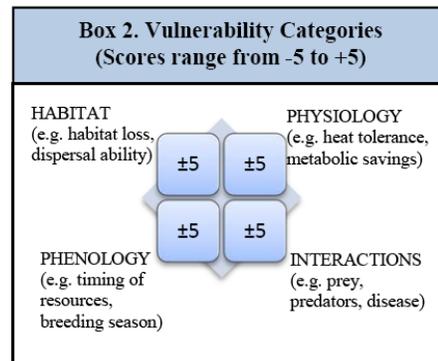
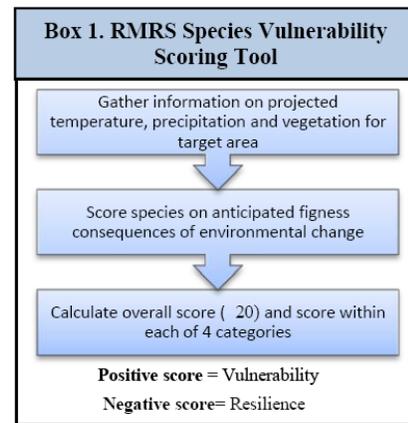
Habitat	1.9
Physiology	2.1
Phenology	-0.4
Interactions	1.0
Overall	6.3

Key Vulnerabilities and Resilience

Habitat: Preferred habitat (Mixed Conifer & Pine Oak Forest) will decrease under warmer conditions and large trees/snags necessary for nesting are likely to decrease with increases in catastrophic fire. Use of static cliff crevices may also create issues if ideal foraging grounds shift away. However, this species is able to travel large distances and can readily colonize new areas, which may mitigate some of the habitat changes in the short term.

Physiology: Spotted Owls are relatively intolerant of high temperatures and lack metabolic (torpor) and behavioral (caching) mechanisms for energy savings. **Phenology:** Mexican spotted owls typically produce only 1 clutch/year which limits their resilience to variable conditions. However, this species does not migrate long distances and, thus, is less prone to some of the phenological consequences of warming trends. **Biotic**

interactions: Prey abundance affects juvenile and adult survivorship. However, it is not clear how the prey base (small mammals) may respond to climate warming. *Mexican woodrats* are only slightly vulnerable (score = 3.1) and *Peromyscus maniculatus* are neutral (score near 0) to climate change affects in these forests. Though these species are more abundant in montane forests, they also appear to do well in early seral stage forest habitat, have several physiological advantages, are opportunistic breeders and have no phenology issues. Common predators of the Mexican spotted owl show neutral (Great Horned owl, score = 0.5) or moderate vulnerability (Goshawk, score= 6.3) to climate change, but it is not clear that this interaction is limiting to the persistence of the Mexican Spotted Owl. **Conclusion:** The Mexican Spotted owl appears to be moderately sensitive to projected climate



changes. Though the Spotted Owl does not possess all vulnerability traits, those that were an issue (e.g. habitat loss) are likely to be detrimental to the persistence of the species.