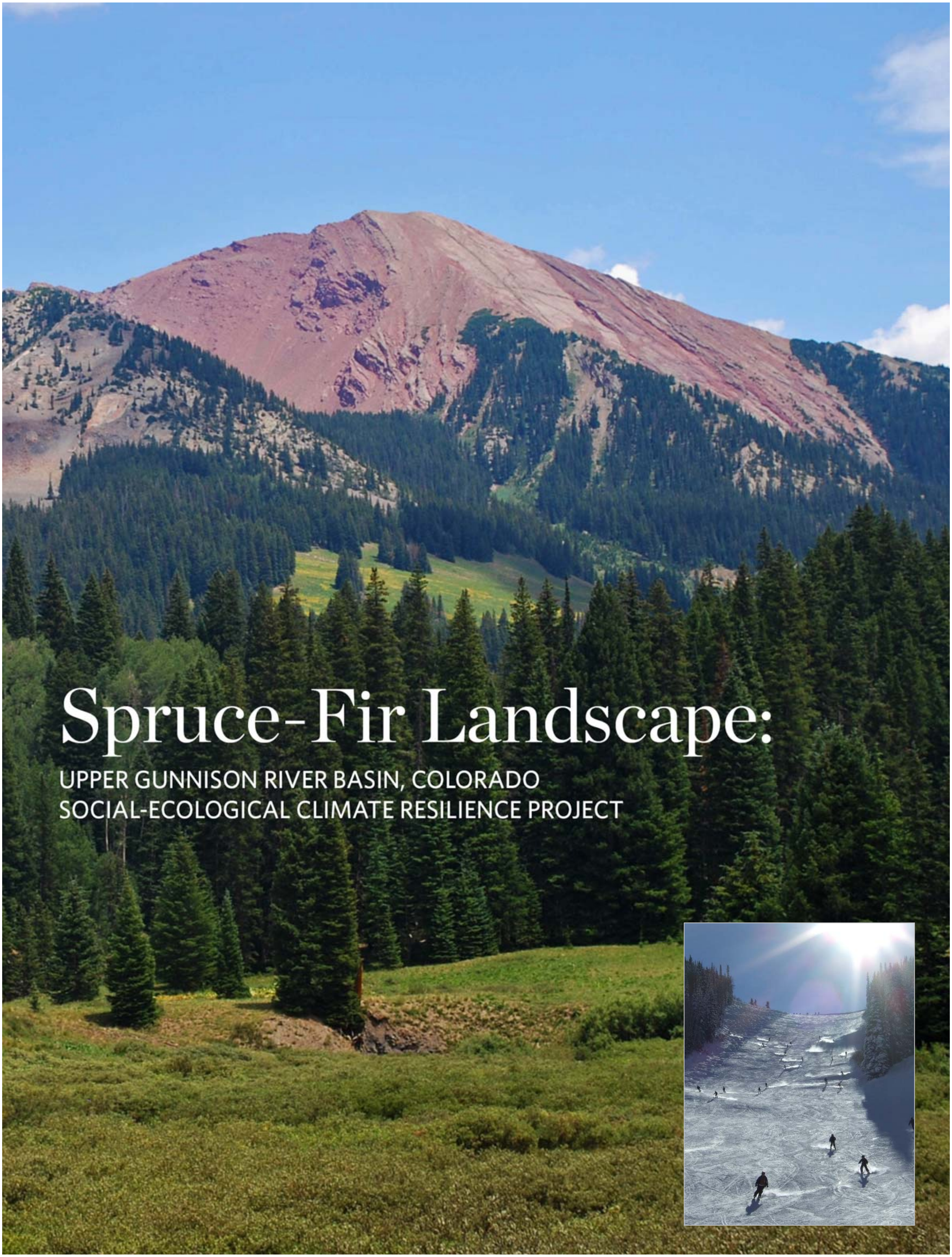
Spruce-Fir Landscape:

UPPER GUNNISON RIVER BASIN, COLORADO
SOCIAL-ECOLOGICAL CLIMATE RESILIENCE PROJECT



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For the
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Spruce-Fir Landscape:
Upper Gunnison River Basin, Colorado
Social-Ecological Climate Resilience Project

EXECUTIVE SUMMARY

Climate change is already having impacts on nature, ecosystem services and people in southwestern Colorado and is likely to further alter natural landscapes in the coming decades. Understanding the potential changes and developing/implementing adaptation strategies can help ensure that natural landscapes and human communities remain healthy in the face of a changing climate.

An interdisciplinary team, consisting of social, ecological and climate scientists, developed an innovative climate planning framework and applied it with the Gunnison Climate Working Group and other stakeholders in the Upper Gunnison River Basin to develop adaptation strategies for two significant landscapes, spruce-fir forests and sagebrush shrublands, under three future (2020-2050) climate scenarios. This report summarizes the planning framework and results for the spruce-fir landscape (see separate report for sagebrush results). This framework can be utilized to develop strategies for other landscapes at local, state, and national scales.

Diagrams, narrative scenarios and maps that depict climate scenarios and the social-ecological responses helped portray the climate story in the face of an uncertain future. Interviews and focus groups with managers, agency staff and stakeholders, users of the spruce-fir landscape, provided important context and to improve the planning process for developing strategies that meet both social and ecological needs.

Utilizing the climate stories to understand the impacts to social and ecological landscapes, the team worked with stakeholders to develop three overarching landscape scale adaptation strategies for the spruce-fir landscape. Each of these strategies has a suite of potential actions required to reach a desired future condition.

The two primary disturbances of concern that are likely to be exacerbated by climate change in the spruce-fir forest are wildfire and insect outbreaks; the impacts of greatest concern to this landscape are altered fire regime and altered species composition. The three key strategies developed through this project to address these and other climate impacts are: 1) identify and protect climate refugia sites (persistent areas), 2) maintain or enhance the resilience of the climate refugia sites, and 3) accept, assist, and allow for transformation in non-climate refugia sites.

If adopted by the local community, including land managers and landowners, the framework and strategies resulting from this project can help to reduce the adverse impacts of climate change, allowing for a more sustainable human and natural landscape.

ACKNOWLEDGEMENTS

This project would not have been possible without the participation of the Gunnison Climate Working Group, an informal public-private partnership that has been working since 2009 to prepare for change in the Upper Gunnison River Basin. We particularly thank Andrew Breibart and Brian Stevens (Bureau of Land Management), Jonathan Coop (Western State Colorado University), Frank Kugel and George Sibley (Upper Gunnison River Water Conservancy District), Jonathan Houck (Gunnison County), Michael Battaglia (US Forest Service Rocky Mountain Research Station), Carol Howe, Matt Vasquez, Clay Speas, Matt Bienkowski, Gretchen Fitzgerald and Jim Worrall (US Forest Service), Amy Seglund (Colorado Parks and Wildlife), and Mike Babler (Teocalli Consulting LLC) for continued participation and expertise throughout this project. We thank the many stakeholders, agencies and representatives of the academic community who participated in interviews, focus groups, and series of workshops almost three years, and who reviewed products and reports.

We greatly appreciate funding, programmatic and technical support from the Department of Interior's (DOI) North Central Climate Science Center in Ft. Collins, Colorado. Special thanks to Jeff Morisette and his staff at the North Central Climate Science Center for helping to assemble the great team that it took to accomplish this project. We particularly thank our Principal Investigator Nina Burkardt (US Geological Survey) and Rudy Schuster (US Geological Survey) for guiding this project. We appreciate the technical support of cooperators on this project: Shannon McNeeley and Dennis Ojima (North Central Climate Science Center), John Sanderson (The Nature Conservancy), and Molly Cross (Wildlife Conservation Society). We thank Molly Cross for advising the team at strategic steps. We thank Dan Williams (USFS Rocky Mountain Research Station) and Dan Murphy (University of Cincinnati) for providing technical advice on the social section aspects of this project. We also thank the USFS Rocky Mountain Research Station for providing financial support for social science expertise on this project.

Karin Decker (Colorado Natural Heritage Program) formatted this report and developed the figures. Kristen Ludwig and Teresa Stoepler (US Geological Survey) developed the *Chains of Consequences*. Imtiaz Rangwala, Western Water Assessment and NOAA, developed the climate scenarios. Terri Schulz (The Nature Conservancy) developed the Ecological Response Models, *Situation Diagrams*, and *Results Chains*. Special thanks to Marcie Bidwell (Mountain Studies Institute), who co-led a parallel effort in the San Juans, for working with us on project planning, methods and workshops.

Special thanks to Jim Worrall (US Forest Service), for providing the bio-climatic models, and to Jonathan Coop (Western State Colorado University), Jim Cochran (Gunnison County), and Ken Stahlnecker (Curecanti National Recreation Area and Black Canyon of the Gunnison National Park) for providing meeting space for workshops. Thanks to Ken Stahlnecker and Brian St. George (Bureau of Land Management) for providing early support and inspiration for this project. Thanks to Bill Travis (University of Colorado) for his assistance on the original proposal and for mentoring Katie Clifford on the social science component of this project.

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ACRONYMS

ACT	Adaptation for Conservation Targets Planning Framework
BLM	Bureau of Land Management
CNHP	Colorado Natural Heritage Program
COSF	Colorado State Forest Service
CPW	Colorado Parks and Wildlife
CSU	Colorado State University
CU	University of Colorado- Boulder
DOI	Department of Interior
GCWG	Gunnison Climate Working Group
GMUG	Grand Mesa, Uncompahgre and Gunnison National Forest
MSI	Mountain Studies Institute
NCCSC	North Central Climate Science Center
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
RCP	Reflective Concentration Pathways
RMBS	Rocky Mountain Biological Station
SECR	Social-Ecological Climate Resilience Project
TNC	The Nature Conservancy
UM	University of Montana
USFS	United States Forest Service
USFS RMRS	United States Forest Service Rocky Mountain Research Station
UGRWCD	Upper Gunnison River Water Conservancy District
USGS	United States Geologic Survey
US	United States
WCS	Wildlife Conservation Society
WSCU	Western State Colorado University
WUI	Wildland Urban Interface
WWA	Western Water Assessment

INTRODUCTION

Environmental change is a constant feature of natural resource management in the western US. Fire, drought, insect infestations, and invasive species present pervasive challenges to conservation and management. Southwestern Colorado is already experiencing higher temperatures, more frequent and prolonged drought, earlier snowmelt, larger and more intense wildfires, more extreme weather events, and spread of invasive species (Saunders et al. 2008; Rangwala et al. 2010; and Lukas et al. 2014). These changes are expected to intensify as a result of climate change, putting livelihoods, ecosystems, public lands and species at risk.

Climate change poses significant challenges for both ecological systems, human communities and natural resource managers in Southwestern Colorado. Resource managers need to consider climate change in management decisions and long-term planning. Yet, while they are increasingly being tasked to incorporate climate change into planning and management, many barriers and challenges exist that complicate integrating climate information and producing robust adaptation strategies. Climate change information is often available at a coarse spatial scale and projected over long time periods with a large spread in the projections between the different climate models. This makes it difficult for managers to integrate climate change into local management plans which often have shorter time horizons. Furthermore, the uncertainty of how climate will change in hard-to-model mountainous landscapes increases the difficulty of this task.

To address these challenges, a team of social, natural and climate scientists and planners worked for almost three years with the Gunnison Climate Working Group [1] (GCWG), a public-private partnership working to prepare for change in the Gunnison Basin, and other stakeholders on this collaborative effort to develop practical adaptation strategies for selected systems in the Gunnison Basin. The GCWG consists of natural resource management agencies, non-profit organizations, university professors, local government officials and other stakeholders. The team was led by the Colorado Natural Heritage Program (CNHP), The Nature Conservancy (TNC), University of Montana (UM), and U.S. Geological Survey (USGS). A second team led by Mountain Studies Institute and CNHP completed a similar effort in the San Juan Basin focused on pinyon-juniper woodlands and seeps and springs.

The goal of this project was to facilitate climate change adaptation that contributes to social-ecological resilience, ecosystem and species conservation, and sustainable human communities in southwestern Colorado. This collaborative effort has developed and piloted an integrated adaptation planning framework, consisting of tools and principles that merge the strengths of the iterative scenario process (Murphy et al. 2016), Stein et al. 2014, the Adaptation for Conservation

[1] Gunnison Climate Working Group Members: Bureau of Land Management-Gunnison Field Office, Colorado Natural Heritage Program; Colorado Parks and Wildlife, Curecanti National Recreation Area and Black Canyon of the Gunnison National Park, Gunnison Conservation District, Gunnison County, Gunnison County Stockgrowers Association, Gunnison Conservation District, Lake Fork Valley Conservancy, Natural Resources Conservation Service, Rocky Mountain Biological Lab, The Nature Conservancy, Upper Gunnison River Water Conservancy District, US Fish and Wildlife Service, US Forest Service, Western State Colorado University, and Western Water Assessment.

Targets (ACT) planning framework (Cross et al. 2012), institutional analysis, and climate change modeling.

The framework was used to generate practical strategies and scientific knowledge to advance climate change adaptation in the Gunnison and San Juan Basins and, potentially, other landscapes. A key objective of this project was to work with decision-makers to develop social-ecological adaptation strategies and actions to reduce the impacts of a changing climate on nature and people. To accomplish this objective, the project blended science (biophysical and social) with participatory approaches to integrate expert knowledge, land management decision making, and local needs

For the purposes of this project, an adaptation target is a feature (livelihood, species, ecological system, or ecological process) of concern that sits at the intersection of climate, social and ecological systems (adapted from Cross et al. 2012). Resilience is the capacity of a system to absorb disturbance and continue to retain its basic function and structure. Resilience strategies may include managing for the persistence of current conditions, accommodating change, or managing towards desired new conditions (Department of Interior NPS, 2016). Transformation is the expectation and acceptance that a conversion to a new ecosystem type is likely to occur. Transformation strategies support and facilitate system changes to an altered state based on a predicted future climate. These and other terms are defined in the glossary (Appendix A).

The intended audience for this report is the implementers of the adaptation strategies – the stakeholders and partners who participated in the project process for almost three years: natural resource managers, non-profit organizations, local officials, local community members, and others.

Project Objectives

1. Build knowledge of social-ecological vulnerabilities to inform adaptation planning.
2. Create social-ecological scenarios and models to facilitate decision-making under uncertainty.
3. Develop a detailed set of actionable and prioritized adaptation strategies designed to conserve key species, ecosystems, and resources, and to address the needs of local communities and natural resource managers.
4. Identify the adaptive capacities and the institutional arrangements needed to move these strategies into decision-making arenas.
5. Document best practices for effectively bringing climate science into decision-making.

Deliverables

1. Innovative, effective, integrated social-ecological adaptation planning tools and principles that can be applied in other landscapes.
2. Climate scenarios and narrative scenarios of landscape change in southwestern Colorado and conceptual ecological models (ecological response models) that can be used in adaptation planning.
3. Summary reports on interview and focus group results.
4. An institutional analysis.
5. A set of actionable adaptation strategies for priority ecosystems that include specific conservation/adaptation targets and action steps/paths to implementation.

6. Manuscripts focused on adaptation decision-making and adaptive capacity, institutional analysis, and results and lessons learned from the integrated adaptation framework.
7. Guidelines and a toolkit for practitioners to employ integrated adaptation planning in other landscapes.

Funding

This project was funded by the Department of Interior's (DOI) North Central Climate Science Center (NCCSC), Ft. Collins, Colorado. The Nature Conservancy provided additional funds, largely for workshops and meetings, to leverage the NCCSC grant. The USFS Rocky Mountain Research Station (RMRS) also provided financial support for social science expertise.

Project Team and Gunnison Basin Partners

The project team consisted of representatives of Colorado Natural Heritage Program (CNHP), Colorado State University (CSU), Mountain Studies Institute (MSI), RMRS, The Nature Conservancy (TNC), University of Cincinnati (UC), University of Colorado (CU) and University of Montana (UM), U.S. Geological Survey (USGS), and Western Water Assessment (WWA)/National Oceanic and Atmospheric Administration's (NOAA) Physical Sciences Division.

Key partners and stakeholders participating in this project include the Gunnison Climate Working Group (GCWG), consisting of the Bureau of Land Management (BLM)-Gunnison Field Office, Colorado Parks and Wildlife (CPW), Gunnison County, Curecanti National Recreation Area and Black Canyon of the Gunnison National Park (NPS), Natural Resources Conservation Service (NRCS), Upper Gunnison River Water Conservancy District (UGRWCD), US Forest Service (USFS) Gunnison Ranger District and Gunnison, Grand Mesa, Uncompahgre National Forest (GMUG), and Western State Colorado University (WSCU). See Appendix B for full list of workshop participants.

Overview of Planning Framework and Process

Planning Framework Key Steps

The project team developed and implemented a Social-Ecological Adaptation Planning Framework for this project (see Figure 1 below). Components were adapted from Stein et al. 2014, Cross et al. 2012, and Murphy et al. 2016. Key steps are summarized below. Note that a key step, assessing ecological vulnerabilities, was conducted in the Gunnison Basin prior to this project (Neely et al. 2011). In addition, Knapp (2011) conducted a social resilience and vulnerability assessment of land-based livelihoods in the Gunnison Basin.

1. Assess social-ecological vulnerabilities.
2. Select socio-ecological landscapes to be the focus of the project and conduct literature search regarding natural processes, and climate impacts.
3. Develop three plausible climate scenarios.
4. Develop ecological response models to help understand impacts under three climate scenarios to help inform development of robust adaptation strategies for the targeted landscapes.

5. Develop three narrative scenarios for focus groups.
6. Understand decision-makers through interviews and focus groups.
7. Develop social ecological response models to identify impacts and interventions using *Situation Analysis* and *Chain of Consequences*.
8. Hold a series of workshops to develop and refine adaptation strategies/actions to address current and future climate vulnerabilities, using the *Results Chains* method.

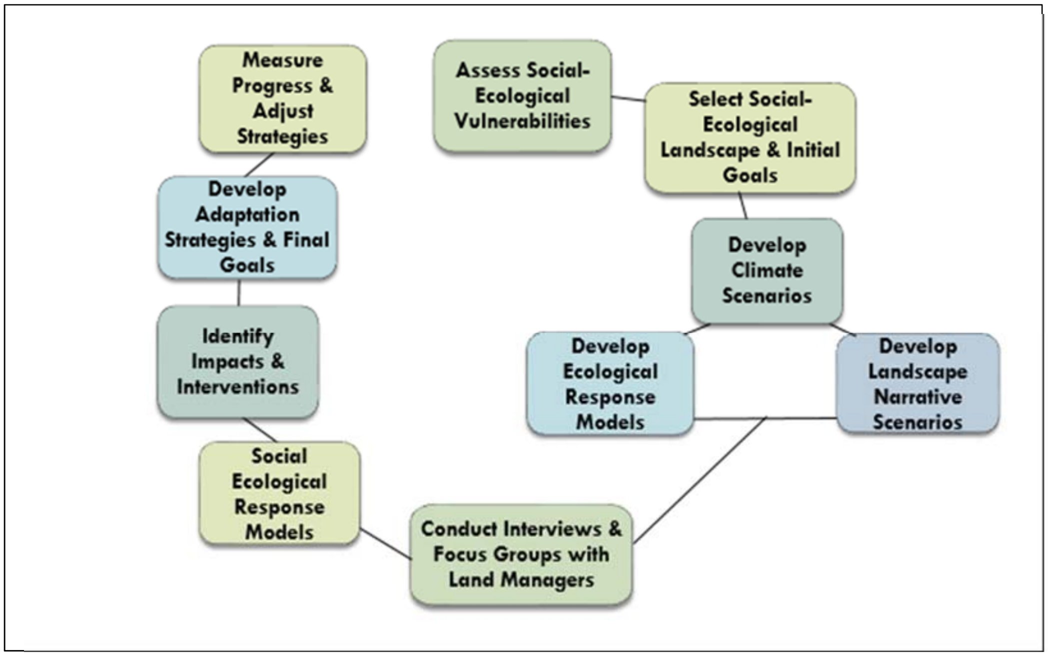

Figure 1. Social-ecological adaptation planning framework developed and applied through this project. Adapted from Cross et al. 2012, Stein et al. 2014, and Murphy et al. 2016.

Landscape Selection

In January, 2014, the GCWG partners selected the spruce-fir and sagebrush landscapes (the sagebrush results are provided in a separate report) to be the focus of this project because of their social, economic, and ecological importance to the Gunnison Basin. Criteria considered included: vulnerability rank from Gunnison Basin Vulnerability Assessment (Neely et al. 2011), nested species and vulnerability rank, opportunity for success in building resilience, social concerns and livelihoods benefitting from the system, relevance to decision-makers regarding upcoming management decisions, available data, biodiversity values, and wildlife values.

Three Climate Scenarios

Uncertainties in the future climate present managers with important challenges in developing effective management plans. The scenario planning approach can offer important insights to managers for developing robust strategies to manage for future climate change impact under a range of plausible climate futures (National Park Service, 2013; Rowland et al. 2014; Murphy et al. 2016). To facilitate this, Imtiaz Rangwala (WWA/NOAA), developed attributes associated with three climate scenarios for southwestern Colorado and the Gunnison Basin for the year 2035 (i.e., 2020-2050 period). He used a base of 72 global climate models and two future greenhouse gas emissions scenarios (8.5 and 4.5 Representative Concentration Pathways-RCP) from the Coupled Model Intercomparison Project – Phase 5 (CMIP5) (Taylor et al. 2012), and then identified three potential clusters that represent different future pathways for the region. The scenario clusters represent three different plausible futures: 1) a hotter, drier future; 2) a warmer future where annual precipitation increases; and 3) a future with high-inter-annual variability between hot dry years and warm wet years.

These climate scenarios were identified as: 1) Hot and Dry; 2) Warm and Wet; and 3) Feast and Famine (moderately hot, no change in precipitation over a long term but increased inter-annual variability). See Appendix C.

Renée Rondeau (CNHP) researched the potential ecological impacts of the three climate scenarios to the targeted landscapes. This information was then used to develop a set of three narrative scenarios and ecological response models to assist managers in developing social-ecological adaptation strategies under the three climate scenarios.

Narrative Scenarios

Renée Rondeau (CNHP) and Imtiaz Rangwala (WWA/NOAA) developed three narrative scenarios for the Gunnison Basin that described plausible spruce-fir landscape changes that could take place over the next 20 years. The scenarios were descriptive stories depicting potential changes in the landscape based on the climate scenarios and are referred to as Hot & Dry, Warm & Wet, and Feast and Famine." These narrative scenarios were developed for use during the focus groups. They were reviewed by the project team and subject experts familiar with the ecosystems; their comments were incorporated into the final narrative tool that was used with stakeholders (see Appendix D).

Ecological Response Models

The team, working closely with natural resource managers and researchers, developed reference condition and ecological response models for the spruce-fir landscape in the Gunnison Basin. The purpose of the ecological response models was to evaluate and depict potential impacts of the three climate scenarios on the spruce-fir landscape. The team held a series of workshops between June and November, 2015 to develop and refine reference condition models and ecological response models. Participants included representatives from BLM, CNHP, CPW, MSI, NRCS, TNC, USFS, WSCU, WWA, and private consultants. See Appendix B for workshop participants, Appendix E for spruce-beetle activity map and Appendix G for ecological response models.

Spatial-Ecological Response/Bioclimatic Models

Jim Worrall (USFS, Gunnison Service Center) developed the spatial ecological response models (or bioclimatic niche models) for two dominant species, Engelmann spruce and subalpine fir, in this landscape in the Gunnison Basin, using methods described in Rehfeldt et al. 2015 and Worrall et al. 2016. The bioclimatic niche models were used to develop spatially explicit projections of climate change impacts to the spruce and fir species. The model evaluates grids of historic climate and topographic variables, resulting in an estimate of the suitability for the species of each cell in the grid, giving a map of suitability at 90-meter resolution. The maps accurately predicted current species distributions.

Similarly, grids of future climate variables can be used to map suitability in the future. Three future climates were used that matched the climate scenarios used in this report and represent the decade around 2060 (see Appendix F).

For ease of interpretation and to enhance utility in management, the results are presented as spatially explicit change zones or bio-climatic zones:

1. **Lost** areas are where the future climate is highly unlikely to support spruce-fir, and the area is most likely to transform after a large disturbance.
1. **Threatened** areas may be able to survive changes, but future climate is marginal and may hinder regeneration.
2. **Persistent** areas are the refugia or areas likely to maintain a suitable climate for spruce-fir.
3. **Emergent** areas are where the future climate will likely support spruce-fir habitat, but the area does not current support spruce-fir.

Results can be used to identify the most appropriate management actions for climate adaptation of vegetation for specific zones.

In assessing and using the results, it should be noted that there are many sources of uncertainty, and these are generally not quantifiable. These include errors and inaccuracies in training data and especially the fact that we don't know which climate prediction best represents the future. Although these projections are the best and most detailed that are currently available, users should look at them as general directions of change. They should not be interpreted in detail at high resolution, and should not be considered to represent an exact point in time (Worrall, pers. Communication).

Understand the Views of Decision-Makers

Katie Clifford, Geography Department, University of Colorado, Boulder, collected social science data through stakeholder interviews to assess the decision-making context of the spruce-fir landscape. She also used focus groups, utilizing narrative scenarios, to assess future climate projections and impacts and identify potential adaptation strategies for the spruce-fir landscape. (See Appendix H).

Fieldwork was conducted from June through October, 2015. Ms. Clifford conducted 22 in-depth, semi-structured interviews with ranchers and public land managers at five agencies as well as four climate scenario-driven focus groups with 18 participants consisting of natural resource managers with a mix of agencies and specialties. Results were audio-recorded and transcribed verbatim to assist in analysis. Transcripts were then coded using Nvivo software. Coding was used to identify themes and facilitate analysis.

Each focus group was centered on the three climate scenarios described above (Hot and Dry, Warm and Wet, and Feast and Famine). Scenarios were presented individually and then followed by a series of questions regarding anticipated impacts, management needs, conflicts, compromises and potential strategies.

Together, the ecological response models and social science data showed that the two primary disturbances of concern that may be exacerbated by climate change were wildfire and insect outbreak (e.g., spruce beetle) for the spruce-fir landscape. These disturbances were the focus for developing social-ecological climate response models based on stakeholder's participation in the *Chains of Consequences* and *Situation Analysis* methods during the workshops. A brief description of the methods used at this workshop follows in the next section.

Socio-Ecological Response Models

The team worked with stakeholders to integrate social and ecological responses of climate change on the spruce-fir landscape using two different approaches: *Situation Analysis* and *Chain of Consequences.*

The *Situation Analysis* approach defines the context within which a project is operating and, in particular, the major forces influencing the landscape, including the direct and indirect threats, opportunities, and scope (Foundations of Success, 2009). The process of developing a *Situation Diagram* helped to create a common understanding of the biological, environmental, social, economic, and political systems affecting the targeted landscape. This method has been used around the world by the Conservation Measures Partnership, including TNC, and many others.

The DOI Strategic Sciences Group developed the *Chain of Consequences* method for teams of scientists to identify the potential short- and long-term environmental, social, and economic cascading consequences of an environmental crisis and to determine intervention points to aid decision-making. The method has been used to identify the consequences and potential interventions of the Deep Water Horizon Oil Spill in the Gulf of Mexico and Hurricane Sandy (DOI Strategic Sciences Working Group 2010, 2012; Department of the Interior, 2013).

Stakeholder Adaptation Workshops

The Project Team hosted a series of workshops with the GCWG and other stakeholders from April 2015 through April 2016 to identify climate impacts to the landscapes under climate scenarios, identify interventions (preliminary adaptation strategies), develop social-ecological response models, develop goals and objectives, and identify adaptation strategies/actions. These workshops are summarized below.

April 2015 Climate Adaptation Strategy Workshops

To prepare participants for the workshops, the team held a series of pre-workshop webinars on the following topics: 1) three climate scenarios; 2) ecological response models for spruce fir landscape; 3) methods for identifying preliminary interventions; and 4) preliminary results of interviews and focus groups. The team also developed a participant packet of materials including an agenda, materials produced to date, description of methods, and the approach for facilitating discussion focused on climate change.

At the April, 2015 workshop, participants developed social-ecological climate response models for the spruce-fir landscape, identified a suite of preliminary intervention points and potential high-level adaptation strategies for one climate scenario, and prepared for a fall workshop to develop in-depth adaptation strategies. Due to time constraints, the workshop focused on only one climate scenario, Feast and Famine, with the intention of addressing the two other scenarios at future workshops. The workshop provided an opportunity to compare two methods (*Situation Analysis* and *Chain of Consequences*) for developing interventions and identifying preliminary adaptation strategies. See Appendix I for an overview of methods.

The outcomes of the April, 2015 workshop included: 1) integrated findings from climate models, ecological response models and interviews and focus groups to produce social-ecological response models for the Feast and Famine climate scenario; 2) comprehensive list of preliminary interventions that provided a foundation for developing more in-depth adaptation strategies for the spruce-fir landscape under three climate scenarios; and 3) improved stakeholder buy-in for developing and implementing local and regional interventions and adaptation strategies. The team summarized the results of the workshop in a draft report entitled: *Gunnison Basin Climate Adaptation Workshop, Phase 1: Sagebrush and Spruce-Fir Landscapes* and distributed it for review by participants in August, 2015.

November 2015 Climate Adaptation Workshops

After the April workshop, the team synthesized the results into summary tables of interventions by impacts for the Feast and Famine scenario, and developed a process to identify interventions for the other two scenarios (Hot and Dry; Warm and Wet). The team then convened a small group of experts in November, 2015, to review the interventions developed for the Feast and Famine climate scenario and evaluate how well they address the potential impacts of the two other climate scenarios. Participants reviewed the differences in the three climate scenarios, and then discussed the impacts, interventions and scoring. The participants recommended meeting again to refine the interventions, develop goals and objectives for the spruce-fir landscape prior to holding a final workshop with a broad audience in April, 2016.

February 2016 Climate Adaptation Workshops

At the February, 2016 workshop, stakeholders drafted goals and objectives and developed a set of three climate adaptation strategies for the spruce-fir landscape by creating *Results Chains. Results Chains* are diagrams that depict assumed causal linkages between strategies and desired outcomes needed to reduce climate impacts and other threats through a series of expected intermediate outcomes and actions *(*Margoluis 2013). This process helped to build a common understanding of the outcomes and actions needed to reduce the impacts of climate change for each strategy.

April 2016 Climate Adaptation Workshops

At the final workshops held in April, 2016, participants revised the goals and objectives for the spruce-fir landscape, refined social-ecological strategies to prepare the landscapes and the people who depend on them for a changing climate, and identified challenges and opportunities to ensure successful implementation of strategies. After managers from CPW, USFS, NPS and NRCS presented the goals/objectives and *Results Chains*, participants provided feedback and refined the goals and strategies, and then identified challenges to implementation and opportunities for successful implementation. Following the workshop, the team revised the *Results Chains* based on the feedback and turned the diagrams into text to summarize each of the strategies, including desired outcome, intermediate outcomes, and actions.

Workshop Participants

Over 70 participants attended the workshops, including land and water managers, wildlife biologists, ecologists, foresters, researchers, planners, professors, researchers, social scientists, county officials, private consultants, and other stakeholders in the Gunnison Basin. The participants represented local, state and federal agencies including BLM, CNHP, CPW, Colorado State Forest Service (COFS), Gunnison County, NPS, TNC, NRCS, Saguache County, USFS, WSCU, WWA, non-governmental organizations, e.g., RMBL, land trusts, MSI, and local county officials. See Appendix B for a full list of workshop participants.

THREE CLIMATE SCENARIOS FOR THE FUTURE

Climate Scenario Summaries

Projected changes in temperature and precipitation by 2035 for the three climate scenarios are shown in Figure 2, and the consequences of these changes are summarized by scenario below. See Appendix C for table comparing the three climate scenarios.

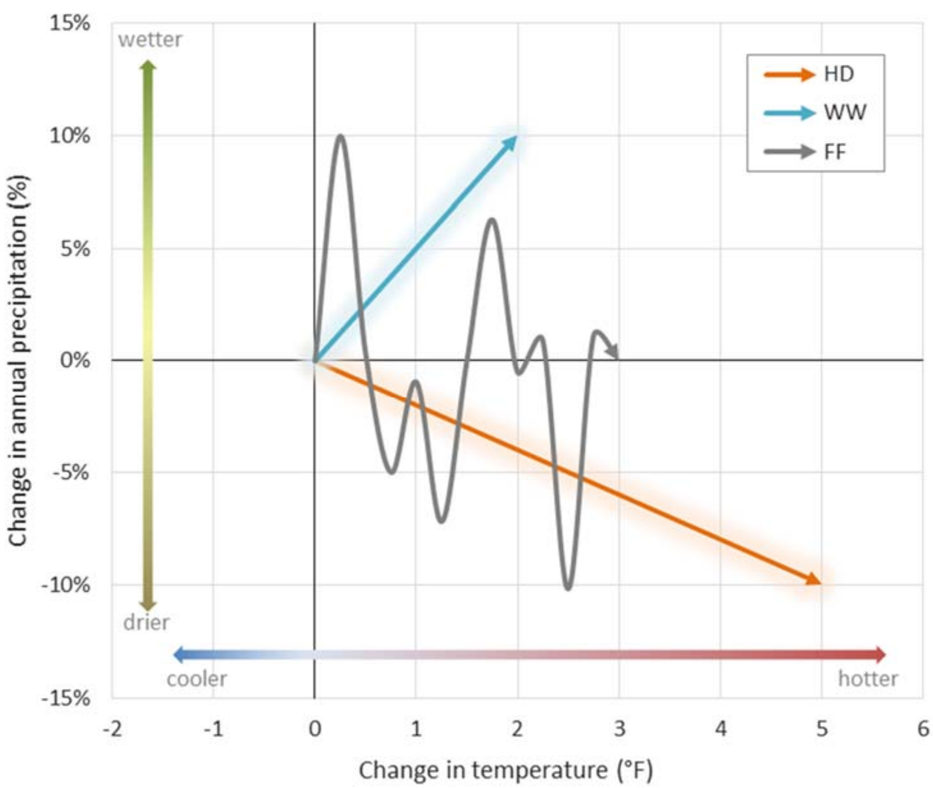

Figure 2. Generalized depiction of change from 1971-2000 baseline, in annual precipitation and temperature for three climate scenarios (Hot and Dry=HD, Feast and Famine=FF, and Warm and Wet=WW).

Hot and Dry (hadgem2-es.1.rcp85)

Average annual temperatures 5°F higher than in the late 20th century, and combined with a decrease in annual precipitation of 10%, produces drier conditions year-round. Summers at lower elevations are expected to have 30 additional days with temperatures above 77°F (25°C), and many nights with lows of 68°F (20°C) or above. Heat wave conditions are severe and long lasting. Rain events are likely to be less frequent, but more intense, and summer monsoon rains decrease (20%

less than recent historic). Droughts comparable to 2002 or 2012 occur on average every five years.

Hot and dry conditions lead to:

- Longer growing season (+3 weeks), reduced soil moisture, increased heat stress
- Snowline moves up in elevation (+1200 ft)
- Frequent extreme spring dust-on snow events
- Earlier snowmelt and peak runoff (+3 weeks, earlier with dust events). Decreased runoff (-20%)
- Longer fire season (+1 month) greater fire frequency (12x) and extent (16x) in high elevation forest

Feast and Famine (Moderately Hot/No Change in Precipitation, cesm1-bgc.1.rcp85)

Average annual temperatures 3°F higher than in the late 20th century, and increased magnitude of inter-annual fluctuations in precipitation levels produces generally drier conditions, especially during the growing season, but some years with strong El Niño patterns may be quite wet. Summers at lower elevations are expected to have 14 additional days with temperatures above 77°F (25°C), and many nights with lows of 68°F (20°C) or above. Heat wave conditions are common every few years. Strong El Niño events can be expected every seven years on average, while droughts comparable to 2002 or 2012 occur on average every decade. During wetter years, increased temperatures lead to increased vegetation growth and subsequent fuel loads for wildfire.

A “feast or famine” pattern fluctuating between hot/dry and warm/wet conditions leads to:

- Longer growing season (+2 weeks)
- Snowline moves up in elevation (+900 ft)
- Increased extreme spring dust events in dry years
- Earlier snowmelt and peak runoff (+2 weeks, earlier with dust events). Decreased runoff (-10%)
- Very high fire risk during dry years following wet years, greater fire frequency (8x) and extent (11x)

Warm and Wet (cnrm-cm5.1.rcp45)

Average annual temperatures 2°F higher than in the late 20th century, and combined with an increase in annual precipitation of 10%, produces generally warmer but not effectively wetter conditions in comparison with recent historic levels. Summers at lower elevations are expected to have 7 additional days with temperatures above 77°F (25°C). Heat wave conditions may occur once a decade. Droughts may be more intense, but with fewer instances of extended drought.

Warmer and slightly wetter conditions lead to:

 Extended growing season (+1 week)

 Snowline moves up in elevation (+600 ft)

 Occasional extreme spring dust events in dry years, comparable to current conditions

 Earlier snowmelt and peak runoff (+1 week). No change in runoff volume

 Increased fire frequency (4x) and extent (6x)

SOCIAL-ECOLOGICAL VULNERABILITIES

To better understand decision-makers and social vulnerability, Katie Clifford, graduate student in Geography at the University of Colorado completed social science research utilizing interviews and focus groups in the Upper Gunnison River Basin during 2014, working closely with Laurie Yung (UM), Nina Burkardt (USGS), Bill Travis (CU) and the team. See Appendix H for final reports summarizing the interview and focus group findings.

Interview Results

The interviews focused on developing a better understanding of how social-ecological systems and decision-making are influenced by climate change to help facilitate climate adaptation. Ms. Clifford conducted 22 in-depth, semi-structured interviews with ranchers and public land managers from five agencies in 2014. In November 2015, she completed a report of her findings, entitled *Climate Adaptation in the Gunnison Basin, Colorado: Social Dimensions and Management Concerns for the Spruce-Fir and Sagebrush Landscapes* (Appendix H)*.* This report summarizes findings from interviews with key decision-makers, designed to provide the following inputs to the larger research project: information on current use, importance, and status of the targeted landscapes; detailed insight into current social and decision-making context of the targets and approach to uncertainty, and identification human communities in the Gunnison Basin likely to be impacted by climate-induced changes to the targeted landscapes, and the nature of those impacts.

Below is a summary of findings from interviews with key decision-makers, which were designed to provide the inputs to the larger research project:

Adaptive and Flexible Management*:*

- Adaptive Management is a popular strategy for managing under uncertainty, but a gap exists between theory and practice because managers do not have the flexibility to respond quickly or adequate baselines to evaluate management strategies.
- Interviewees did not respond well to the idea of managing for a "range of future conditions" because of confusion over what it meant and frustration over how to

implement the strategy.

Uncertainty and Variability:

- Uncertainty elicits a range of responses from land managers from dread to curiosity to confidence; people were comfortable with future uncertainties when they were framed as disturbances.
- Climate change was understood through extremes and variability rather than a simple focus just on increasing temperatures.
- The historic and future range of variability is understood and bounded by previous climate experiences, with regular references to extreme drought years and high precipitation years.
- A lack of information is not the most critical barrier to implementing adaptation strategies in the Gunnison Basin.

Public Influences:

- Interviewees did not deny climate change, but saw public skepticism as a barrier to implementing climate adaptation.
- Recreation pressures (and conflicts) are growing in the Basin and this is compounding the challenges of climate change.

Focus Group Results

Katie Clifford conducted four climate scenario-driven focus groups with 18 participants in Gunnison and Montrose, Colorado in 2014. The objectives of the focus groups were to learn how natural resource managers and users in the Basin would respond to changes under the three scenarios and obtain input on potential adaptation strategies.

In May, 2016, she completed a report of her findings, entitled *Climate Adaptation under a range of scenarios: Natural resource manager focus groups in the Gunnison Basin* (Appendix H). Below is a summary of the findings from four scenario-driven focus groups of natural resource managers. Managers were asked to consider how to incorporate a range of future conditions into resource decisions. The scenarios specifically keyed into the two target landscapes (sagebrush shrublands and spruce-fir forests) due to their social and ecological importance in the Gunnison Basin. These findings can help climate scientists understand how to better design useable climate science and also inform resource managers and researchers about how to develop and support climate adaptation strategies in the Gunnison Basin and beyond.

The focus groups produced a number of key findings about planning for a range of future conditions, and potential adaptation strategies at a local scale. These findings are summarized below.

Perceived Risk

Participants largely agreed that a scenario (Feast and Famine) with high variability in precipitation and temperature would be the greatest challenge for management. Furthermore, managers thought that scenarios without clear warming and drying trends, such as moderate temperature increases or high variability, would be harder for the public to recognize, which could undermine adaptation efforts.

Spruce-Fir Landscape

Participants recognized that the spruce-fir landscape was undergoing change and that they could not manage for current conditions. The spruce-fir forests are already undergoing significant and rapid change and participants expected future disturbances to be longer in duration and of higher magnitude.

Potential Strategies

Participants generated several strategies in response to the scenarios; many were not novel, but instead used and built on previous practices. This either indicates that managers might already have many of the tools and knowledge needed to respond to a changing climate or conversely that it is challenging for them to develop novel approaches. They discussed utilizing existing management strategies and borrowing exemplars from other locations. However, increased flexibility in terms of funding, procedures, and management practices would improve managers' ability to plan for a range of future conditions.

Conflict and Cooperation

Participants interpreted potential changes through existing conflicts, with little discussion of new ones. This may indicate that climate change is not so different from other types of social-ecological changes, or that people have a hard time imagining subtle changes and altered future conditions. Participants felt the Basin has local capacity for cooperation, and they preferred bottom up approaches such as collaboration fostered by locals rather than mandated, top-down adaptation protocols.

Climate Science and Scenarios

Overall, participants reported that the scenarios helped them interpret climate change impacts locally in the Gunnison Basin and consider a range of future conditions. However, participants requested more information about current baselines and that the status of human communities be incorporated into the narratives. Future work should also consider how to promote thinking beyond past experiences.

DESCRIPTION OF SPRUCE-FIR LANDSCAPE, ECOSYSTEM SERVICES AND SOCIO-ECONOMIC OVERVIEW OF THE GUNNISON BASIN

The spruce-fir landscape in the Upper Gunnison River Basin consists of a mosaic of ecosystems that are dominated by Engelmann spruce (*Picea engelmannii*) and Subalpine fir (*Abies lasiocarpa*), ranging from 10,000-12,500 feet in elevation. The lower elevations often consist of dense stands of spruce-fir forest with smaller patches of quaking aspen or lodgepole pine. At the upper elevations, it transitions into a subalpine zone with a mosaic of willows, wetlands, and mesic or dry alpine meadows. Smaller patches of other ecosystems, e.g., wetlands and fens, are scattered throughout the landscape. This landscape consists of over 1/2 million acres within the Basin. See Figure 3 for the distribution of the spruce-fir ecosystem relative to other ecosystems in the Gunnison Basin.

Numerous species and human communities in the Gunnison Basin rely on a functioning spruce-fir landscape that is at risk of changing with the future climate. Characteristic animals include Three-toed woodpecker, Gray jay, Pine grosbeak, Rocky Mountain elk, White-tailed ptarmigan, and marmots. Animals of concern include lynx, pine marten, boreal owls, snowshoe hare, red squirrel, dusky grouse, songbirds, northern goshawk, vole, pygmy shrew, wolverine, white-tailed ptarmigan, and pika. In addition, the subalpine zone is very important for numerous rare plants. Plants of concern include reflected moonwort, fork-leaved moonwort, Mingan's moonwort, pale moonwort, peculiar moonwort, northern moonwort, arctic draba, and Colorado wild buckwheat.

Ecosystem services provided by the spruce-fir landscape include: snowpack and snowmelt, ground water storage and clean water, recreation opportunities (hiking, camping, fishing, rafting, hunting, resort and backcountry skiing, snowmobiling, photography, and mountain biking), food and shelter, wildlife habitat, maintenance of soil moisture, carbon sequestration and storage, forest products and tourism.

The population of the Upper Gunnison Basin is 23,009 (Department of Local Affairs 2010 a-b). Nearly 80% of the basin is public land, which supports about 12% of all jobs (Cheng 2006). The economy of the Basin has transitioned from agriculture and ranching to retirees and tourism (Department of Local Affairs 2010). While agriculture currently accounts for only 10% of the jobs, it impacts 96% of private land and 89% of United States Forest Service lands (Cheng 2006). Tourism and recreation are responsible for 23% of Gunnison Basin economic activity, and local counties have listed tourism as one of their top goals for economic growth (Office of Economic Development 2011 a-c). These land-based livelihoods depend directly on ecosystem services (this paragraph largely from Knapp 2011).

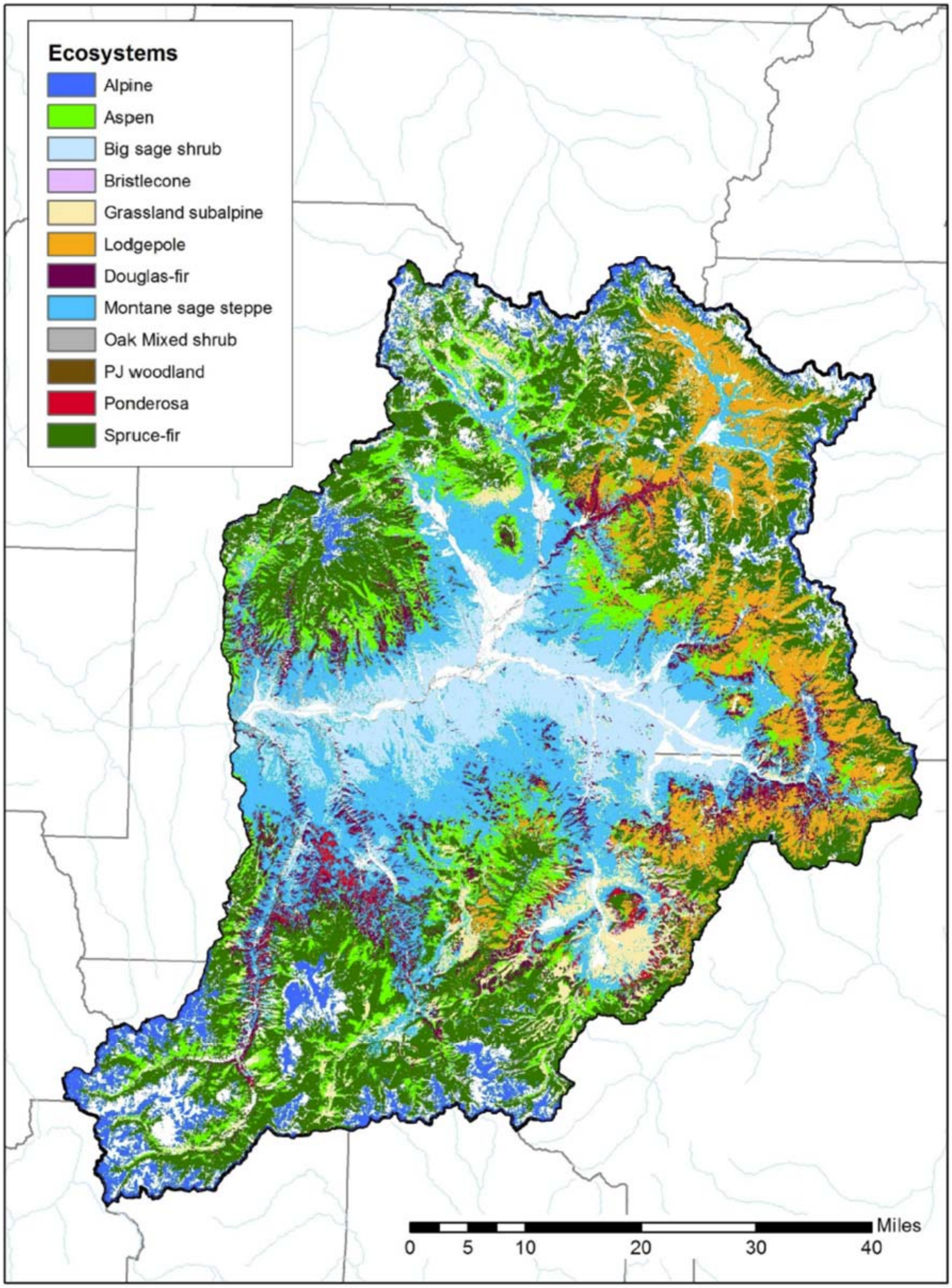

Figure 3. Major ecosystems of the Gunnison Basin, based on Southwest ReGAP. The spruce-fir ecosystem (dark green) occupies the higher elevations.

CLIMATE CHANGE IMPACTS AND ECOLOGICAL RESPONSE MODELS

Ecological Response Models

The reference condition model and ecological response models for the spruce-fir landscape, based on literature review, local knowledge and expert opinion, describe how the landscape operates and provide a context for evaluating potential impacts of different climate scenarios. The models help identify outside environmental influences or drivers, and show the relationships among the main contributing factors that drive one or more of the direct threats that, in turn, impact the spruce-fir landscape. The purpose of assessing the landscape under three different climate scenarios is to provide a foundation of scientific understanding of the range of possible futures that are projected for the region to inform the development of robust social-ecological adaptation strategies for spruce-fir forests in the face of an uncertain future.

Below are general descriptions of the reference condition and a snapshot of the future spruce-fir landscape under each of the three climate scenarios. Additional details on the projected ecological impacts associated with drought, insects, fire, and other factors are also provided. See Appendix G for diagrams of the reference condition model and the ecological response models for the three climate scenarios.

Reference Condition Model

The Reference Condition Model is based on LANDFIRE state and-transition model (Rocky Mountain Subalpine Dry-Mesic Forest and Woodland) with adjacent systems added (LANDFIRE 2007). LANDFIRE developed state-and-transition models to represent pre-settlement reference conditions for all Ecological Systems in the United States through an expert-based model development process. Each model represents a single ecosystem. LANDFIRE used the models to estimate reference conditions, which are used to help assess ecosystem health.

A typical 5 box LANDFIRE model starts in the middle with early successional forest, moving through mid-successional open and closed canopy forests to late-successional open and closed canopy forest. Replacement fires move the forest back to early successional forest. Insects, disease and drought will move the closed canopy forest types to open conditions and younger stands when older trees are killed. Tree invasion will move adjacent mesic and dry meadows as well as shrublands into early successional forests.

Hot and Dry Climate Scenario

In this climate scenario, the changes seen in the Feast and Famine (Moderately Hot) Scenario are increased in size and likelihood. The scope and severity of climate impacts are expected to be much greater to the spruce fir landscape than in the Feast and Famine climate scenario. Drying is likely to occur in the meadows and shrublands. Fires are predicted to change some forest patches into dry meadows. The likelihood of insects, disease and drought is predicted to significantly increase as well as stand replacement fires in the late successional closed canopy forest. In addition, a novel type of system, uncharacteristic vegetation dominated by aspen, shrubs and mixed conifer will likely occur as the result of big intense fires and insect, disease and drought.

Hot and Dry	5°F (2.7°C) increase and 10% decrease in precipitation; an effective 45% decrease in available moisture* Extreme drying and reduction in soil moisture.

Droughts: Severe droughts, such as the 2002 drought, will occur every 5th year. These droughts will kill spruce and fir for up to 5 to 11 years after the drought. Thus we will see large trees dying every year, even after the drought is over (because of 5 and 11-year lag effect). The fir is more susceptible than spruce, thus droughts, will alter the species composition and spruce will become more dominant and fir less dominant.

Insects: Forest insects and diseases will be at their highest rates in this scenario because of the higher temperatures. Warmer winters and warmer summers create the perfect conditions for insects. When these higher temperatures are coupled with drought, the trees tolerance and ability to fight off insects are negligible; thus, the mortality rate is extremely high. We will experience more acres killed from insects and pathogens than from fires under this scenario.

Fire: In this scenario, the fire season widens by one month and fire frequency increases by up to 12 times the 1970-1986 rate; the size of the burned area could increase by 16-20 times due to a 4° and 6° F temperature increase in spring and summer temperatures coupled with a 9 and 20% decrease in spring and summer precipitation, respectively (Westerling 2006 is primary source for this extrapolation).

Other: The climate suitability envelope will primarily eliminate some 60% of the subalpine fir; Engelmann spruce will only lose some 25-30% of area where the climate is suitable. Even if spruce-fir could migrate uphill, it may not be able to have a net gain, i.e., it will still be a net loss for suitable climate area because there are few areas with deep enough soils to support these species at higher elevations. Ponderosa pine, aspen, and Douglas fir may be able to migrate into the existing stands of spruce-fir (at least the climate will be suitable for these species). The combination of fire and insect kill has the ability to alter and transform large areas into a new system (or state) that will not be dominated by spruce or fir, e.g., converting to mixed conifer.

Feast and Famine (Moderately Hot) Climate Scenario

In this climate scenario, drying is likely to occur in the meadows and shrublands. Fires are predicted to transition some forest patches into dry meadows. The likelihood of insects, disease and drought is predicted to increase as well as replacement fires in the late successional closed-canopy forest. In addition, vegetation dominated by aspen, shrubs and mixed conifer will likely expand resulting from big intense fires, insects, disease and drought. In this scenario, there may be more big fires compared to the Hot and Dry Climate Scenario because of build-up of fuels during wet years and extreme drought during dry years.

Moderately Hot	3° F (1.6 °C) increase and no change in precipitation; an effective 15% decrease in available moisture*

Droughts: Severe droughts like 2002 occur approximately every 10th year. This frequency is still higher than our current baseline drought frequency so the species composition will change, albeit at a slower rate than in the previous scenario. Spruce trees will be the winner and subalpine fir will be the loser. Note that both species will have high mortality rates in older trees (same for previous scenario). The younger trees are more likely to withstand the extreme droughts.

Insects: The insect and pathogens are still present in this scenario, with winter and summer temperatures being 3° F warmer. Thus it is a matter of scale—that is, the worst case scenario is the Hot and Dry and the least problematic scenario will be the Warm and Wet for insect impact.

Fire: While the annual fire risk is lower in this scenario than the Hot and Dry scenario, when it does burn, the severity, intensity, and extent could be very high. This potential fire increase is because of the great amplitude between drought and wet years. The wet years build up greater fuels, primarily along the surface and shrub canopy layers; then, when a drought event occurs, the fires are more intense. The fire frequency, at least in the dry years, could be as high as eight times that of the 1970-1986 period with 3 °F increase and the size of the burn could increase by 11 times, thus, there is a high probability of very large fires during the dry years (Westerling 2006)

*This estimate is based on this relationship for this region: 1°F increase in temperature = 5% decrease in runoff; 5% decrease in precipitation = 10% decrease in runoff.

Warm and Wet Climate Scenario

In this climate scenario, not much changes with the above successional and disturbance pathways. Tree invasion into meadows and shrublands is predicted to moderately increase. Replacement fires in the late successional closed canopy forest are also predicted to moderately increase.

Warm & Wet 2° F (1.2 °C) increase and 10% increase in precipitation; in spite of the 10% increase in precipitation, moisture stress is still possible due to the 2°F increase.

Droughts: Severe droughts, such as 2002, will occur approximately every 15th year (not outside of our current natural range of variation). The intensity may become more severe thus there is still some impact. We will still experience mature trees dying from drought; it is just that the droughts will not occur as often.

Insects: The region has already experienced nearly a 3° F increase in summer temperatures and seen large outbreaks of spruce die back just outside of the Gunnison Basin. The spruce beetle outbreak has already impacted and will continue to severely affect mature spruce trees in the Gunnison Basin. Again, the rate and scope of tree mortality will likely be the lowest for this scenario but it is far from non-existent.

Fire: The fire risk is lowest in this scenario; however, it is still elevated over the current condition. An increase in spring and summer temperatures of 2° and 3° F, respectively will increase fire frequency. The warmer spring temperatures will mean an earlier spring runoff (at least one week and it could be even earlier if there is a dust-on-snow event). The longer and hotter growing season will increase fire frequency. When we do have a fire the severity may increase because of high fuel loads, drier fuels that are more available to burn, and hotter summers. The fire frequency increased four times over the 1970-1986 average with a 1.56° F higher spring and summer temperatures that occurred from 1987-2003. The total area burned by these fires was more than 6.5 times its previous level. The increase in precipitation may help offset some of the fire risk but annual variation in the rainfall will still exist and drought years, such as 2002 will occur every 15 years, on average. Lightning strikes may increase by 40%, thus increasing the chance of fire, especially just prior to the monsoon season.

Other: This scenario will have a subtler change than the other scenarios in that species composition is likely to change but the overall forest will still be dominated by spruce and fir.

Impacts and Interventions

In order to focus our attention on the most robust and large-scale adaptation strategies for the spruce-fir landscape, we refined and filtered the list of impacts and intervention points developed at previous workshops. These preliminary intervention points were used as starting points for strategy development to address the three climate scenarios (See Appendices J-L).

Questions

To assist us with filtering and prioritizing the impacts and interventions, we asked three primary questions for the spruce-fir landscape:

1. Which impacts are most likely to be significant across all climate scenarios?
2. Which intervention points are most likely to work across all three climate scenarios?
3. Which intervention points are likely to work at a landscape-level scale?

Methods

To answer the above questions, we categorized the interventions by the impacts that they addressed. We devised a process to score and prioritize the impacts and their interventions by their anticipated significance, likelihood across all scenarios, and landscape scale (large, medium, or small). Impacts and interventions with a high score denoted significant impacts and interventions and would be the focus of our adaptation strategies workshop. We developed a ranking spreadsheet to maintain the scores, summarized in Tables 1-2. Thus, the strategies that we would focus on were: 1) likely to be effective in reducing climate impacts at a large landscape-level scale and 2) likely to be effective across three climate scenarios.

Table 1. Top impacts to the spruce-fir landscape across the three climate scenarios. The higher the score, the greater the scope and severity of the impact across all three scenarios.

Impact	Average Score	Number of Distinct Impacts/Category
Altered fire regime	10.8	12
Altered species composition	11.9	15
Altered hydrologic regime	12.2	5
Education	13.0	6
Fragmentation	12.0	1
Recreation pressure	13.0	2
Research	12.0	1
Social and economic impacts	12.1	9
Wildlife	10.0	1

Table 2. Intervention categories with average total scores and landscape scale. The average of total score is a sum of the intervention and impact score. There were multiple impacts and interventions associated with an intervention category, thus we took the average. The total score, coupled with scale, was used to define which intervention categories would be the focus of our adaptation strategy workshop. The bolded intervention categories became our strategies. Cross-cutting denotes the need to subsume these interventions into all strategies.

Intervention Category	Average of Total Score	Average of Intervention Score	Average of Impact Score	Scale
Identify and protect refugia	13.0	7	6	Large
Improve infrastructure for resilience	13.0	7	6	Small
Cross boundary coordination	12.7	7	6	Cross-cutting
Education and outreach	12.6	7	6	Cross-cutting
Recreation management	12.5	7	6	Small
Research and monitoring	12.5	7	6	Cross-cutting
Assist/allow transformation	12.0	6	6	Large
Water management	12.0	6	6	Small
Proactive treatment for forest resilience	11.5	6	6	Large
Riparian management for water and fish	11.0	6	5	Small
Proactive fire management	10.8	5	6	Small

The top impacts across the three scenarios to the spruce-fir landscape are altered species composition, altered fire regime, and social and economic impacts, followed by education and altered water regime (Table 1). To help narrow down the interventions to work on, we evaluated total scores for impacts, interventions and landscape scale. We also grouped interventions where appropriate. We did not single out cross-cutting interventions, such as education and outreach, because these strategies are likely to be nested under of the other strategies. It is also important to note that not selecting a strategy did not mean that the strategy was not worthy of more attention; rather, in-depth strategies could not be developed for everything in the final workshop due to time constraints. See Appendix L for summary tables of the impacts and interventions associated with the three strategies identified during the February and April, 2016 adaptation workshops.

The three strategies identified for further development were:

1. **Identify and protect persistent areas (refugia)**: protection, management and restoration are much more likely to succeed if within a climate refugia, in addition to a high score.
2. **Proactive treatment for resilience**: this strategy had the most number of identified interventions
3. **Accept, assist and allow transformation**: it is important to recognize that transformation is likely to occur and assist where appropriate, e.g., spruce-fir migrating into new areas and new species moving into current stands.

GOALS AND OBJECTIVES FOR THE SPRUCE-FIR LANDSCAPE

Goal

A resilient spruce-fir subalpine forested landscape that supports viable populations of species of concern (and/or obligate species) and supplies human communities with a suite of ecosystem services in the face of a changing climate. Allow natural processes to function within the landscape (e.g., fires, insects), while protecting people, infrastructure, and refugia. Where spruce-fir is vulnerable and where climate suitability will be changed, facilitate a vegetation conversion to suitable tree species, e.g., aspen/mixed conifer.

Objectives

1. By 2035, protect/conserve areas identified as spruce-fir climate refugia and linkages well-distributed across the landscape and (linkages include migration corridors) that represent at least 80% of the potential refugia and linkages within the Basin for lynx, pine martens, snow-shoe hare, and other obligate species of concern

2. Through 2035, manage for and maintain the opportunity for structural stage and canopy cover class distribution and maintain a variety of spruce-fir age classes across climate refugia within manageable areas.

3. Through 2035, most of new infrastructure or maintenance of existing infrastructure will incorporate improved design or changes so that they are climate smart and reduce risks to people's safety over time. Ensure that roads, powerlines, culverts, etc. are designed to withstand extreme climatic events, e.g., wildfires and catastrophic flood.

4. By 2035, actively reforest areas, where appropriate or feasible, within refugia that are not regenerating naturally and have experienced severe mortality or major disturbance to help ensure these areas will continue to remain as forest.

5. Through 2035, protect and maintain healthy trees within larger stands that are dying from insect, disease and fire when managing for a future forest.

6. By 2035, restore or maintain a mosaic of wet meadows, willow carrs, riparian corridors and their hydrologic regime, and montane grasslands, by removing non-climate stressors, e.g., incompatible grazing, protection during disturbance where feasible, using a climate-smart seed mix or plant materials and anticipating plant growth changes, species changes and seasonal changes in climate.

7. By 2035, identify, maintain or expand warm-dry refugia, e.g., mixed conifer – montane forest, within SF landscape to provide seed source and genotypes to assist with transformation.

8. By 2035, manage for seasonal access and maintain recreational opportunities within the spruce-fir landscape, e.g., harvest spruce-fir forest dependent non-forest timber products, e.g.,

mushrooms/chanterelles, boletes, osha, and arnica, skiing, hiking, and spiritual opportunities.

9. By 2035, allow transformation of subalpine forests in vulnerable areas that may be lost (based on bio-climatic models) into appropriate vegetation type adapted to climate change, e.g., warmer sites that may transform into subalpine grassland or mixed conifer, in coordination with management of other systems.

ADAPTATION STRATEGIES, OUTCOMES AND ACTIONS FOR THE SPRUCE-FIR LANDSCAPE

The climate adaptation strategies for the spruce-fir landscape are presented below in both table format and diagrams or *Results Chains*. These strategies incorporate all the information gathered over the course of this project, e.g., climate scenarios, social response to interviews and narrative scenarios, ecological response models, social-ecological response models, and interventions. See Figures 4-6 for diagrams or *Results Chains* summarizing desired outcomes, intermediate outcomes and actions for each of the three adaptation strategies.

Three Priority Adaptation Strategies for the Spruce-Fir Landscape

<table>
<tr><th>Adaptation strategy</th><th>Bio-climatic zones*</th></tr>
<tr><td>Identify and Protect Refugia (persistent areas)
Identify and manage the areas that are most likely to persist under our future climate. Conservation, management, and restoration of the spruce-fir landscape are much more likely to succeed within a climate refugia.</td><td rowspan="2">Persistent & Threatened
Persistent areas are the “refugia” or areas that are likely to maintain a suitable climate for spruce-fir.

Threatened areas may be able to survive changes, but future climate is marginal and may hinder regeneration for spruce or fir trees.</td></tr>
<tr><td>Proactive Treatment for Resilience
This strategy allows the development of treatment/ restoration plans that will improve the resiliency of the spruce-fir landscape, especially within those areas that are likely to be persistent. This strategy had the most number of identified interventions.</td></tr>
<tr><td>Assist and Allow Transformation
It is important to recognize that transformation is inevitable in many areas and rather than resist this change, change can be accepted and, perhaps, assisted or supported.</td><td>Lost and Emergent
Lost areas are where the future climate is highly unlikely to support spruce-fir and the area is most likely to transform into a grassland or some non-spruce-fir community once a large disturbance removes spruce-fir.

Emergent areas are where we believe the future climate will support spruce-fir habitat, but the area is not currently dominated by spruce-fir.</td></tr>
</table>

Strategy 1: Identify and Protect Persistent Ecosystems

Desired Outcomes (Climate impacts reduced and condition improved)
Protect, maintain and enhance areas identified as spruce-fir climate refugia (persistent areas) and linkages that are well-distributed across the landscapes that support viable populations of species of concern and provide ecosystem services for livelihoods.

Identifying, protecting, and managing patches that are likely to persist in the face of climate change will assist in maintaining a resilient spruce-fir subalpine forested landscape that supports viable populations of species of concern and supplies our human communities with a suite of ecosystem services.

►Intermediate outcomes
✧Actions to achieve outcome

Below are the intermediate outcomes (results) with key actions needed to achieve the desired outcomes. This strategy has one pathway to reach success.

Persistent ecosystems are refugia that are likely to support current ecosystems into the future.

- ► Climate and biophysical attributes identified that characterize persistent areas for three climate scenarios
  - ✧ Identify data gaps
  - ✧ Assess quality of areas
  - ✧ Use forest maps to identify biophysical attributes
  - ✧ Identify climate zones likely to persist

- ► Spruce-fir persistent areas and linkages are identified and mapped that support spruce-fir dependent species
  - ✧ Create map of potential persistent areas and linkages
  - ✧ Assess condition of potential linkages
  - ✧ Identify species and attributes for linkages
  - ✧ Clarify if linkages are for species and/or persistent areas
  - ✧ Compare current vegetation and future potential natural vegetation

- ► Persistent areas and linkages criteria agreed upon by major land managers
  - ✧ Identify stakeholders
  - ✧ Develop and implement outreach plan that communicates and collaborates with community and stakeholders
  - ✧ Assess and monitor wildlife use of linkages and persistent areas

- ► Management targeted within persistent areas and linkages to create more resilient spruce-fir system
  - ✧ Determine desired condition of persistent areas and linkages
  - ✧ Monitor change and effectiveness of management actions
  - ✧ Develop site specific prescriptions for each persistent area
  - ✧ Manage recreation
  - ✧ Implement monitoring
  - ✧ Define management constraints (e.g., wilderness)

- ✧ Determine management strategies for resilience in areas adjacent to persistent areas and within linkages
- ✧ Develop BMPs to incorporate livelihoods and recreation in forest management

► A network of mature spruce-fir forests is protected and maintained across the landscape
- ✧ Ground-truth linkages to ensure functionality.

Why this Strategy is Important

Persistent ecosystems, i.e., refugia, are areas likely to support spruce-fir forests into the future. This strategy is important as it is easier to maintain existing systems than to restore systems and adapt to climate change. The scale of linkage zones may vary depending on the species, e.g., large for lynx, smaller for martin, and species genetics. Management depends on the targeted species and objectives of the linkages. The refugia sites are likely to maintain a suite of ecosystem services that will benefit human communities, e.g., snow retention, flood mitigation, tourism, hunting and gathering, etc.

Challenges to Implementation

The key challenges to implementing this strategy are: 1) public understanding and/or acceptance, buy-in on the need for refugia, and finding willing landowners; 2) funding to protect and manage these areas; 3) existing policies provide sideboards as to what kinds of management can occur and may not easily allow the needed management; 4) ESA constraints around listed species, e.g., lynx, may limit management allowed; 5) potential push back from the timber industry if strategies constrain their ability to operate; 6) push back from environmental groups; and 7) physical and operational challenge of working on steep slopes.

Opportunities for Successful Implementation

Opportunities for successful implementation of this strategy include: 1) the ability to structure conservation easements to accommodate, support and encourage certain types of management; 2) mechanisms to work with private lands and implement at the landscape scale, e.g., the USFS Forest Legacy program, and working with private landowners through the Wyden Amendment; 3) opportunities for funding and learning through collaborative field trips, e.g., Uncompahgre Project, and 4) share the importance of refugia and the need to manage for resilience.

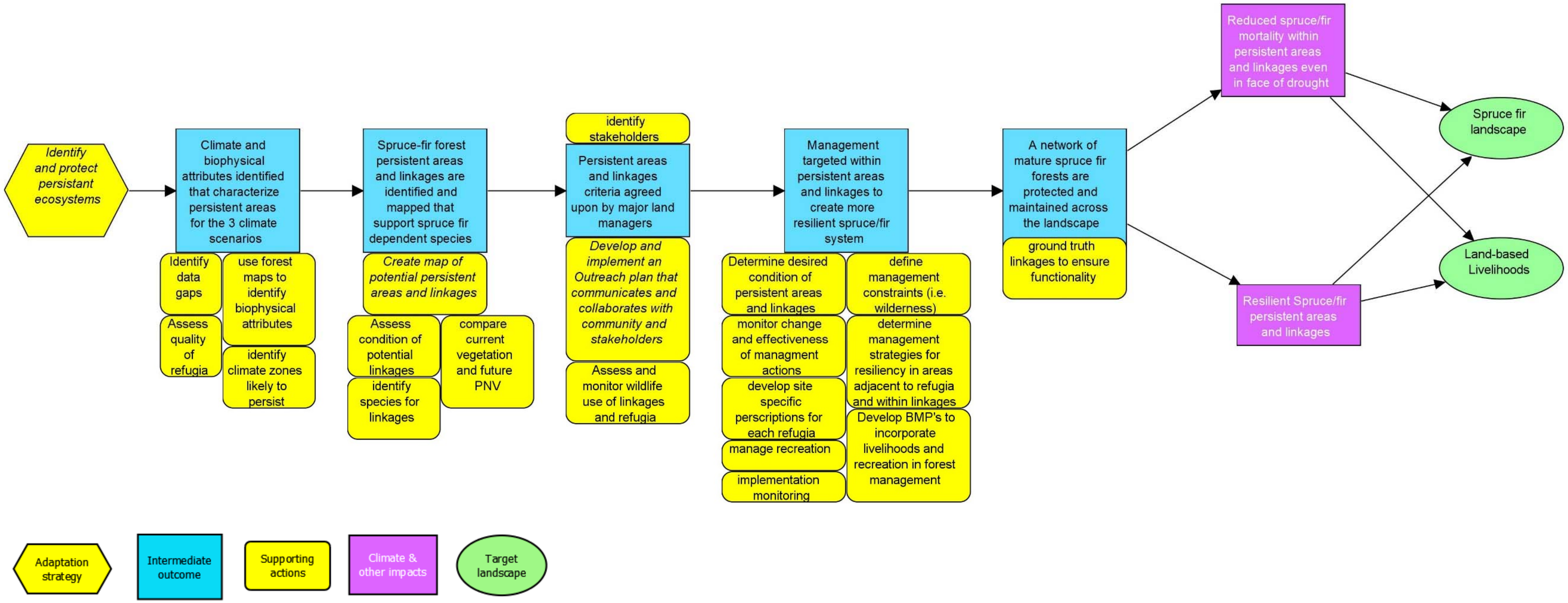

Figure 4. Results chain describing intermediate outcomes and actions for the *identify and protect persistent areas* strategy for the spruce-fir landscape.

Strategy 2. Proactive Treatment for Resilience

Desired Outcomes (Climate impacts reduced and condition improved)

Enhanced resiliency of the spruce-fir landscape to climate stressors by maintaining ecological processes and restoring or improving the condition of the system to support ecosystem services, wildlife, and social values.

This strategy applies to persistent and threatened zones and includes private landowners in both the Wildland Urban Interface (WUI) and the more remote parts of the forests. Ultimately we want to maintain a functional spruce-fir landscape that supports biodiversity and land-based livelihoods.

► Intermediate outcomes
✧ Actions to achieve outcome

Below are the intermediate outcomes (results) with key actions needed to achieve the desired outcomes.

Multiple parallel interconnected outcome paths are needed for success.

One path relates to insect outbreaks:

- ► Following insect and disease outbreaks, management activities create resilient forest
  - ✧ Protect live trees in high priority areas
  - ✧ Reforest as needed after outbreaks
  - ✧ Manage for age and species diversity
  - ✧ Collect tree genotypes that escape outbreaks

Management response following insect outbreaks is different from that following severe fire.

Another path relates to severe fire:

- ► Following severe fire, through management activities a resilient forest is created
  - ✧ Identify genotypes for future climate scenarios, e.g., Warm and Wet or Hot and Dry, as the climate could be a combination of all three scenarios
  - ✧ Plant trees in areas with low regeneration
  - ✧ Plant climate smart seeds that can grow under all scenarios

We need to identify desired condition in advance so we are ready to respond appropriately when disturbances happen; need to look at how climate influences the potential vegetation in the future. Seed mix should apply to all possible futures.

Another path relates to management:

- ► Experimental design and stratification system created
  - ✧ Articulate key questions needing addressing and what needs to be tested
  - ✧ Collect plant species for understory that could grow under all scenarios
  - ✧ Research how climate change will impact rare plants and pollinators
  - ✧ Prioritize where to work

  - ✧ Determine management constraints
  - ✧ Develop climate smart native species mixes for reseeding following disturbance
  - ✧ Experiment in different watersheds and monitor response
  - ✧ Reassess adaptive management objectives

An interconnected pathway leads through forest and fire management:

- ► Public educated to prepare for change and manage for resilience
  - ✧ Identify stakeholders, e.g., youth, advocacy groups that use the forest, community members
  - ✧ Develop and implement an outreach and education plan that communicates and collaborates with community and stakeholders on climate impacts and need for active management
- ► Forest and fire management create more resilient forests
  - ✧ Educate those that live in wildland urban interface (WUI) on fire adapted communities
  - ✧ Adaptively manage forests
  - ✧ Manage for drier and frost tolerant genotypes, age and structural diversity
  - ✧ Create forest mosaic
  - ✧ Protect live trees when salvage logging
  - ✧ Design silvicultural prescriptions to promote a resilient forest
  - ✧ Reforest as needed after forest management
  - ✧ Create fire breaks especially in WUI
  - ✧ Manage for diverse age and structure
  - ✧ Manage to protect infrastructure

Following forest and fire management, several pathways can be taken:

- ► Timber and salvage logging products and biomass economic opportunities developed
  - ✧ Non-timber forest products including osha and mushroom collecting do not impact forest resiliency
  - ✧ Take actions to achieve forest timber products

Following fire and forest management, another path relates to invasive species:

- ► Invasive species management plan developed and implemented
  - ✧ Map invasive species
  - ✧ Implement and monitor impact of weed treatments

Another path relates to recreation:

- ► Recreation managed so it does not negatively impact resiliency
  - ✧ Restrict recreation when impact is high on wildlife, soil, water, etc.
  - ✧ Educate public about need for sustainable recreation

Another path leads through hydrologic regime:

- ► Hydrologic regime managed and improved
  - ✧ Restore degraded wet meadows, willow carrs and wetlands
  - ✧ Replace culverts with climate-wise culverts
  - ✧ Establish climate wise roads and trails
  - ✧ Maintain willow carrs
  - ✧ Maintain/restore fens to increase soil carbon

Then,

- ► Soil productivity maintained
  - ✧ Consistent management to promote soil health
  - ✧ Monitor soil productivity
  - ✧ Monitor soil moisture
  - ✧ Manage/restore degraded areas for soil carbon storage
  - ✧ Determine carbon sequestration potential

Why this Strategy is Important

This strategy, when coupled with the refugia strategy, leads to a well-maintained and resilient spruce-fir landscape that provides the ecosystem services for human and natural communities. It is a critical strategy for promoting the capacity of the system to withstand change, retain vital characteristics and ecosystem services, and for reducing impacts from extended droughts and altered species composition. This strategy needs to apply to lands managed by private landowners within WUI as well as the more remote parts of the forests. It also outlines the risks that the forest landscape faces.

Challenges to Implementation

The key challenges to implementing this strategy are: 1) public acceptance of the need for proactive management; 2) NEPA processes may not fit well within framework; 3) the scale of needed treatment is challenging, e.g., removing hazard trees along road is fine, but treatment half mile from road is less acceptable, e.g., within wilderness or roadless areas; 4) litigation can hold up getting work done; 5) working with multiple stakeholders; 6) impacts on wildlife habitat, e.g., potential for conflicts between lynx and other species; 7) treatments may be expensive on large acreages; 8) experimental design may take time as the trees grow very slowly - adaptive management takes a long time and could be expensive; 9) securing funding for proactive treatments; 10) skilled labor needed to maintain the timber industry; and 11) maintaining momentum to continue and adapt this project as new information becomes available after this project ends.

Opportunities for Successful Implementation

Opportunities for successful implementation of this strategy are: 1) to increase public and local community understanding of the importance of the impacts and that there is something we can do to address climate change; 2) local businesses can potentially help tell the message; 3) removal of spruce could help cover costs of other treatments; 4) alternative products, e.g., biomass products, can help increase markets; 5) funding projects by FEMA and/Colorado Water Plan and Basin Round Table, Stream Management Planning, or local governments; 6) incorporate climate-smart strategies into the 10-12 year USFS Spruce Beetle Epidemic and Aspen Decline (SPEADMR) Project; 7) work with graduate students, researchers, and willing landowners to test treatments and/or fill data gaps; 8) share information among agencies; 9) county commissioners can advocate for the project; 10) Colorado State Forest Service funding for fire restoration projects to support climate-smart projects; 11) funding for land acquisition and land stewardship from towns and counties; 11) engage youth, e.g., the WSCU Masters in Environmental Management Program; and 12) influence GMUG forest plan revision.

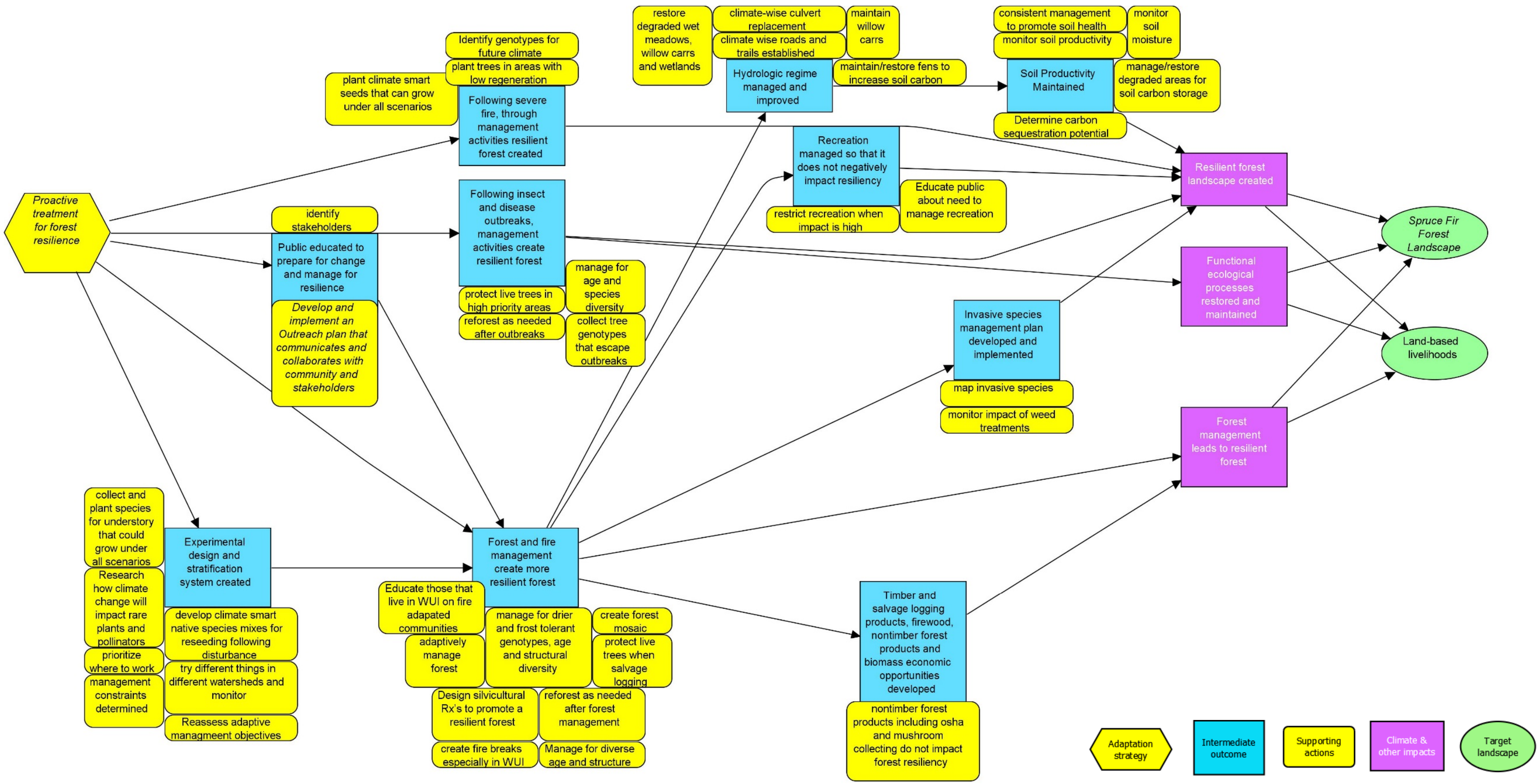

Figure 5. Results chain describing outcomes and actions for the *proactive treatment for resilience* strategy for the Spruce-Fir Landscape.

Strategy 3: Assist and Allow Transformation

Desired Outcomes (Climate impacts reduced and condition improved)
Recognition and acceptance that some sites will not support current spruce-fir stands under future climate and that other areas will become suitable habitat. Rather than resist the transformation we will assist the transformation.

This strategy accepts that some areas are unlikely to be repopulated by a spruce-fir forest after a disturbance kills the stand (the opposite of a refugia), as well as the likely natural migration of spruce-fir into the alpine region.

▶Intermediate outcomes
✧Actions to achieve outcome

Below are the intermediate outcomes (results) with key actions that may be needed to achieve the outcomes.

Multiple parallel interconnected outcome paths are needed for success. One path leads through warm refugia:

- ▶ Research and monitoring program created to guide transformation
  - ✧ Identify warm refugia areas
  - ✧ Protect warm refugia
  - ✧ Map lower edge of spruce-fir landscape
  - ✧ Monitor

Then,

- ▶ Warm refugia expanded within current spruce fir landscape and within mixed conifer
  - ✧ Manage for the expansion of refugia by protection from wildfire, e.g., thinning
  - ✧ Collect seeds from warm refugia and spread seeds and genetic material
  - ✧ Manage for seed source of drought tolerant species within the spruce-fir landscape
  - ✧ Monitor impact on wildlife of tree species changes

Warm refugia are existing sites within the spruce-fir landscape that represent a warmer climate. These sites are likely to provide an excellent seed source as well as a reference site. The vegetation within these warm refugia is an indicator of the species that are most likely to persist and "emerge" into adjacent areas once a disturbance kills the adjacent spruce-fir forest.

Another path leads through public education:

- ▶ Public is educated about change, insects, disease and need for transformation
  - ✧ Conduct public outreach to build acceptance and teach people how to live with fire and the need for on the ground management before forest becomes overgrown and dense.

Then,

- ▶ Climate-smart revegetation strategy developed
  - ✧ Develop new guidelines and change policies allowing for seed transfer of trees, shrubs, forbs and grasses between zones
  - ✧ Develop native materials program including shrub, forb, grass and tree species
  - ✧ Collect seed cones and seeds from highest elevation species
  - ✧ Collect mixed ecotypes not just leading edge

- ✧ Collect seed cones and seeds from lowest elevation species

Then either:

- ► Following insect events, facilitate transition to drier species at lower edge
  - ✧ Manage fuels in beetle areas

Or:

- ► Aspen stands expanded where appropriate
  - ✧ Manage elk population
  - ✧ Adaptively manage and monitor impacts of elk, deer, cattle and sheep grazing
  - ✧ Monitor impact on wildlife of tree species changes
  - ✧ Manage aspen as fire breaks

The above pathways flow through this intermediate outcome:

- ► Fire management facilitates transition to drier species, fire resistant/resilience species at lower edge
  - ✧ Manage burned areas to ensure fire frequency is low
  - ✧ Identify and reinforce natural fire breaks
  - ✧ Educate recreationalists to prevent human fire starts
  - ✧ Replant trees where needed
  - ✧ Mechanical fuel treatments
  - ✧ Manage for mosaic, e.g., warm refugia

Then,

- ► Climate-adapted vegetation communities (species mixes) facilitated
  - ✧ Research seed sources and regeneration of new species within and outside of basin
  - ✧ Plant fire adapted and drought resistant species mix from lower and upper elevation

- ► Planning and zoning integrated into plans to reduce home building in forests
  - ✧ Develop county regulations with incentives for height, density, and fire smart activities
  - ✧ Include insurance companies and real estate companies to ensure homes are safe and people have fire insurance

- ► Forest is managed for healthy carbon cycle as an ecosystem service
  - ✧ Research baseline for carbon sequestration

Why this Strategy is Important

This strategy is focused on emergent and lost zones of the spruce-fir landscape. It is our only strategy that accepts and embraces major changes. These major changes are more likely to occur in the low-elevation areas that are currently very dry sites and at high elevations. Management options are more limited in the emergent zone, where many rare plants occur. It is important to pay attention to rare plant populations and what can be done to protect them as they may have no place to go; specific rare plant areas will need research and monitoring. Experimental design and monitoring are needed early on for implementing this strategy as there is great uncertainty about the speed of the transformations and results of the actions. Emergent areas may not be located in wilderness. Species composition in the alpine is already changing, likely because of longer growing season. Spruce-fir is getting squeezed and krummholz (the transition between alpine and subalpine) trees are bolting. Timber industry is already looking at different tree species.

Challenges to Implementation

In many ways, this is our most challenging strategy, as we are accepting a change but we are not highly confident on what the change will be. The key challenges to implementing this strategy are: 1) public acceptance of change, e.g., public response to gaining trees is very different from losing trees; 2) likelihood of more frequent fires in the WUI with increased warm refugia; 3) funding and resources for implementing this strategy could be problematic; 4) obtaining clearance for genotypes of plants suitable for revegetation; 5) potential conflicts between carbon storage and letting forests burn (need balance between putting out fires and overly dense forest; carbon storage is an ecosystem service); 6) gaining support for assisted migration; and 7) only a small percent of the forest is manageable (however, you can seed in Wilderness areas after fire).

Opportunities for Successful Implementation

The key opportunities for implementing this strategy are: 1) to form partnerships with WSCU and other universities to conduct research to address key data gaps and monitoring to inform management associated with this strategy; 2) creativity to use various tools such as snow fences and/or new technology such as drones and cameras to monitor change; 3) to plant aspen around the WUI as it is less flammable than conifer species; 4) to change the dialogue from climate change to managing for natural resiliency and healthy forests; 5) to increase carbon sequestration, although we recognize that there will be tradeoffs; and 6) to include this strategy into silvicultural prescriptions for management for the Colorado State Forest Service as a way to improve forest health.

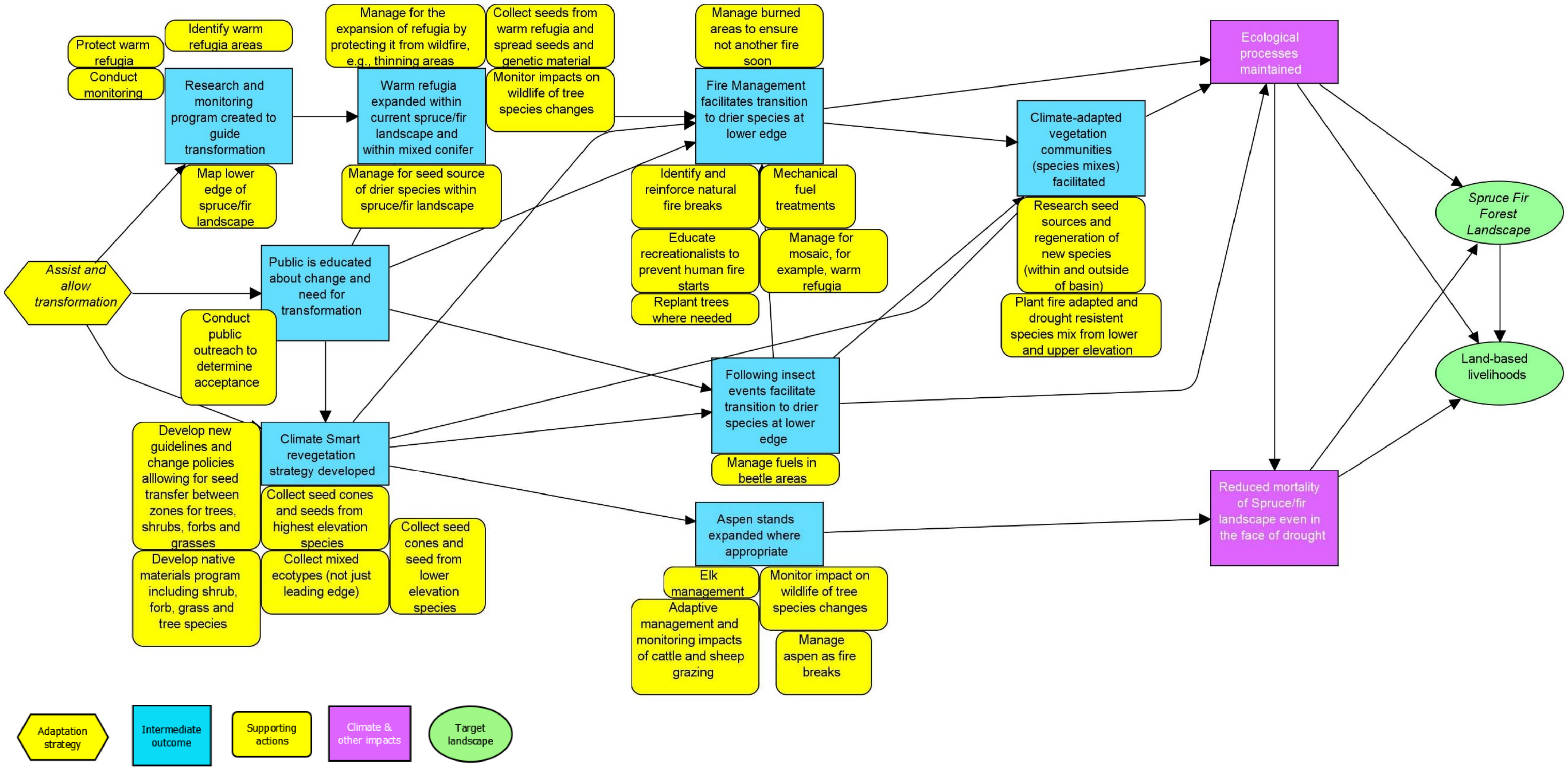

Figure 6. Results chain describing outcomes and actions for the *assist and allow transformation* strategy for the spruce-fir landscape.

Overarching Challenges and Opportunities for Application of the Three Climate Adaptation Strategies

At the final workshop in April, 2016, participants articulated overarching challenges to implementing the three climate adaptation strategies and the use/application of workshop results, summarized below.

Challenges/Barriers

1. Human use, e.g., housing development, as population increases in Colorado and beyond
2. Acceptance by the public of the reality of climate change and that it isn't going away
3. Agency capacity and funding to implement the strategies and actions
4. Funding to support proactive management when wildfire may get worse and most of the funding goes to fire-fighting/fire suppression
5. Some groups oppose the USFS Spruce Beetle Epidemic and Aspen Decline Management Response project.

Opportunities to Use and Apply the Project Results

Participants were asked at the final Spruce-Fir Workshop in April, 2016: How can you take this information and use it? How are you going to use it?

1. Inform agency planning, actions, and decisions: Partners noted that the project and results will help them to prioritize future work. There is currently an opportunity to inform the Grand Mesa, Uncompahgre, Gunnison National Forest (GMUG) plan revision, e.g., to identify the refugia and define linkages. The Colorado State Forest Service (CSFS) can use projected models for forest type distribution in silvicultural strategies. Partners noted that this project has helped educate them on climate change and strategies to cope with change.
2. Application at larger scales: Some agencies have been using these techniques at smaller scale and this work will help with strategic decisions regarding management and land acquisition/easement acquisition at larger scales.
3. Sharing results: Participants stressed the importance of sharing the strategies with stakeholders and upper-level managers within the Gunnison Basin, and sharing the methods for potential application in other landscapes.
4. Wildlife management: This information can help CPW managers think about how wildlife populations will respond, inform management plans and number of licenses to offer, and how to stay ahead of the game.
5. Working with landowners: The CSFS will be able to share this information for use on specific projects working with landowners.
6. Identify refugia and linkages: BLM and USFS are interested in identifying refugia with geographic representation where spruce-fir can be conserved.
7. Prioritization of work: The results will help land trusts prioritize conservation and land acquisition. They can also help CPW to refocus and think differently about how to prioritize work, from species to habitats.
8. Tools: The tools and information can help USFS and others manage landscapes and meet their mission of healthy landscapes and multiple uses. It can also help communities who are

dependent on public lands and their ecosystem services, continue to persist and thrive.
9. Research: This effort will help drive research on unanswered questions for managers. Funding is needed for research to support adaptive management.
10. Garnering support for action: This information will be helpful to share with people to help gain support for taking climate action.
11. Funding: Some partners indicated that reactive vs proactive strategies are more likely to be funded, e.g., timber budget has gone up 50% to address beetle mortality. The USFS is implementing the Spruce Beetle EIS and currently have increased budgets.

NEXT STEPS

Refining the Framework:

1. Develop a streamlined template of the framework that can be applied to other conservation landscapes in and beyond the Basin.
2. Scale-up lessons learned regarding how to integrate social, ecological and climate science and share the model with others conducting similar projects.

Implementation:

1. Further develop the strategies/actions and develop an implementation plan, particularly for the assist and allow transformation strategy to help clarify desired outcomes and audience.
2. Initiate "the identify and protect refugia" strategy and actions with stakeholders, managers and project team.
3. Apply and refine the planning framework to other targeted landscapes. Bring communities together around key topics, e.g., drought, fire and invasive species.
4. Implement the strategies/actions and develop a monitoring program to detect trends and progress towards goals and objectives.
5. Develop criteria to evaluate progress in implementing the strategies and evaluate progress (identify barriers to implementation).

Sharing Results:

1. Share project results with upper-level managers of key federal and state agencies, e.g., USFS, BLM, NRCS, and NPS.
2. Present and discuss results with a broader audience representing non-governmental stakeholders from the recreation, range, ranching, and fire sectors, non-profit organizations, and representatives from other towns, as well as governmental officials.
3. Develop an outreach plan for the project and key strategies.
4. Develop a high-level executive summary of the project to share with stakeholders and partners; share results broadly.
5. Develop a clearinghouse for sharing maps, data, charts, graphs, bio-climate models, and other products that is accessible to managers, participants and stakeholders.

Conclusions and Lessons Learned

The planning framework used for this project builds on earlier social-ecological vulnerability assessments. It consists of selecting social-ecological landscapes, developing climate scenarios, developing narrative scenarios and ecological response models, conducting interviews and focus groups, developing social-ecological response models, identifying impacts and interventions, and developing strategies and actions. The framework was applied with natural resource managers, researchers and other stakeholders to develop robust climate adaptation strategies for the sagebrush landscape in the Gunnison Basin.

The project team worked with the GCWG and other stakeholders to apply the planning framework to the sagebrush landscape in the Gunnison Basin. At the same time, another group of stakeholders focused on pinyon-juniper woodlands and seeps and springs in the San Juan Basin. The two groups ended up with similar themes of adaptation strategies: conserve climate refugia, proactively treat for resilience, and assist/allow transformation.

The adaptation strategies are based on three basic principles for different zones for the sagebrush landscape in the face of a changing climate: 1) work in sagebrush shrublands most likely to persist in the future, 2) focus on proactive treatment to build resilience in persistent sagebrush areas; and 3) assist and/or allow transformation in emergent and/or lost zones.

Important next steps include sharing results, further developing the strategies and actions, implementing actions and designing a monitoring program to track progress towards goals and objectives, evaluate the efficacy of strategies and actions, and adjust actions as needed.

This framework could be applied in other landscapes and inform on-the-ground work to prepare for a changing climate and associated impacts.

Lessons Learned

Climate Scenarios and Bio-Climatic Models

Utilizing three climate scenarios was useful in understanding the uncertainty associated with climate. Developing strategies for one climate scenario (Feast and Famine) first and then evaluating how well those strategies addressed the two other scenarios helped to streamline the process while effectively dealing with the breadth of potential climates. Many workshop participants commented about the utility of the bio-climatic models to help visualize geographical opportunities for implementing strategies. However, it is important to note that these are models and may not represent reality. One participant suggested the need for more consideration of extreme events in all scenarios, interventions and strategies.

Situation Analysis and Chain of Consequences Methods

Workshop participants suggested using a combination of both the *Situation Analysis* and the *Chain of Consequences* methods for identifying interventions. The *Situation Analysis* can be used first to understand the landscape context and explore a broad range of impacts, followed by the *Chain of*

Consequences to drill down into more specific interventions. It is important to allow enough time to develop comprehensive chains and interventions, potentially up to one-half day per impact. Additional preparation may improve efficiency given the time constraints, e.g., having a draft list of primary consequences to react to and build from may have saved time at the workshop.

Opportunity to Compare Results developed by Different Groups

Different participant groups produced different results at the April, 2015 workshop using the two different methods, *Situation Analyses* and *Chain of Consequences*. While the primary consequences were similar among groups, the choice of which chains to further develop, chain length, and the focus on ecological versus socioeconomic consequences differed among groups. Some results clearly reflected the composition of the group (e.g., groups with more social scientists explored more social and economic issues), thus it is important to recruit a diverse set of participants to workshops to ensure a balanced outcome that integrates both social and ecological perspectives.

Interviews and Focus Groups

The interviews and focus groups helped the team understand the natural resource managers and stakeholders making decisions about adaptation in this landscape, including how they might respond to local climate impacts, what they need to respond, and the decision-context within which they work. Further, this part of the social science research helped identify risk perceptions and key barriers to effective adaptation. These were critical insights that ensured that adaptation strategies addressed important risks and recognized barriers to be tackled in the future. Additionally, utilizing scenarios in the focus groups built knowledge of how decision-makers navigate uncertainty when planning for climate change and made uncertainty explicit in the decision-making process. Thus, while we learned from the focus groups that planning for a range of futures was particularly challenging, we integrated a range of futures into the steps that followed, building capacity to plan in the face of uncertainty.

In this project, climate science was integrated into social science research through the scenario-based focus groups, which built a dialogue between social, ecological, and climate processes that informed our overall understanding of the systems. Ultimately, engaging with decision-makers through in-depth interviews and scenario-based focus groups enabled the group to develop useable, relevant tools and products that are feasible within the current institutional, governance, management and regulatory context.

Results Chains

Workshop participants noted that walking through the *Results Chains* step by step, discussing gaps or redundancies, was useful in developing the strategies and stimulating discussion and refinement. The *Results Chains* provided a structure to develop actions, but due to time constraints we were not able to develop more detailed and measurable actions. Engaging participants to present the draft *Results Chains* of the strategies increased understanding and discussion. Including text with the diagram to describe the *Results Chain* was a useful way to communicate the strategies/actions.

Workshops

The workshops provided an opportunity for thought-provoking discussion, interaction and learning for an interdisciplinary group of stakeholders, managers, and academics with different perspectives. The process of discussing goals and outcomes with state and regional stakeholders enabled participants to put their work into the larger perspective. Participants noted the importance of providing all materials developed through this project for reference at each workshop. The workshops, held in Gunnison, provided a wonderful opportunity for professors and graduate students from WSCU to engage with natural resource managers and community stakeholders. After the earlier workshops, several participants commented that it would have been useful to have more diverse user groups, e.g., non-governmental stakeholders; the team worked to broaden representation at later workshops.

Connecting Social and Ecological Components

Connecting social and ecological components of the targeted landscape was a challenge. There are opportunities to improve the integration of social-ecological components. It matters who participates in the workshops. We recommend that social scientists and users across sectors (e.g., recreation, grazing permittees) participate in all meetings. It is important to clearly define and name the targeted landscape that includes both the ecological and social systems. For example, we called the target the sagebrush landscape, but we suggest that we use a term such as sagebrush and working rangelands landscape. Finally, A social and economic vulnerability analysis would be a nice addition to the vulnerability analysis. This would help tie the livelihoods, users and their economic value. For example, in ranching is a prime economic value; if sagebrush has a high vulnerability, it affects the livelihoods.

Approach and Duration

This project applied multiple methods to identify impacts of climate change on the sagebrush landscape and to develop social-ecological adaptation strategies, e.g., three climate scenarios, ecological response models, *Chain of Consequences*, *Situation Analysis*, interviews and focus groups, and *Results Chains*. This process took almost three years to implement. Application of different methods resulted in similar adaptation strategies. For example, the refugia strategy rose to the top across the different targeted landscapes. Thus, in the future, to increase efficiency in developing adaptation strategies for other landscapes or ecosystems, teams may utilize only one or two methods to develop robust strategies. Developing the products over a shorter timeframe might help with ensuring consistent participation at workshops.

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Appendix A. Glossary

Adaptation

Climate change adaptation for natural systems is a management strategy that involves identifying, preparing for, and responding to expected climate changes in order to promote ecological resilience, maintain ecological function, and provide the necessary elements to support biodiversity and sustainable ecosystem services.

Adaptation Actions

Specific on-the-ground management or conservation actions associated with adaptation strategies that will strengthen the resistance and resilience of sites, habitats, and species under a changing climate. Actions designed specifically to address the impacts of climate change.

> *Example: Plant riparian vegetation along target streams in areas that have been denuded to provide stream shading and buffer floods.*

Adaptation Strategies

Management efforts designed to help nature and people prepare for and adjust to climatic changes and associated impacts. Strategies are focused on reducing impacts of climate change on nature and people, reducing non-climate stressors, protect ecosystem features, ensure connectivity and restore ecosystem structure and function on a large scale.

In-depth strategies have nested actions and articulate what you are trying to do, how, when and where you will implement actions to meet goals and objectives. Ideally, the strategies are robust across different climate scenarios. They are not intended to be decision making, rather for informing decision-making.

> *Example of a high-level adaptation strategy for the Gunnison sage-grouse brood-rearing habitat: Retain water in most-vulnerable brood-rearing habitats through water management: restore wet meadows across the Gunnison Basin to build ecosystem resilience and help the Gunnison sage-grouse and other wildlife species adapt to drought and intense precipitation events associated with climate change.*

> *Example: Shift the age class distribution of conifer forest in 10 locations across the basin, by planting diverse species of trees, following best practices.*

Adaptation Target

A feature (livelihood, species, ecological system, or ecological process) of concern that sites at the intersection of climate, social and ecological systems (adapted from Cross et al. 2012).

Chain of Consequences

Identifies the potential short- and long-term environmental, social, and economic cascading consequences of an event or disturbance, and determines intervention points. Methods developed by the Department of the Interior (US Geological Survey). Method used at the April 2015 climate adaptation workshop.

Climate Scenarios

To aid in decision-making in the face of uncertainty, climate scientist Imtiaz Rangwala (PSD/NOAA; WWA/CIRES, University of Colorado) developed three climate change scenarios for southwestern Colorado based on a range of temperature and precipitation projections by 2035 from 72 global climate models that considered 2 RCP-representative concentration pathways (8.5 and 4.5). These scenarios represent three plausible but divergent future climate pathways for southwestern Colorado during the 21st century (Rangwala, 2015).

> *Climate scenarios for this project are: 1) Hot and Dry, 2) Warm and Wet; and 3) Feast and Famine (moderately hot, no change in precipitation, increased climate variability).*

Conservation Target

For the purposes of this project, a conservation target consists of a large-scale landscape, consisting of both natural and human systems, that is targeted for conservation and adaptation strategy development. The targeted landscapes for the Gunnison Basin include sagebrush shrublands and spruce-fir forests. Numerous animal species, plant species and human communities in the Gunnison Basin rely on functioning sagebrush and spruce-fir landscapes that are at risk of a changing climate.

The sagebrush shrubland landscape consists of a mosaic of ecosystems dominated by Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) at the lower and drier elevations and mountain sagebrush (*Artemisia tridentata ssp. vaseyana)* at the wetter and upper elevations. Smaller patches of other ecosystems are scattered throughout the landscape including: montane grasslands, windswept low sagebrush, high elevation meadows, low-elevation aspen patches, low-elevation grasslands, wet meadows, and groundwater dependent wetlands. It is the core habitat for Gunnison sage-grouse and includes seasonal habitats as well as the lek grounds, nesting, and brood-rearing habitats. At the upper elevations it is bounded by aspen or mixed-conifer stands. Characteristic animals include Brewer's sparrow, Sage sparrow, Sage thrasher, Green-tailed towhee, Gunnison Sage grouse, Gunnison's prairie dog, and Pronghorn. This landscape ranges in elevation from 7,500 ft. to 9,500 ft. and encompasses over 1/2 million acres within the Basin.

The spruce-fir landscape consists of a mosaic of ecosystems dominated by Engelmann spruce and subalpine fir, ranging from 10,000-12,500 ft. in elevation. The lower elevations often consist of dense stands of spruce-fir forest with smaller patches of aspen or lodgepole pine. At the upper elevations it transitions into the alpine zone with a mosaic of willows, wetlands, and mesic or dry alpine meadows. Smaller patches of other ecosystems, e.g., wetlands and fens, are scattered throughout the landscape. Characteristic animals include Boreal Owl, Three-toed woodpecker, Gray Jay, Pine Grosbeak, Pine Marten, Snowshoe Hare, and Lynx. Characteristic animals include Boreal owl, Three-toed woodpecker, Gray jay, Pine grosbeak, Pine marten, and Lynx. This landscape supports White-tailed ptarmigan, marmots, pikas, and elk and is very important for numerous rare plants. It primarily ranges from approximately 10,000-12,500 ft. with very dense stands below 11,000 ft. At around 11,500 feet the dense stands transition into a patchy mosaic of trees, willows, wetlands, and mesic and dry alpine meadows - the subalpine zone. This landscape encompasses over 1/2 million acres within the Basin.

Ecological Response Models

Ecological response models, based on literature review and expert opinion, describe how the landscape operates and provides a context for evaluating potential impacts of different climate scenarios. Models help identify outside environmental influences or drivers, and show the relationships among the main contributing factors that drive one or more of the direct threats that, in turn, impact the landscape. The purpose of assessing the model under three different climate scenarios is to provide a foundation of scientific understanding and inform the development of robust social-ecological adaptation strategies in the face of an uncertain future.

Goal

Broad aspiration or overarching vision for focal features. Should be forward looking rather than retrospective.

> *Example: Maintain forest cover of sufficient structural and compositional complexity that it can sustain key ecosystem functions, particularly providing habitat for forest-dependent songbirds and other wildlife.*

Intervention Points

Elements in the system that can be manipulated or influenced through management and/or conservation actions; *starting points for developing in-depth adaptation strategies, policies and actions.* For this project, interventions were identified through situation analyses and chain of consequences for the feast and famine scenario at the April 2015 workshop. Interventions were then evaluated to see how well they work for the other two scenarios at the November 2015 workshop.

> *Examples for managing stream flows for cold-water fish: withdrawals, snowpack management and riparian vegetation management.*

> *Example for Gunnison sage-grouse identified at the 2009 Climate Adaptation Workshop is groundwater (water table levels) and vegetation management within brood-rearing habitat.*

Linkages

Also known as corridors. Any space, usually linear in shape, that improves the ability of organisms to move among patches of their preferred habitat. What serves a corridor for one species may not serve as a corridor for other species. Corridors can be natural features of a landscape or can be created by humans. Connectivity is a measure of the ability of organisms to move among separate patches of suitable habitat and can be viewed at various spatial scales (Hilty et al. 2006)

Objectives

Specific, measurable aims towards achieving goals. Ideally, defines the what, when, why and where.

> *Examples: By 2035, increase abundance of historically dominate boreal conifers, e.g., white spruce, white pine, tamarack, by 5 % with 80% confidence; Increase native fish populations to viable numbers, restore 1200 acres of salt marsh habitat with 90% confidence.*

RCP – Representative Concentration Pathway

Representative concentration pathways (RCPs) are climate scenarios implemented in the IPCC Fifth Assessment Report. Each RCP (2.6, 4.5, 6.0, and 8.5) provides projections of atmospheric greenhouse gas concentrations over time, based on assumptions about economic activity, energy sources, population growth and other socio-economic factors. RCPs have generally replaced the emissions scenarios (A1, A2, B1, B2, etc.) used in previous climate projection efforts.

For each category of emissions, an RCP contains a set of starting values and the estimated emissions up to 2100 (the data also contain historic, real-world information). While socio-economic projections were drawn from the literature in order to develop the emission pathways, the database does not include socio-economic data.

Refugia

Physical environments that are less affected by climate change than other areas (e.g., due to geographic location) and are thus a "refuge" from climate change for organisms. Protection, management and restoration are much more likely to succeed if within a climate refugia.

Resilience

Traditionally, resilience refers to actions designed to improve the capacity of a system to return to desired conditions after disturbance, or to maintain some level of functionality in an altered state. In the adaptation literature, resilience is considered part of a continuum of strategies, from resistance, to resilience and transformation. Recently, the concept of resilience has been used more expansively to embrace the potential for continued functionality and self-organization in the process of ecological transitions. Managing for resilience can be considered a way to enhance the natural adaptive capacity of systems by increasing their ability to self-organize in response to change (Stein et al. 2014).

The NPS Director's Order #100 (Resource Stewardship for the 21st Century) defines resilience as the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. Resilience strategies may include managing for the persistence of current conditions, accommodating change, or managing towards desired new conditions. Resilience strategies may vary and desired conditions must be clearly identified (Department of Interior NPS, 2016).

Because the term has multiple meanings, it is important to clearly state the context in which it is being used, e.g., resilience of what (e.g., ecosystems, livelihoods), to what changes (floods, drought) and how much of what kinds of changes (in structure or function).

> *Example: Resilience of North Woods Forests to negative effects of warming, drying of forest vegetation; keep system a forest, prevent conversion to shrub/grassland, but accept changes in composition.*

Resistance

The ability of an organism, population, community, or ecosystem to withstand a change or disturbance without significant loss of structure or function. From a management perspective, resistance includes both (1) the concept of taking advantage of/boosting the inherent (biological) degree to which species are able to resist change and (2) manipulation of the physical environment to counteract/resist physical/biological change.

Results Chain

A diagram that depicts the assumed causal linkage between a strategy and desired outcomes needed to reduce climate impacts (and other threats) through a series of expected intermediate outcomes and actions (modified from Margoluis 2013). Results chains are important tools for helping teams clearly specify their theory of change behind the strategies/actions they are implementing. Results chains can help teams to make assumptions behind strategies/actions and develop relevant indicators to monitor and evaluate whether their actions will have the intended impact.

Situation Analysis

Identifies specific connections between people and nature and allows exploration and understanding of the political, socioeconomic, cultural, institutional and ecological context of a landscape. This analysis describes the current understanding of a project's ecological status and trends, and the human context. It is used to identify intervention points for developing strategies. Methods were developed by the Conservation Measures Partnership and used at the April 2015 climate adaptation workshop.

Transformation

The expectation and acceptance that a conversion to a new ecosystem type is likely to occur, i.e., a transformation from one ecosystem type to a new ecosystem type. Transformation strategies support and facilitate system changes to an altered state based on a predicted future climate. The altered state is unlikely to support the climate processes necessary for regeneration of the dominant species for which the system is known.

> *Example: Due to a new climate, a low-elevation sagebrush stand is unlikely to support sagebrush and is likely to transform into a new ecosystem type such as a desert grassland or a grassland dominated by cheatgrass.*
>
> *Example: A low-elevation montane aspen stand is killed due to a drought and mountain sagebrush moves into the area, and the climate no longer supports aspen regrowth.*

Appendix B. Workshop Participants

Participant	Organization	January 8, 2014	June 23 &/or November 20, 2014	April 23, 2015	February 24, 2016	April 14, 2016
Rob Addington	TNC		X			
Gay Austin	BLM		X			
Mike Babler	Consultant	X		X	X	X
Mike Battaglia	USFS RMRS				X	X
Kristen Barker	CPW	X				
Marcie Bidwell	MSI		X	X		X
Andrew Breibart	BLM			X	X	
Matt Bienkowski	USFS				X	X
Brian Brown	BLM		X			
Ian Billick	RMBL			X		
Chris Bove	NRCS	X				
Brian Brown	BLM			X		X
Nina Burkardt	USGS	X				
Esme Cadiente	MSI			X		
Matt Castle	USFS	X				
Katie Clifford	CU	X				
Casey Cooley	CPW					X
Jim Cochran	Gunnison County	X				
Jonathan Coop	WSCU			X	X	
Trevor Even	NCCSC					X
Karin Decker	CNHP		X			
Gretchen Fitzgerald	USFS				X	X
Robert Frank	WSCU					X
John Gioia	WSCU			X		X
Lee Grunau	CNHP					X
Jonathan Houck	Gunnison County			X		X
Carol Howe	USFS		X	X	X	X
Merrill Kaufmann	Consultant		X	X	X	
Corrie Knapp	WSCU					X
Paula Lehr	Private		X			
Paige Lewis	TNC		X			
Frank Kugel	UGRWCD					X
Kristen Ludwig	USGS			X		
Shannon McNeeley	NCCSC	X				X
Pat Magee	WSCU	X				

Participant	Organization	January 8, 2014	June 23 &/or November 20, 2014	April 23, 2015	February 24, 2016	April 14, 2016
Susan Marketi	USFS FHP		X			
Pat Medina	USFS			X		
Wendi Maez	Saguache County					X
Sarah Miller	USFS		X			
Jeff Morisette	NCCSC	X				
John Murphy	USFS	X				X
Julia Nave	WSCU					X
Betsy Neely	TNC	X	X	X	X	X
Johanna Nosal	USFS		X	X		X
Sam Pankrantz	CSFS			X		X
Chris Parmeter	CPW					X
Suzie Parker	USFS		X			
Hedda Peterson	CRLT					X
Imtiaz Rangwala	WWA, NOAA		X	X	X	
Jim Ramirez	USFS			X		X
Bruce Rittenhouse	BLM					X
Renée Rondeau	CNHP	X	X	X	X	X
Trey Schille	USFS		X			X
Terri Schulz	TNC		X	X	X	
Rudy Schuster	USGS	X				
Amy Seglund	CPW	X		X	X	
Nathan Seward	CPW	X				
George Sibley	UGRWCD			X		
Jason Sibold	CSU				X	
Clay Speas	USFS			X	X	X
Brian St. George	BLM	X				
Sam Stahley	USFS			X		
Ken Stahlnecker	NPS	X				
Rebecca Stern	WSCU					X
Brian Stevens	BLM				X	X
Teresa Stoepler	USGS			X		
Bill Travis	CU	X				
Michael Waldon	USFS		X			
Chris Wehrli	USFS					X
Matt Vasquez	USFS	X		X	X	X
J Wenum	CPW					X
Jim Worrall	USFS FHP		X	X	X	
Laurie Yung	UM	X				

List of abbreviations used to indicate participant agency affiliation

BLM	Bureau of Land Management
CBLT	Crested Butte Land Trust
CNHP	Colorado Natural Heritage Program
CPW	Colorado Parks and Wildlife
CSFS	Colorado State Forest Service
CSU	Colorado State University
CU	University of Colorado
FHP	Forest Health Protection
MSI	Mountain Studies Institute
NCCSC	North Central Climate Science Center
NOAA	National Oceanic and Atmospheric Administration
RMBL	Rocky Mountain Biological Laboratory
TNC	The Nature Conservancy
UGRWCD	Upper Gunnison River Water Conservancy District
USFS	US Forest Service
USFS RMRS	US Forest Service Rocky Mountain Research Station
USGS	US Geological Survey
UM	University of Montana
WSCU	Western State Colorado University
WWA	Western Water Assessment

APPENDIX C. CLIMATE SCENARIOS

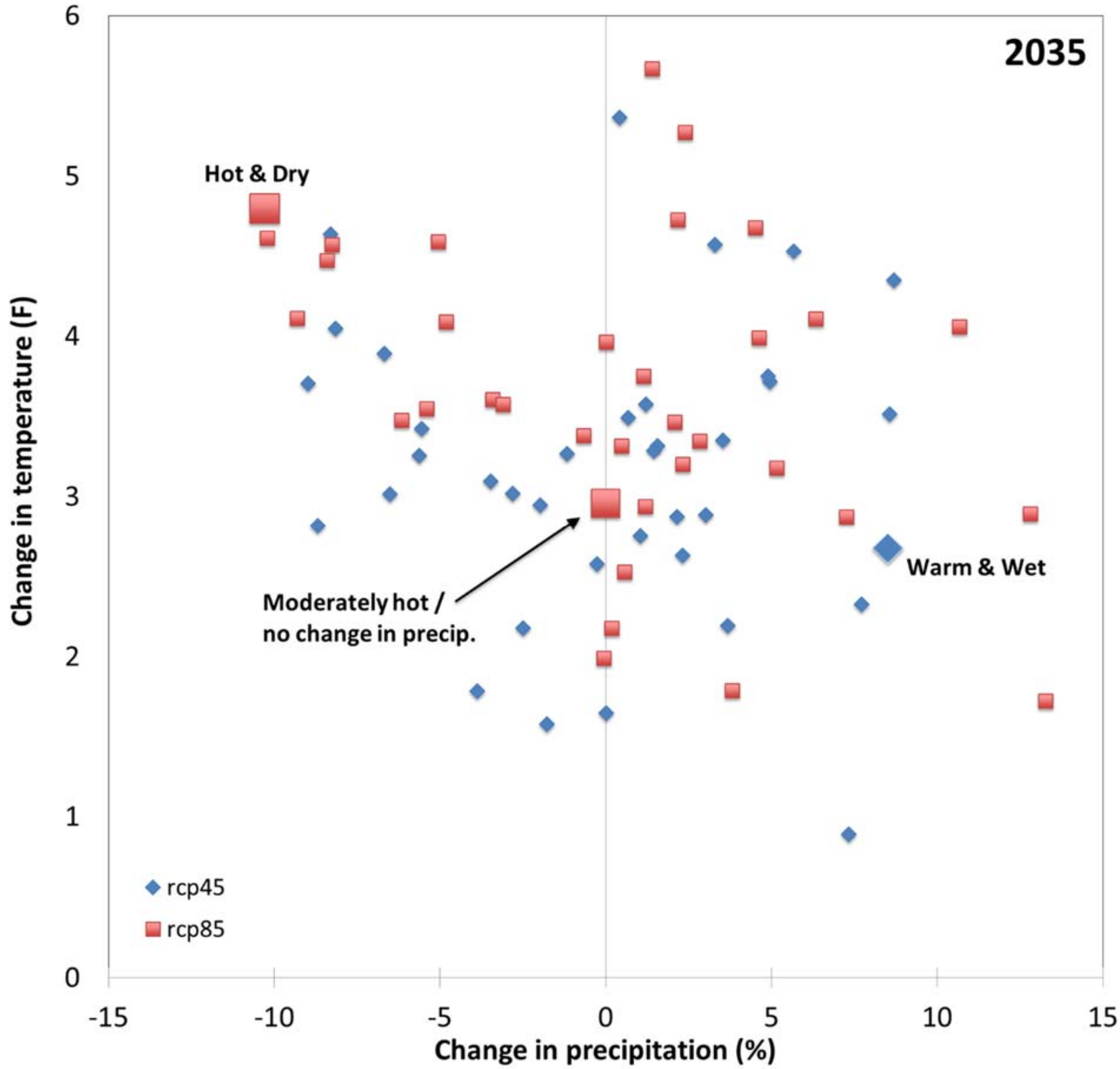


Figure C-1. Models selected for the three climate scenarios used in the project.

Table C-1. Three Climate Scenarios for the Gunnison Basin Region by 2035. The following summary was compiled from three climate scenarios and a review of literature. The **Hot and Dry** scenario is from hadgem2-es.1.rcp85; the **Moderately Hot and No Change in Precipitation** is from cesm1-bgc.1.rcp85; and the **Warm and Wet** is from cnrm-cm5.1.rcp45. Imtiaz Rangwala, Western Water Assessment and NOAA.

	Hot/Dry	Moderately Hot/No Change in Precipitation	Warm/Wet
Temperature	Annual temperature increases by 5°F; At lower elevations: summer days with temperature above 77°F (25°C) increases by 1 month, and nights with temperature above 68°F = 10	Annual temperature increases by 3°F; At lower elevations: summer days with temperature above 77°F (25C) increases by 2 weeks, and nights with temperature above 68°F = 20	Annual temperature increases by 2°F; At lower elevations: summer days with temperature above 77°F (25°C) increases by 1 week
Precipitation	Annual precipitation decreases by 10%; less frequent and more intense individual rain events; summer monsoon rains decrease by 20%	Annual precipitation does not change but much greater fluctuations year to year (leading to more frequent feast or famine conditions); El Nino of 1982/83 strength occurs every 7 years	Annual precipitation increases by 10%; more intense individual rain events; summer monsoon rains increase by 10%
Runoff	Runoff decreases by 20% and peak runoff occurs 3 weeks earlier	Runoff decreases by 10% and peak runoff occurs 2 weeks earlier	Runoff volume does not change but peak runoff earlier by 1 week
Heat Wave	Severe and long lasting; every summer is warmer compared to 2002 or 2012 (5°F above normal)	Hot summers like 2002 and 2012 occur once every 3 years	Hot summers like 2002 and 2012 occur once every decade
Drought	More frequent drought years like 2002/2012 - every 5 years	Drought years like 2002/2012 occur once every decade	No change in frequency but moderate increases in intensity; fewer cases of multi-year drought
Snowline	Snowline moves up by 1200ft	Snowline moves up by 900ft	Snowline moves up by 600ft
Wildfire	Fire season widens by 1 month; greater fire frequency (12x) and extent (16x) in high elevation forest	Fire risk during dry years is very high at all elevations b/c of large fuel build up from wet years; on average fire frequency increases 8x, and area burnt increases 11x	Increases in fire frequency (4x) and extent (6x)
Dust Storms	Extreme spring dust events like 2009 every other year; causing snowmelt and peak runoff to be six weeks earlier	Frequency of extreme dust events increases from current but tied to extreme dry years	Same as current
Growing Season	Increases by 3 weeks	Increases by 2 weeks	Increases by 1 week

Three Climate Scenarios for the Southwest Colorado by 2035: Summary & Hard Numbers

Hot and Dry	❑ Sustained and longer duration drought: 2002-like drought occurs every 5 years ❑ Chronic summer-time dry conditions: Summer monsoons are significantly reduced (-20%) ❑ Chronic summer time heat waves: Every summer warmer compared to 2002 (5^oF above normal)
Warm and Wet	❑ Water availability does not change but climate is warmer ❑ Timing of snowmelt, streamflow, growing season change but more moderate compared to other scenarios ❑ Chronic flood risks because of increases in moisture and more heavy precipitation events
Feast and Famine	❑ No long-term droughts but more frequent and intermittent severe-drought conditions (2002 drought once every decade) ❑ Large year-to-year fluctuations that go from "hot and dry" to "warm and wet" conditions ❑ Doubling in the frequency of alternating extreme dry and wet conditions relative to present

	Hot and Dry	Warm and Wet	Feast and Famine
Annual temperature increase (F)	5	>2	2.9
Winter temperature increase (F)	4.1	3.5	3.3
Spring temperature increase (F)	3.8	2.3	2.2
Summer temperature increase (F)	6	2.8	3.4
Fall temperature increase (F)	5.3	2.1	2.9
Annual precipitation (%)	decrease 10%	increase 10%	no change but large year to year variation
Winter precipitation (%)	19	13	6
Spring precipitation (%)	-9	6	0
Summer precipitation (%)	-19	8	3
Fall precipitation (%)	-15	10	-9
Freezing level	shifts up by 1200 ft	shifts up by 600 ft	shifts up by 900 ft
Runoff	> 20% decrease	stays the same as baseline	10% decrease
Timing of peak runoff	earlier by 3 weeks	earlier by 1 week	earlier by 2 weeks
Summer monsoon	decrease by 20%	increase by 10%	large year to year fluctuation
Summer like 2002	every summer	every 10 years	every 3 years
Severe drought duration	1-5 years	1 year	1-2 years
2002/2012 Drought	every 5th year	every 15th year	every 10th year
Strong El Nino return frequency	no change	no change	doubles

(Source: Imtiaz Rangwala, Western Water Assessment & NOAA PSD, Boulder; Renee Rondeau, Colorado Natural Heritage Program

Seasonal Temperature and Precipitation Graphs

Winter

- mean temperature
- avg minimum temperature
- avg maximum temperature
- mean precipitation

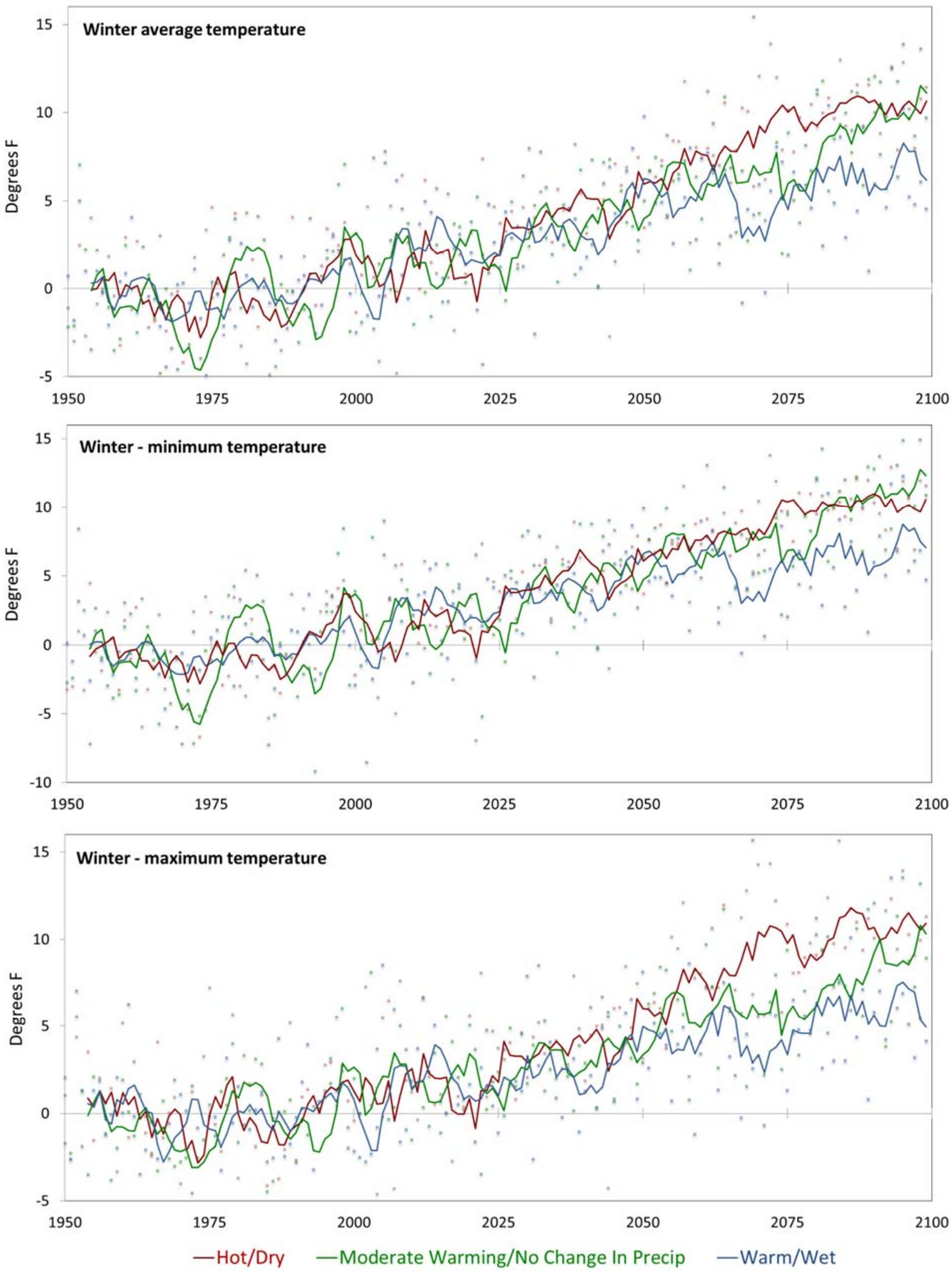
Summer

- mean temperature
- avg minimum temperature
- avg maximum temperature
- mean precipitation

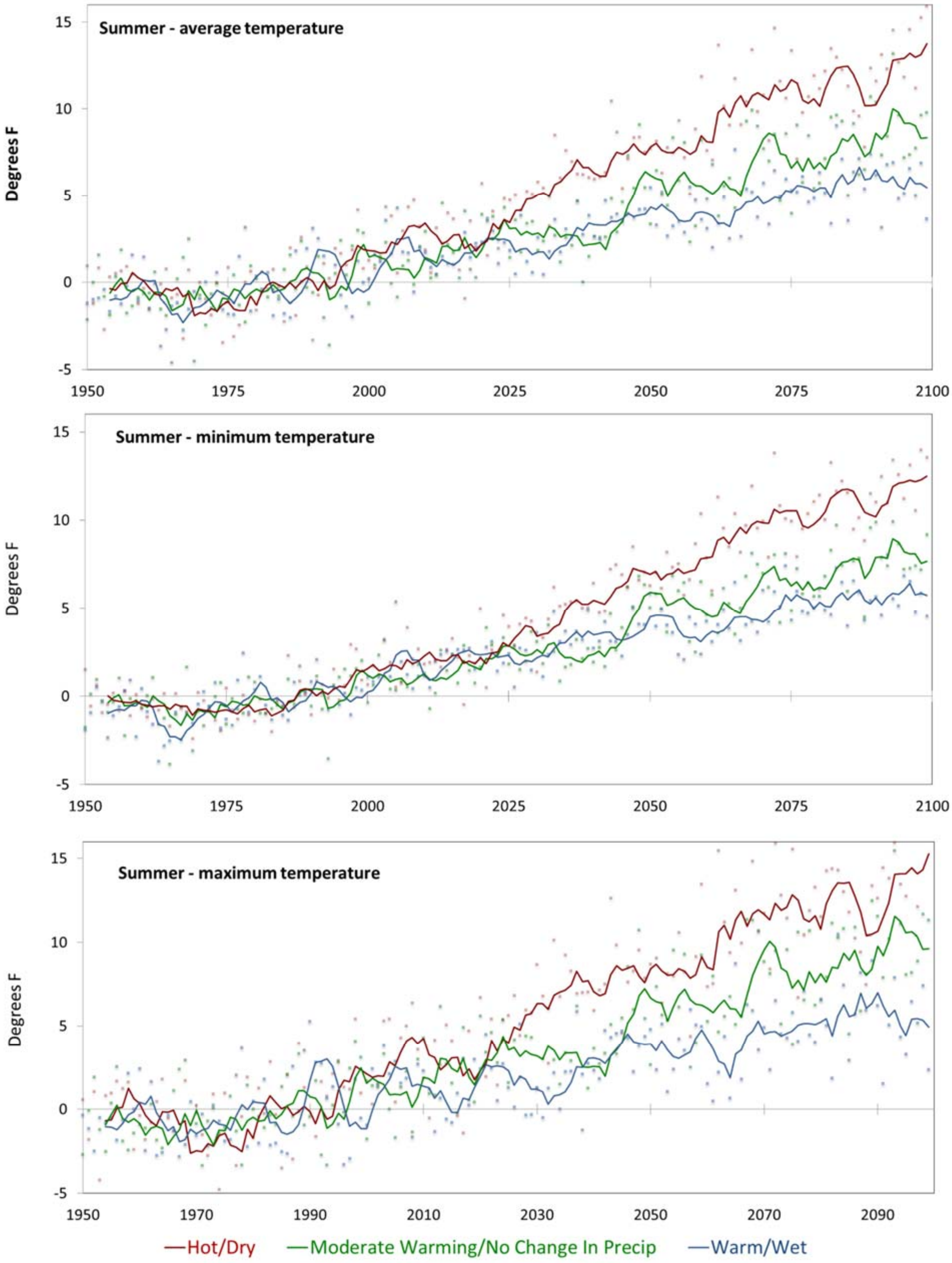
Annual

- mean temperature
- avg minimum temperature
- avg maximum temperature
- mean precipitation

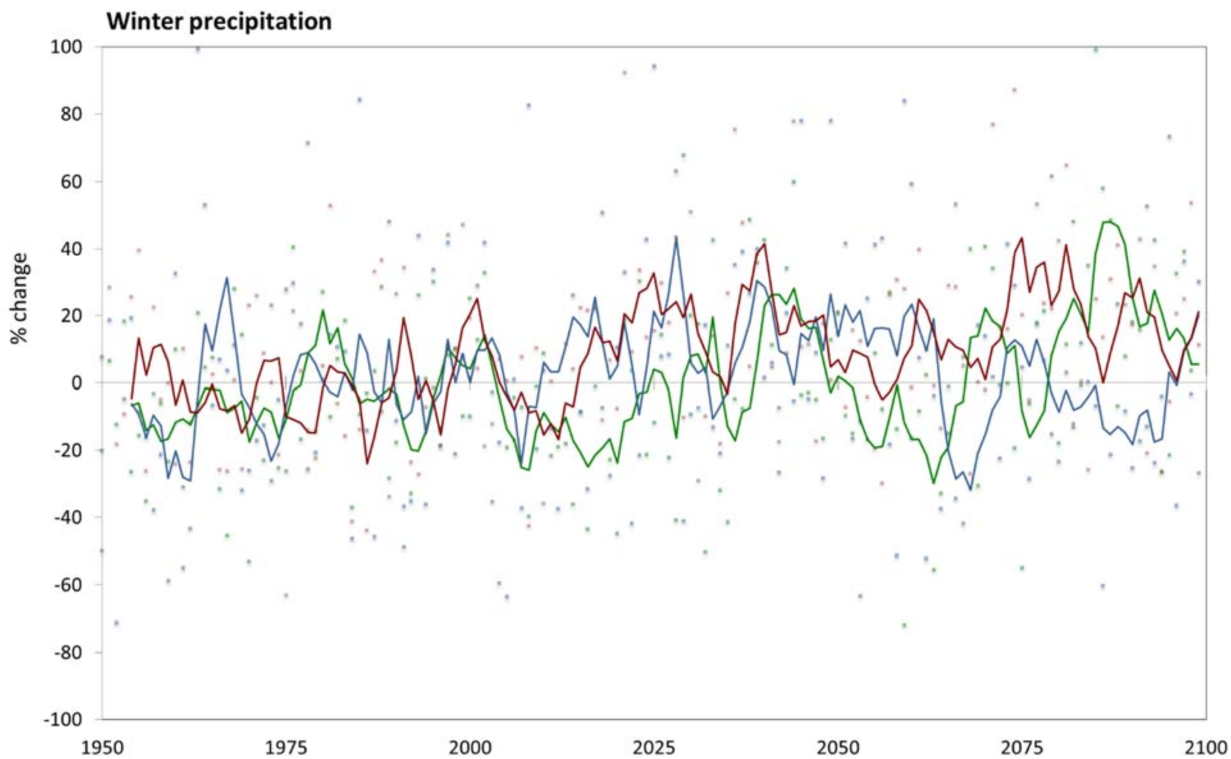
Growing season length
Rainy days (>trace)
Rainy days (>20m)
Max # consecutive dry days
Warm spell duration
Tropical nights (>68F)
Tropical nights (>68F) low elevation regions
Summer days >77 F low elev

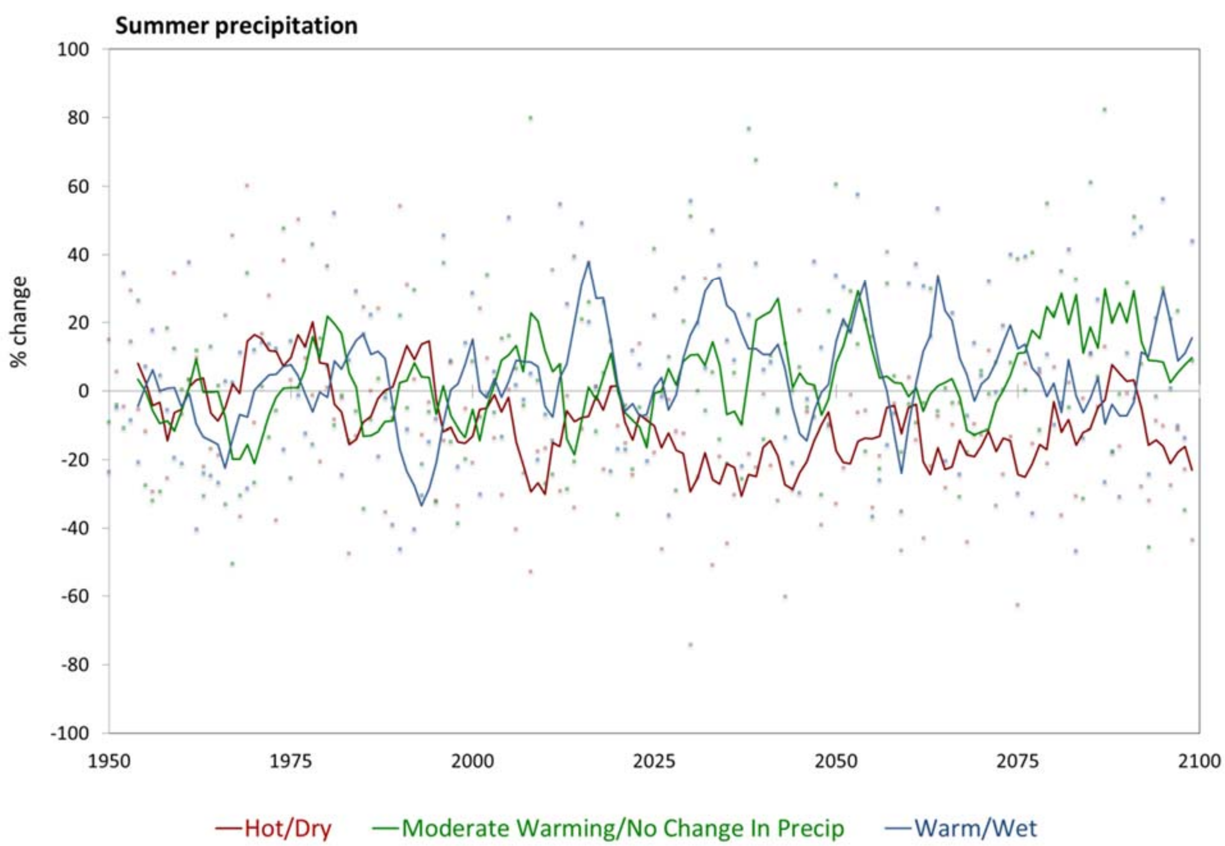


Difference in winter (Dec-Jan-Feb) temperatures compared to 1971-2000 normals.



Difference in summer (Jun-Jul-Aug) temperatures compared to 1971-2000 normals.





Difference in winter (Dec-Jan-Feb) and summer (Jun-Jul-Aug) precipitation compared to 1971-2000 normals.

APPENDIX D: THREE NARRATIVE SCENARIOS

Scenario 1: Hot and Dry

In this scenario annual temperature increases approximately 5^0 F by 2035. To put that in perspective, Gunnison's temperature becomes similar to the current climate of Ridgeway, CO. By 2035, every summer will be warmer than 2002 and 2012 – years when we experienced excessive heat waves. At elevations below 7,000 feet, for at least two weeks during the summer, nighttime lows will not dip below 68^0 F (a typical tropical night), and summer will expand by a month. Annual precipitation will decline by 10%, and the combined effect of warming and lower precipitation will result in nearly 45% decrease in annual runoff. There will be a large increase in the frequency of extreme drought years. Roughly every fifth year, we experience droughts similar to 2002 and 2012 (in these years, precipitation was 40% below average).

Fire: Not every year will be an exceptional fire season but average fire frequency, intensity, and size will increase. The average fire season will lengthen by one month and the average fire frequency will increase up to 12 times while the total area burned in any given year will increase 16 times[1]. The largest burns will be in coniferous forests, including spruce-fir, lodgepole pine, mixed-conifer, and ponderosa pine. Once burned, these areas are likely to transform into aspen, shrublands, or grasslands. The growing season will increase by three weeks, however, with less precipitation the understory herbaceous growth (fine fuels) will decrease which may reduce fire risk in the sagebrush. If a fire occurs in the lower elevation sagebrush zone the site will transform into grassland or rabbitbrush/grassland rather than return to a sagebrush system. There is a good chance that the "new" grassland will be dominated by cheatgrass. Note that sagebrush requires at least 7.5 inches of annual precipitation, and the large water stress in this scenario will make it difficult for the low elevation sagebrush to regenerate.

Drought: In this scenario, Gunnison's annual precipitation declines and becomes similar to the current precipitation of Del Norte[2]. Spring snowpack will decline by 10% and spring temperatures will increase by 4^0 F. This combination of a reduced snowpack and warmer spring temperatures will reduce the available water during the growing season. Trees and shrubs (especially sagebrush) rely on winter and spring snows. The snowpack allows for deep soils to remain moist during the growing season, therefore a reduced snowpack associated with a warmer and drier spring will negatively impact vegetation with deep roots (most trees and shrubs). Summer precipitation will decrease by 20% and have a large negative impact on vegetation, especially shallow rooted plants (mostly grasses and forbs). Snowline shifts up by 1200 feet and could impact the lower elevations of the Crested Butte ski resort. In addition, the average timing of snowmelt will shift a full three weeks earlier from temperature increases and more frequent dust-on-snow events (which will occur every year). Higher than average peak spring flows followed by lower summer flows will reduce the amount of water available for fish, riparian vegetation, migratory birds, and grazing animals, especially during summer. Endangered fish would most likely suffer from lower in-stream flow and increased stream temperature. Less precipitation in winter and summer will significantly decrease surface water and shallow ground water. Seeps, springs, and mesic meadows associated with shallow groundwater will decline and species composition will be greatly altered. We will likely see a shrub invasion into mesic meadows and a decline in nearby aspen stands.

Insects: Tree mortality due to insect and disease outbreaks will greatly increase with a hot and dry climate, more so than in any other scenario. The current spruce-bark beetle infestation will likely expand and cause significant mortality in the mature trees[3]. Species that rely on mature spruce-fir forests, such as Lynx, Boreal owl, Snowshoe hare, and Pine marten, will decline due to lack of food and shelter. Aspen trees at lower elevations will experience die-back associated with increased temperatures and decreased soil moisture. However, aspen stands at upper elevations may increase as coniferous trees decline due to fire and beetle kill.

Scenario 2: Warm and Wet

In this scenario, annual temperature increases 2^0 F by 2035. To put this in perspective, temperatures in Gunnison will resemble current temperatures in Cimarron. Summer will expand by a week. Annual precipitation will increase by 10% (in terms of soil moisture and stream flows a 5% increase in precipitation is needed to offset a 2^0 F increase in temperature with its associated higher rate of evapotranspiration). Drought years, such as 2002, will occur every 15th year, similar to today's frequency. However, the intensity and severity of droughts will increase because of higher temperatures.

Change: While the water stress from 2^0 F temperature increase will be offset by a 10% increase in precipitation, ecosystems will change in measurable ways. For example, the ratio of warm season to cool season grasses will change, and we could see declines in western wheat grass, needle and thread grass, while blue grama and galleta grass expand. The snowline will shift upwards by 600 feet. As a result, the current vegetation in the 8,500-9,000 feet elevation band will begin to shift from mixed conifer or aspen to ponderosa pine. Due to increased precipitation, overall runoff will increase by 10%, while warmer temperatures mean that peak runoff will occur a week earlier. In this scenario, heat waves similar to 2002 (5^0 F above normal) will occur once every decade. Fire risk in this scenario is the lowest of any scenario but fires will be present, and intermittent dry conditions may cause severe fire hazards because of high fuel loads. These high fuel loads are a result of increased winter, spring, and summer precipitation producing more foliage. A 2^0 F increase in temperature will increase the fire frequency up to 4 times and the annual area burned by 6 times[1].

Weeds: We will have greater than normal winter snowpack above 10,000 feet and spring, summer, and fall precipitation will increase at all elevations. The increase in year-round moisture coupled with a moderate increase in temperature will promote invasive species (more so than any other scenario). Current invasive species such as leafy spurge, knapweed, and yellow toadflax will expand into low to montane elevations and new invasive species such as Japanese brome or purple loosestrife will likely move into the area. Rangelands will become degraded by invasives, and knapweeds and leafy spurge expand into rangelands that have never had a serious weed problem. Further, invasive species will out-compete the native vegetation and create a high density of fine fuels for fires, especially at the lower elevations.

Water: We will still experience droughts; however, they will be less frequent than in the other scenarios. Disease and insect outbreaks are expected to be lower than the other scenarios, however, insect outbreaks will still increase, as the droughts that do occur will be more intense than the droughts experienced during the 20th century. When we do experience a beetle outbreak, the recovery time may be quicker than in the other scenarios. Seeps, springs, and other groundwater dependent wetlands will increase or experience very little change. There will be some drought years that impact low elevation wetlands, but for the most part, wetlands will benefit from the years of increased annual precipitation. Higher elevation wetlands will do exceptionally well and possibly expand due to the greater snowpack above 10,000 feet. Higher soil moisture will likely eliminate or reduce invasive species in wetlands.

Scenario 3: Feast or Famine

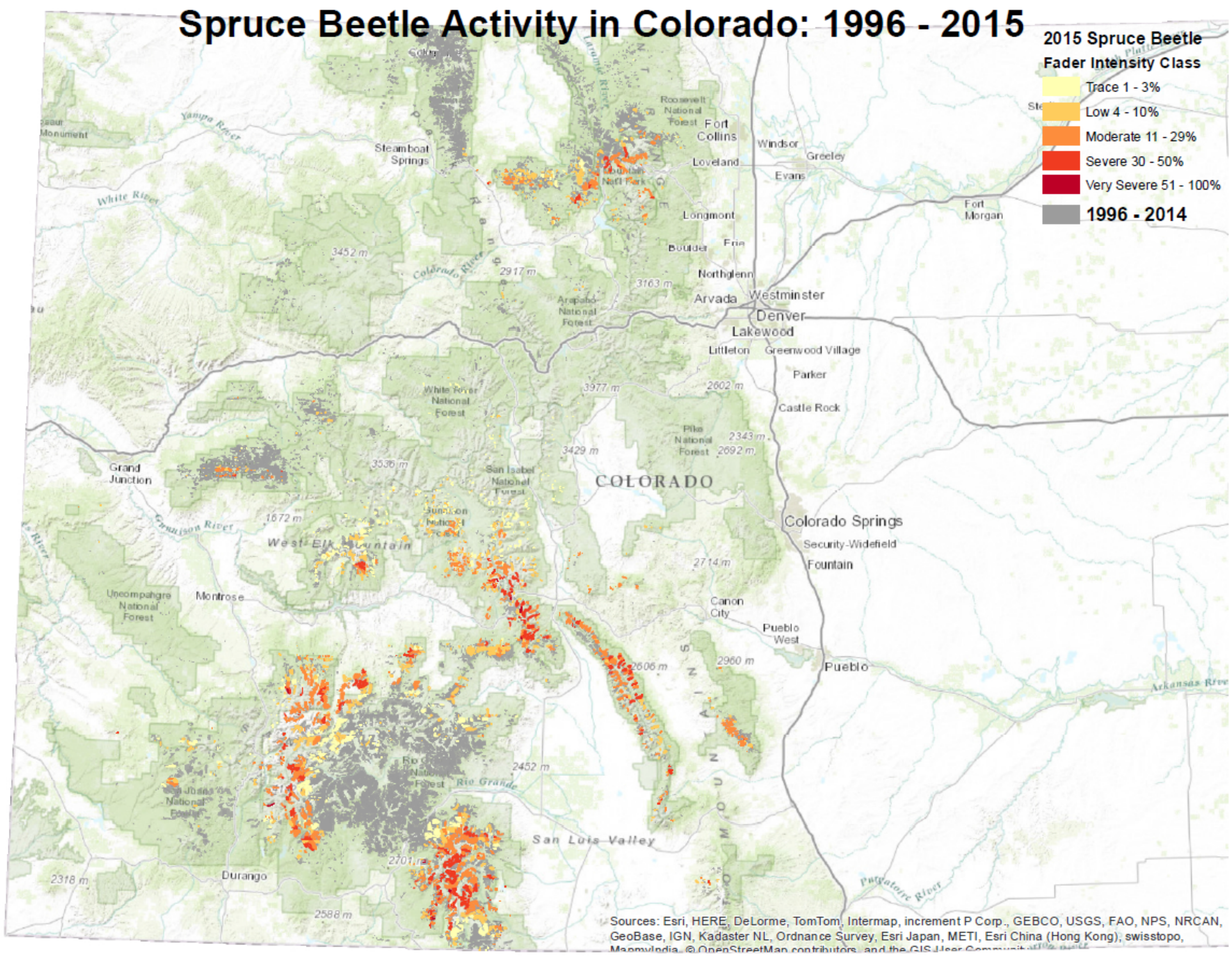
In this scenario, annual temperature will increase approximately 3^0 F by 2035. To put that in perspective, Crested Butte's temperature will be similar to the current temperature of Lake City. Average annual precipitation does not change; however, we will experience larger year to year fluctuations in precipitation, with some very wet years and some intense drought years, as compared to our current climate. Winter precipitation will increase, but precipitation will decline in the other seasons. When droughts occur, they will be more intense than present but generally less than two years long. Once every decade we will experience a drought similar to the 2002 and 2012 droughts (years when precipitation was 40% below average).

Feast: The growing season will expand by 2 weeks and during wet years vegetation growth will be exceptional with trees, shrubs, and ground cover greatly increasing. The frequency of severe El Nino and La Nina events will double to an average of once every seven years. We experienced severe El Nino years in this region in 1982/83 and 1997/98 with annual precipitation at roughly 20% above average. Invasive species will do well under El Nino conditions but decline in La Nina conditions (drought years). The annual fire risk is lower in this scenario than the hot and dry scenario. Large fluctuations between wet and dry years will increase fuel growth during wet years. This means that when a fire does occur, the severity, intensity, and size could be very high, and in a bad fire year the average fire frequency will increase up to 8 times and the area burned will increase 11 times[1]. Year to year, summer monsoons will be more variable than they are currently. Large spring floods will be more likely as earlier rain on snow events will cause abrupt snowmelt. Dust-on-snow events, coupled with warmer spring temperatures, will also increase the chance of spring flooding, especially during El Nino years. The largest flooding events will generally occur from heavy monsoon precipitation. During these floods, there will be severe erosion in small streams as water runs over banks and culverts.

Famine: Intense droughts will more frequently follow extreme wet years. Bark beetles will expand during these drought years, causing extensive conifer mortality. The difference between this scenario and the hot and dry scenario is that multi-year droughts will be less likely in this scenario, so bark beetle dieback may not be as severe as in the hot and dry scenario. It is important to note that most conifer forests can regenerate more easily following beetle outbreaks than fires because bark beetles do not kill the young trees. However, insect kill in mature trees will diminish seed production. This reduction in seed crop will hurt the animals that rely on conifer seeds. In the event that a fire occurs after a beetle outbreak, tree regeneration is nearly impossible due to a lack of a nearby seed source and nurse plants. The large fires associated with drought years will result in younger forests, more open structure, more early successional species, and more invasive species. Large landscape scale disturbances, such as fire and insect outbreaks, will fragment coniferous forests and negatively impact Lynx, Snowshoe hares, Pine martens, and other species that rely on large intact functioning forests, while possibly being a benefit to those species that prosper from a more open forest canopy.

Seeps, springs, and other groundwater dependent wetlands will experience a moderate decline, especially below 8,500 feet, where spring precipitation will fall as rain rather than snow. Increased evapotranspiration, driven by higher temperatures, will reduce soil moisture and streamflow. Consequently, species that can handle drier soil conditions, for example sagebrush, shrubby cinquefoil, and rabbitbrush will flourish; invasive species such as cheatgrass and knapweed will likely increase, especially at the lower elevations. Juniper establishment in the sagebrush is likely during wet years that follow a drought year.

Appendix E. Spruce Beetle Activity Map



US Forest Service, Aerial Detection Survey http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd489945.pdf

APPENDIX F. BIO-CLIMATIC ZONES

The maps presented below were provided by James Worrall, US Forest Service, and represent projected bio-climatic change zones for Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Note that the target period for these projections is 2060, i.e. later than the period used in other work for this project.

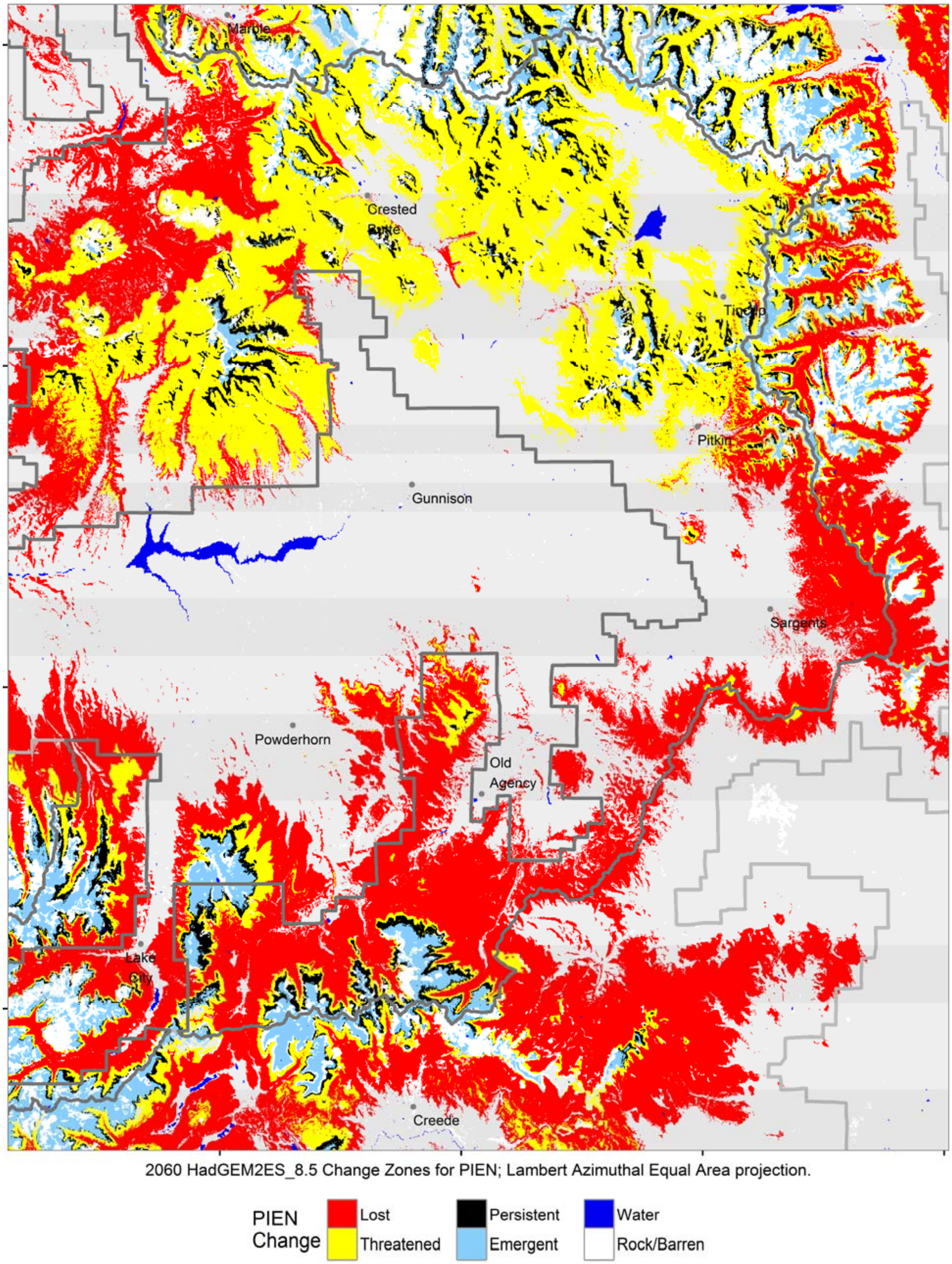


Figure F-1. Engelmann spruce Hot and Dry Scenario

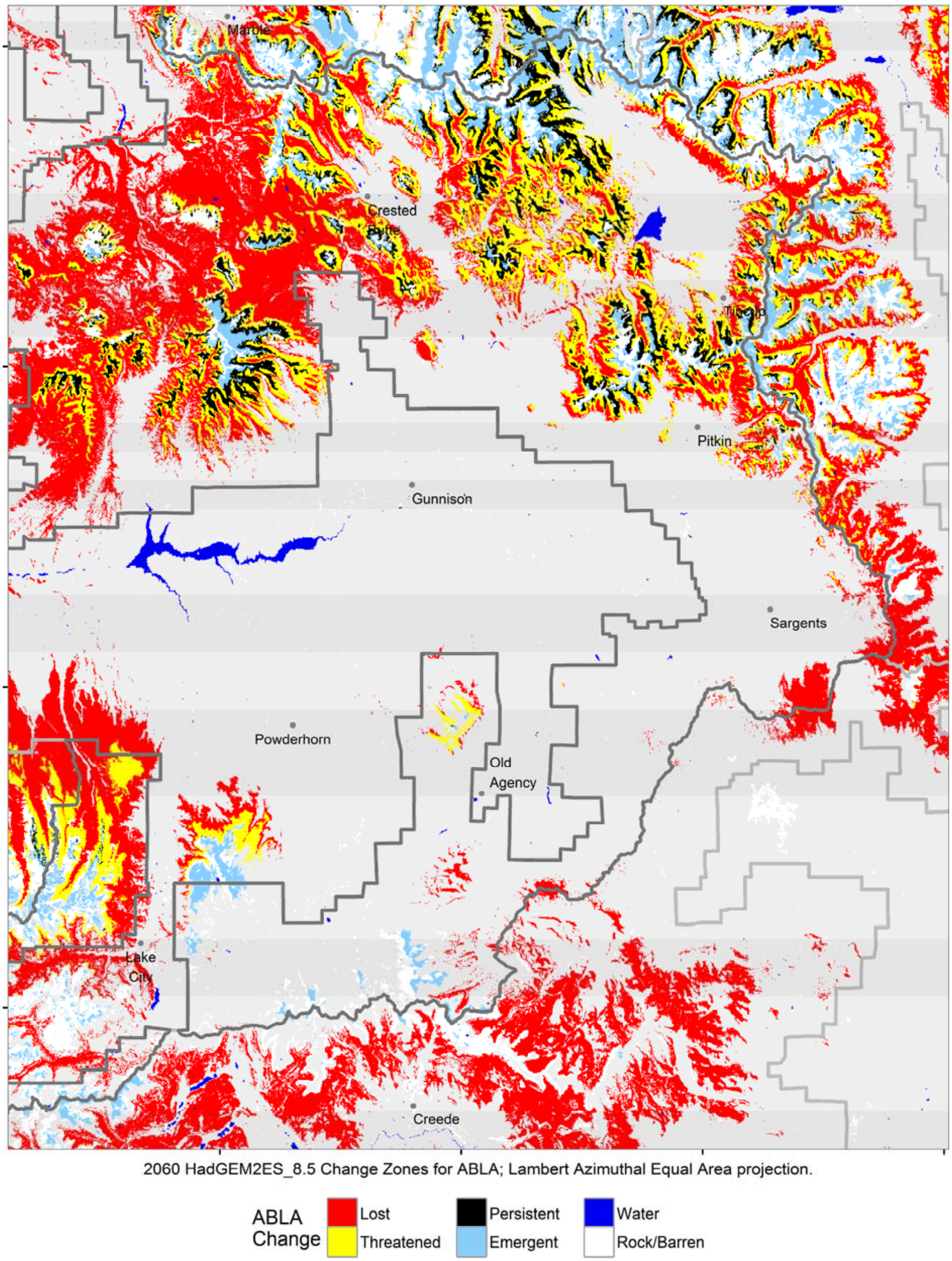


Figure F-2. Subalpine fir Hot and Dry Scenario

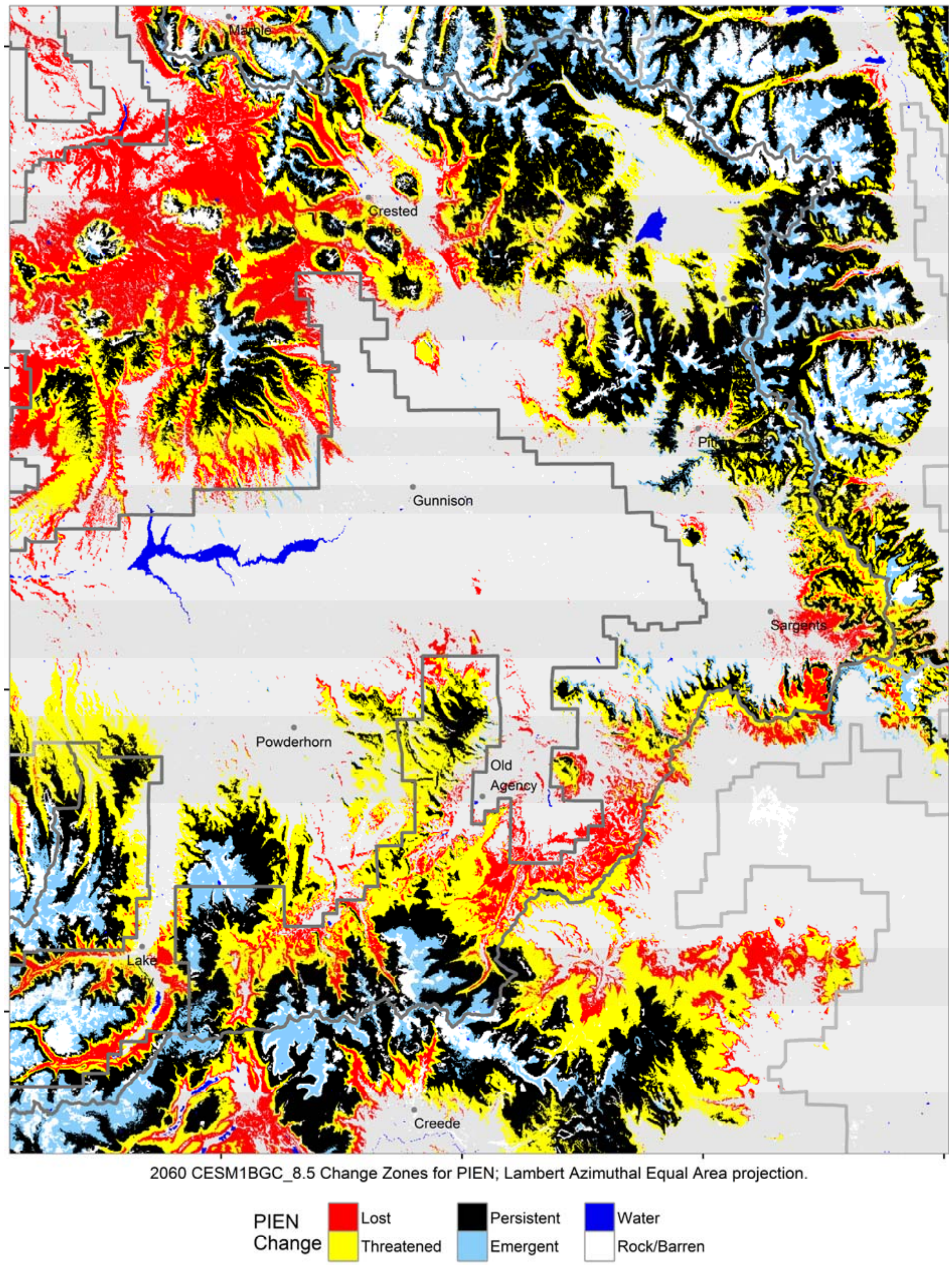


Figure F-3. Engelmann spruce Moderately Hot

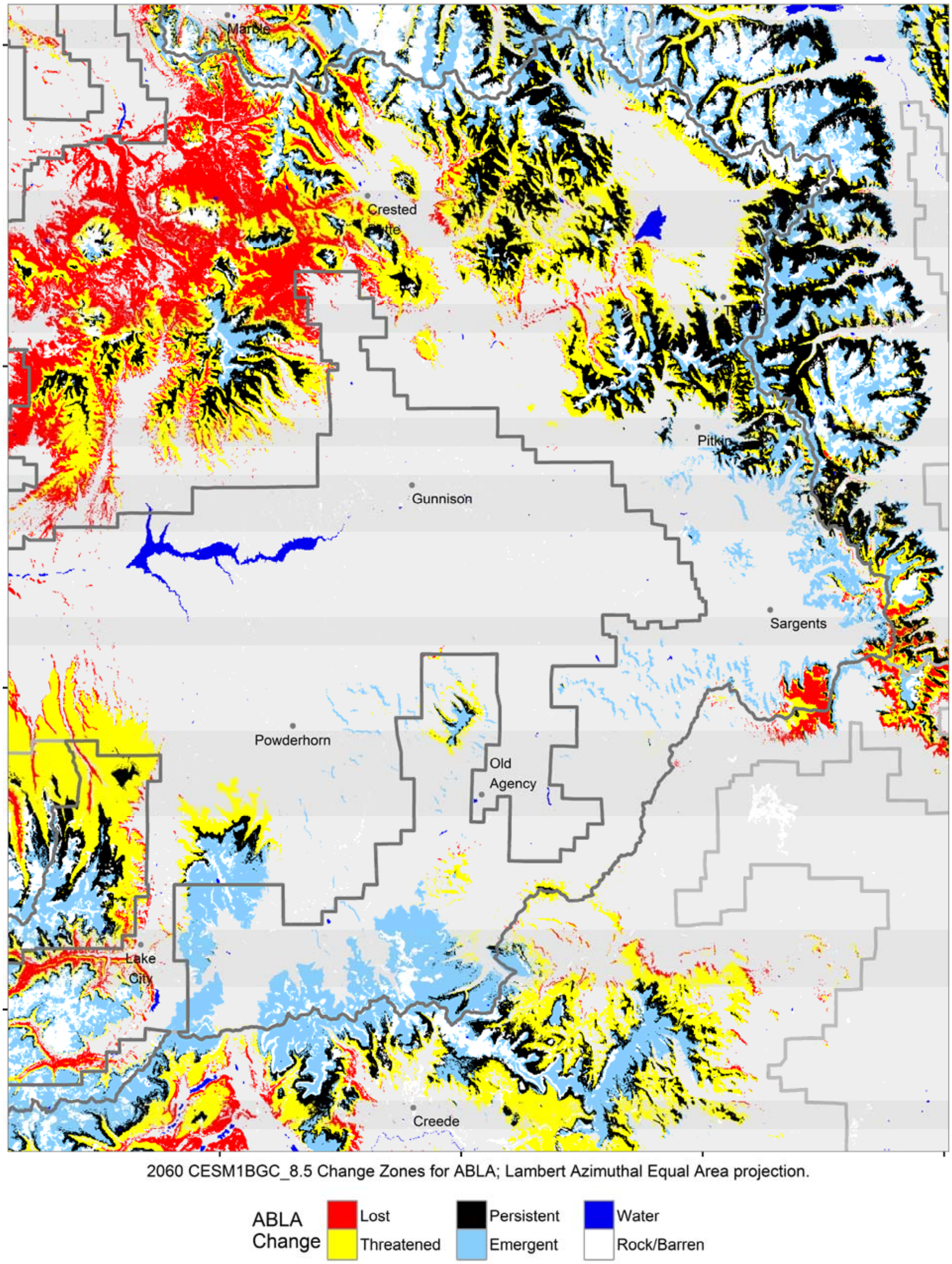


Figure F-4. Subalpine fir Moderately Hot

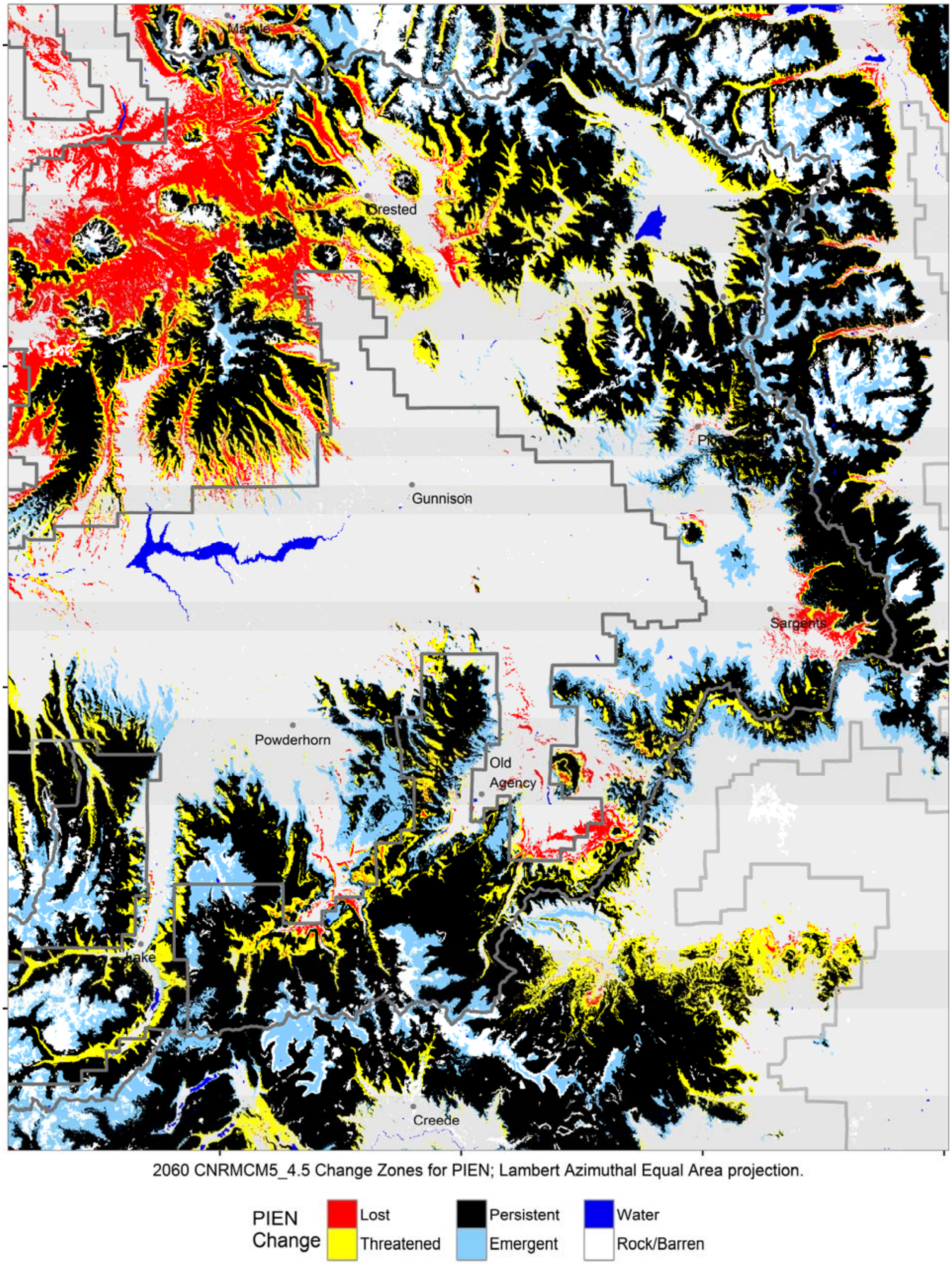


Figure F-5. Engelmann spruce Warm and Wet

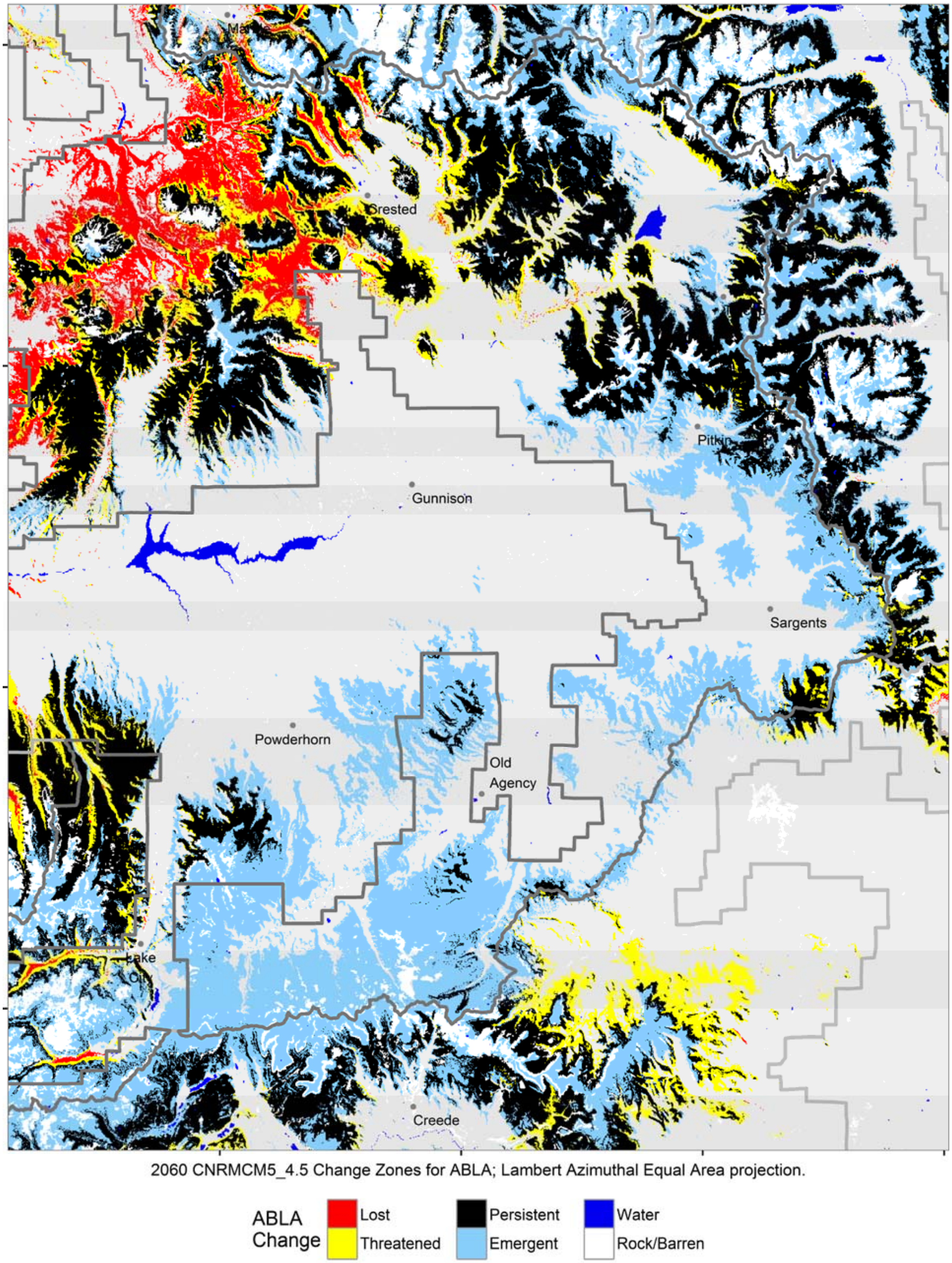


Figure F-6. Subalpine fir Warm and Wet

Appendix G. Ecological Response Models

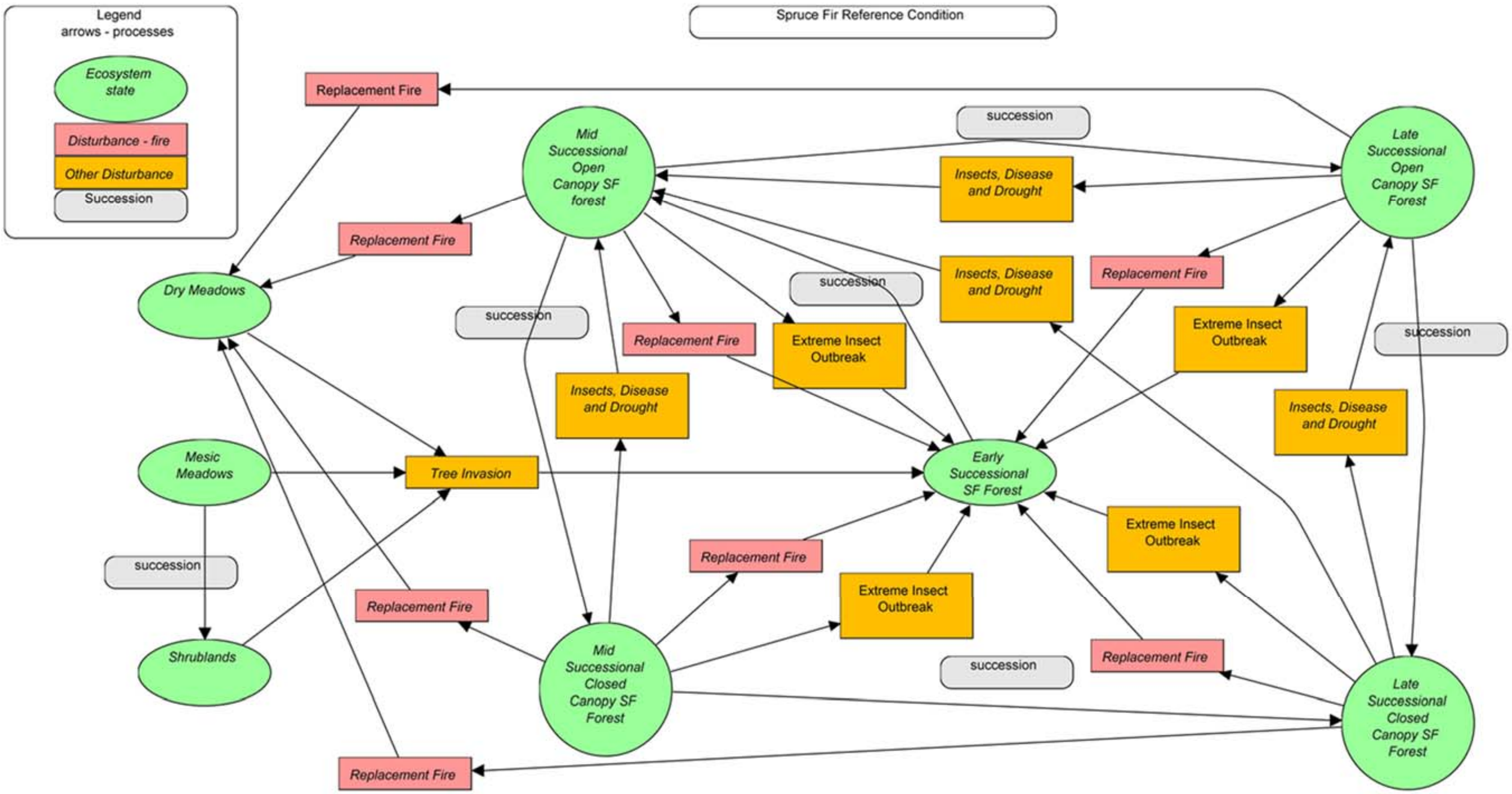


Figure G-1. Reference condition model for spruce-fir landscape

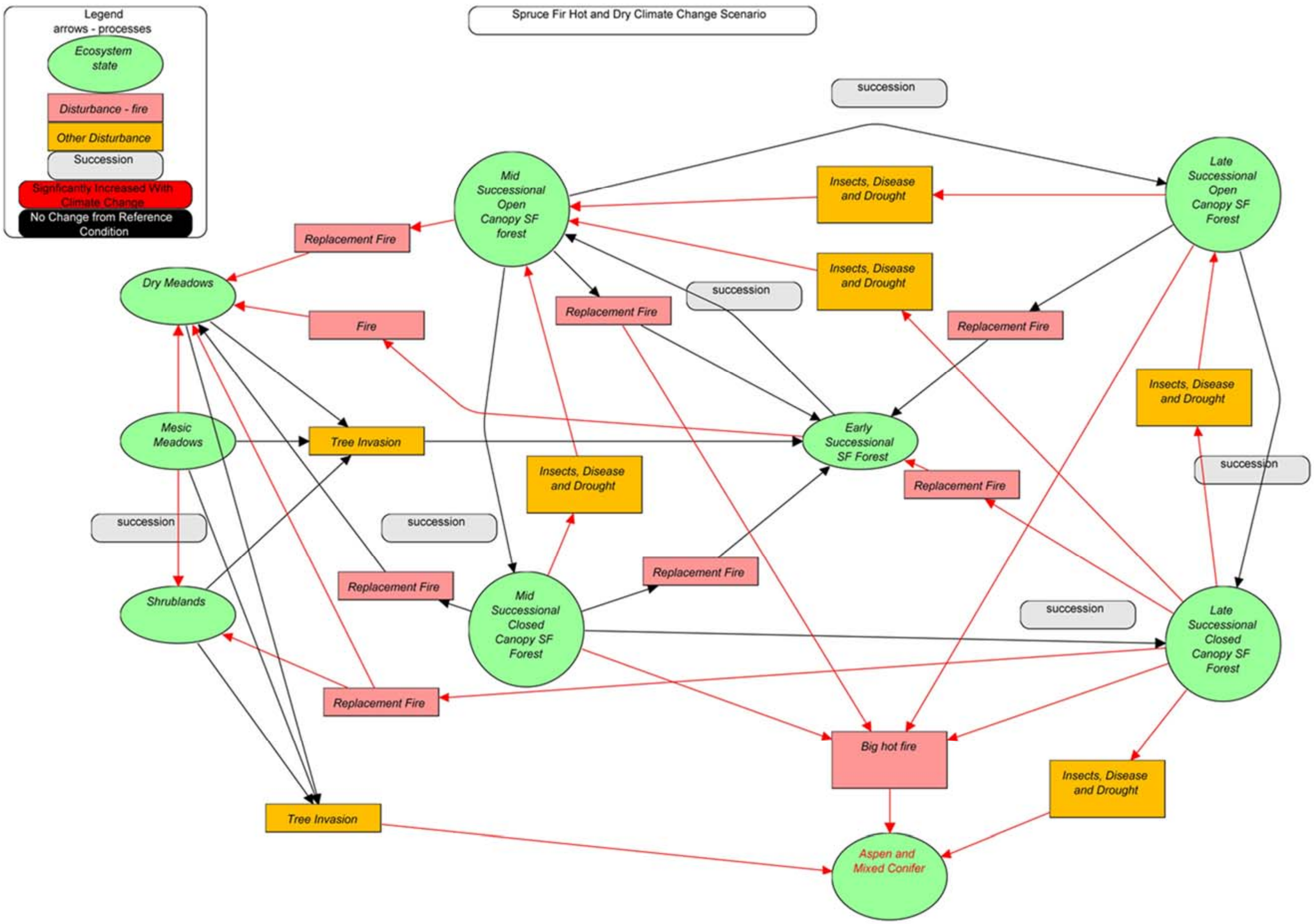


Figure G-2. Ecological response model for the sf landscape under the hot and dry scenario

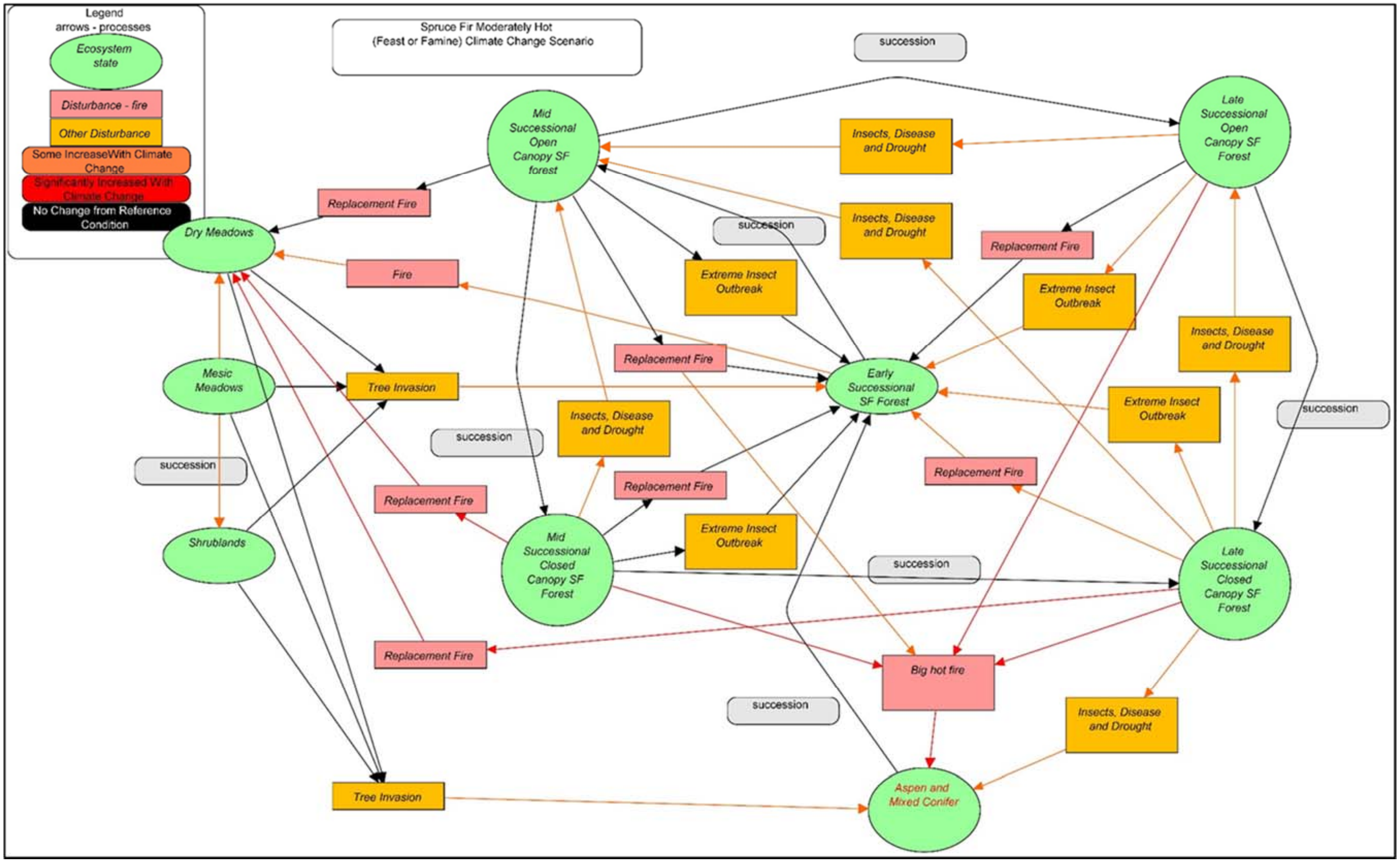


Figure G-3. Ecological response model for the sf landscape under the moderately hot (feast or famine) scenario

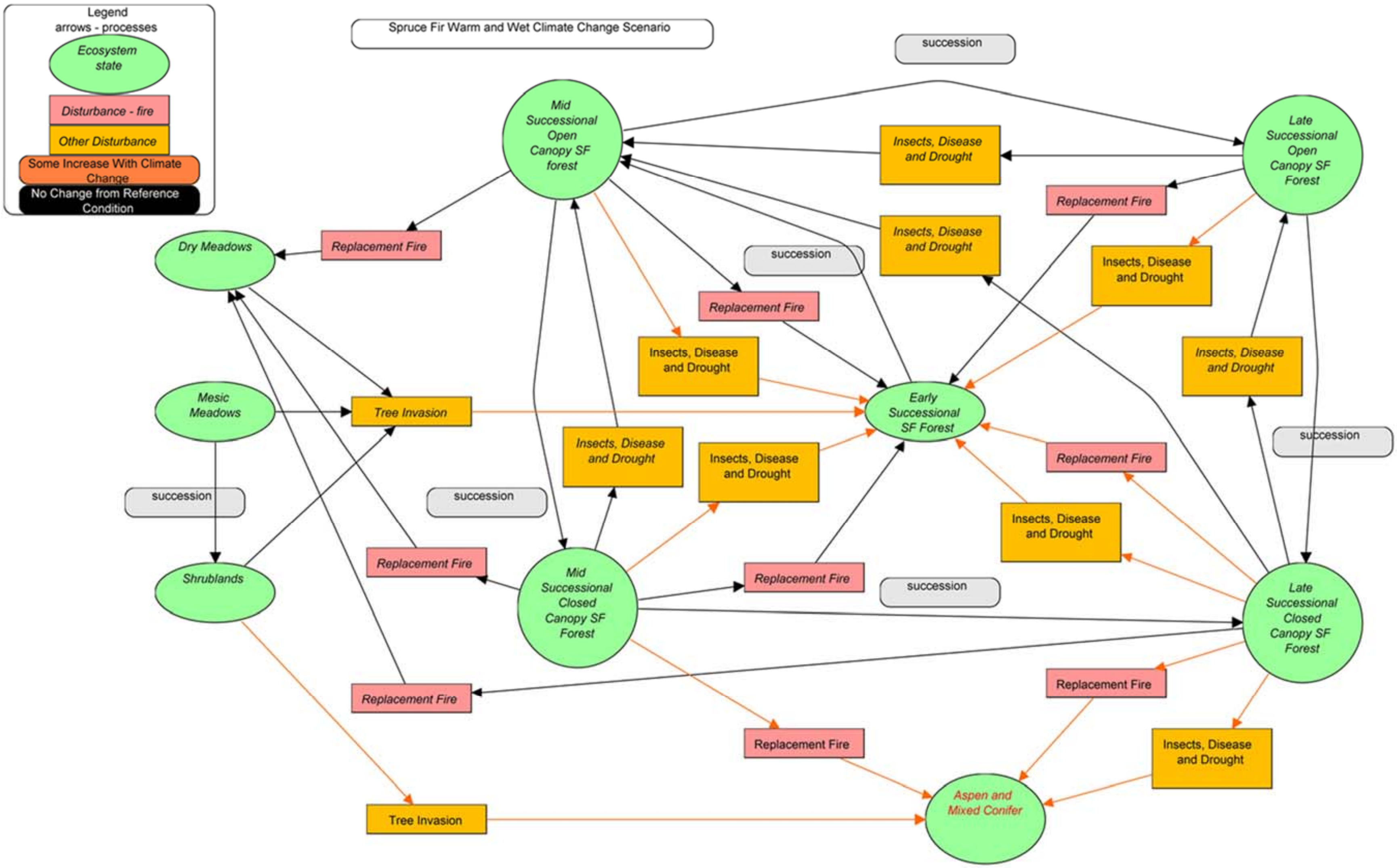


Figure G-4. Ecological response model for the sf landscape under the warm and wet scenario

APPENDIX H. SOCIAL SCIENCE INTERVIEW AND FOCUS GROUP REPORTS

Climate Adaptation in the Gunnison Basin, Colorado: Social dimensions and management concerns for the Spruce-Fir and Sagebrush Landscapes

November, 2015
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North Central Climate Science Center (NCCSC)
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University of Colorado, Boulder

Introduction

Climate change is projected to have widespread impacts in the American West. The impacts move beyond "global warming" and temperature rises to include changes to complex relationships between climatic, ecological and social processes. Climate change can transform landscapes, both in how they function and in their aesthetics. It may alter a number of ecological characteristics such as distribution of plant and animal species, invasive species migration, snowpack, wildlife populations, insect and disease cycles, and fire regimes. Ecological impacts cascade into social impacts for the local communities, and even to far-flung communities that depend on the region's resources. Westerners are grappling with how to respond to change, and important actors in this response are the public land agencies that manage large portions of the land and water.

Public lands are a critical resource and play a significant role in the Rocky Mountain West. Large portions of the West are managed by different federal and state agencies making their natural resource management decisions salient to human and ecological communities. Many livelihoods are tied to public lands in the West, and management of public lands spills over to adjacent private lands. Natural resource managers are not new to implementing large-scale prescriptions at various timescales or thinking about landscape change. Disturbances regularly occur and require management responses, but climate change may pose a greater challenge for natural resource management agencies. New mandates require managers to include climate change in their management, but it can be challenging to connect theory with practice.

This report is part of the Southwest Colorado Social-Ecological Resilience Project (SERC, a collaborative endeavor funded by the Department of Interior's North Central Climate Science Center (NCCSC)[1]. The multifaceted research project aims to facilitate climate change adaptation that contributes to social-ecological resilience, ecosystem and species conservation, and sustainable human communities in southwestern Colorado., and brings together scientists, land managers, and key stakeholders in the San Juan and Gunnison Basins. The project team provided downscaled climate information, ecological response models, and tools for managers to develop strategies in anticipation of climate change.

[1] Colorado Natural Heritage Program, The Nature Conservancy, Colorado State University, Mountain Studies Institute, University of Colorado, University of Montana, U.S. Geological Survey, Western Water Assessment and the Gunnison Climate Working Group.

Project Goal:

The research component of this project examines key social-ecological-climate vulnerabilities and adaptive capacities and the knowledge, institutional structures, and mechanisms that will enable adaptation in the context of uncertainty. We aim to provide tools and principles for decision-makers (both public and private natural resource managers) that will generate strategies and scientific knowledge to facilitate climate adaptation and enhance the resiliency of communities. A social-ecological approach was used to understand key interactions, including intersections between the social and biophysical environments. Specifically, this report focuses on adaptation planning for two important adaptation targets: the spruce-fir and the sagebrush landscapes.

The Gunnison Climate Working Group (GCWG), a collaborative group of community members representing land and water managers, ranchers, county officials, university scientists and other interested parties, selected the targeted landscapes. Spruce-fir and sagebrush landscapes will likely be affected by climate change, and projected impacts, community feedback on their importance, and other key criteria, motivated their selection as research targets. These two landscapes cover approximately one million acres within the Gunnison Basin, with the sagebrush occupying the lower elevations and the spruce-fir extending to higher elevations; the alpine environment was not captured in these two targets.

Key Criteria for Targeted Landscape Selection

- Vulnerability (of natural and social systems)
- Greatest opportunity for success
- Social concern (livelihoods, culture, values, etc.)
- Relevance to decision-makers and policy
- Scope of system and benefits (ecosystem services)
- Other potential criteria (available data, supports high biodiversity, etc.)

This report summarizes findings from interviews with key decision-makers, which were designed to provide the following inputs to the larger research project:

- gather information on current use, importance, and status of the targeted landscapes;
- provide detailed insight into current social and decision making context of the targets and approach to uncertainty, and
- identify human communities in the Gunnison Basin likely to be impacted by climate-induced changes to the targeted landscapes, and the nature of those impacts.

Methods and Case Site

Research was conducted between June and October 2014 in the Gunnison Basin on Colorado's Western Slope. The social science fieldwork employed mixed methods with interviews and focus groups, but this report summarizes the findings of the interviews only. Complementary research was conducted by social scientists in the San Juan Basin as well as natural scientists in both sites to help build further understanding of integrated social-ecological systems.

Interviews were a critical method to understand how decision-makers approached climate change and the two targeted landscapes. Twenty-two in-depth, semi-structured interviews were conducted with public land managers and ranchers. Public land managers accounted for 18 of the interviews and represented five different agencies (National Park Service, Bureau of Land Management, Forest Service, Natural Resource Conservation Service, Colorado Parks and Wildlife). The interviewees represented different levels within the agencies as well as different focal areas (i.e., wildlife, range, forestry, etc.). Additionally, three ranchers were interviewed largely because of their management of public lands (through grazing leases) and recognizing the critical role private lands play in the larger landscape.

Interviews focused on three themes and were structured around the two targeted landscapes. Interviews only included questions about one of the targeted landscapes so participants self-selected which landscape they were best equipped to discuss. The ranchers received a different interview guide tailored to their management decisions, experiences with the sagebrush landscape, and relationships with the permitting agencies.

Research Results

Key findings were extracted from the interviews through qualitative data analysis. All interviews and focus groups were audio recorded with informed consent and then transcribed verbatim. Interview transcripts were analyzed for cross-cutting themes and coded using NVivo software. *A priori* codes were established by the larger social science research team and shared between the San Juans and Gunnison case studies to promote comparison and cohesion between research sites. Emergent codes were added during the analysis to capture new themes and Gunnison-specific findings. Codes are words or word assemblages that signal themes, attitudes, policies, or other repetitive elements of peoples' perceptions and attitudes about natural resources, their management, and climate change. These findings should be understood as insights into, and excerpts from, a complex fabric of social and ecological connections rather than an exhaustive analysis of the social-ecological dynamics in the Gunnison Basin. This report summarizes key themes that emerged in the interview transcripts and offers related quotations to give detail to specific responses that illustrate findings.

Targeted Landscapes:

Importance and Perception

Interviewees had a complex understanding of both targeted landscapes and understood them as systems rather than just particular plant species. Interconnections among species, between climate and ecology, and between people and the targets were described in interviews, revealing a highly detailed and complex understanding of the systems. Scientific and precise indicators and measurements were used to describe targets as well as personal experience and landscape observations.

Spruce-fir:

Both target landscapes played critical roles in the Basin and were the sites of important activities for the community. People in the Gunnison Basin value spruce-fir forests for ecological services and for the activities that take place within the system. Ecologically, spruce-fir is valued for its plant and wildlife communities and its ecosystem services. Spruce-fir provides habitat for a range of species, including habitat specialists with restricted ranges, threatened species such as the Canadian Lynx, and game species such as elk and deer. Spruce-fir also contributes ecosystem services such as carbon storage, water storage, soil moisture, snowpack and snowmelt, and by how its physical nature alters local wind and weather patterns.

Spruce-fir contributes to the local culture and economy; however, its social importance is changing as a reflection of changing demographics and laws. Historically timber was a significant economic driver in the Basin and a critical component of management. Forest regulations and laws such as the Wilderness Act of 1964 and administrative policies such as the Roadless Area Conservation Rule ("Roadless Rule") of 2001 were discussed in interviews as major barriers to active management and timber development, and as driving the change in how spruce-fir was valued. In response to decreasing timber acreage, a number of timber mills shut down; currently Gunnison only has access to one remaining mill. Locals blamed new populations of amenity migrants, newcomers who move to an area for its recreational or natural resources, for decreasing timber harvests and altering spruce-fir's value from production to aesthetics. This demographic shift is increasing the value of the spruce-fir landscape for recreation; the economy remains one tied to its natural resources, but it is shifting from an extractive economy to a tourism-based economy.

Tourism is becoming increasingly important to the local economy and relies heavily on the spruce-fir landscape. Heritage tourism centers on historic sites and on mining establishments. Interviewees explained that this was often overshadowed by recreation tourism, but was important, especially to communities such as Lake City. Interviewees felt that recreation-based tourism was experiencing significant growth and that most recreation occurred within the spruce-fir forests. Recreation activities include hiking, camping, fishing, rafting, hunting, resort and backcountry skiing, snowmobiling, photography, and mountain biking. Additionally, many discussed how big game species relied on spruce-fir for habitat, which provides a critical influx of funds for the community and wildlife projects as well as supports an activity central to the community culture. All of these activities are vulnerable to climate impacts to the spruce-fir, and interviewees worried about how this would impact the local economy. People cited the West Fork fire of 2013 in the San Juan Mountains, which according to locals had a marked impact on local recreation tourism (up to 70% decline during the fire according to interviewees). It was feared that Gunnison's economy could take a similar hit due to a dramatic change in the spruce-fir landscape.

Sagebrush:

The value of sagebrush is also changing, but this was due to changes in perception rather than economic forces. Historically sagebrush was thought of as a nuisance and not considered an important ecological system. This gradually changed as a more integrated ecological view was adopted, and more recently as legal restrictions have thrust this system into the limelight. The recent federal listing of the Gunnison sage-grouse, which uses sagebrush shrublands as its primary habitat, has increased the visibility of sagebrush. At the time research was conducted, the Gunnison sage-grouse was only proposed for listing, but it has since been listed as "Threatened" by the US Fish and Wildlife under the Endangered Species Act. Lines blur between Gunnison sage-grouse and sagebrush, and they often are discussed interchangeably, with questions about sagebrush often answered in terms about sage-grouse. Very rarely was sage-grouse not discussed in relation to why sagebrush was important to the Basin, and this was usually phrased as a product of legal regulations- and their implications- rather than the inherent or ecological values.

However, after sage-grouse topic was covered, a number of other factors emerged regarding sagebrush's importance. It was discussed as especially important during the winter when the high-elevation systems were harder to access. Other plant and animal species use sagebrush, and it provides critical winter range to big game species such as deer and elk, which have significant economic importance. Even in the summer when recreation moves up in elevation to the spruce-fir system, sagebrush is used for a number of recreation activities such as hiking, camping, and fishing. Ranching was one of the most important activities occurring in the sagebrush. Interviewees commented on how critical the sagebrush was to grazing and how permittees were able to utilize sagebrush as transition range before higher elevation pastures opened up. The community valued its ranching roots, and even as tourism takes a greater hold on the economy, they felt that ranches were important in preventing landscape fragmentation and as well as to the community culture.

Climate Change:

Both spruce-fir and sagebrush landscapes were perceived as vulnerable to climate change and likely to experience significant impacts. Climate change impacts were compounded by social and ecological changes, and often intertwined in interviewee responses. The main difference between the targets was that changes were perceived on different timescales: current and anticipated changes.

Interviewees expressed that spruce-fir was already undergoing radical changes and that climate change impacts were not hypothetical with the spruce-fir system. Beetle infestations and altered fire regimes were largely agreed to have drastic impacts on the spruce-fir system and have potential to completely transform the landscape. People felt that this transformation had already begun with high rates of beetle-related mortality; then expected this to greatly alter the age class of the spruce-fir system, and this—along with climate change— would usher in a new fire regime. Both beetle and fires were discussed as natural disturbances that were exacerbated by climate drivers. Beetle populations grew with the warmer winters and fire season increased due to extended periods of fire weather.

These disturbances would act in tandem to greatly alter the spruce-fir system; interviewees thought that a landscape dominated by old growth spruce fir was going to be a relic of the past. Spruce-fir changes would usher in a new landscape and have cascading impacts for managers, increasing recreation hazards or decreasing habitat for certain species. Future generations would inherit a starkly different Basin that would be in early states of succession. Interviewees explained how they thought they wouldn't see the current spruce-fir system again in their lifetime. An "awkward period" was expected, referring to the time between when the spruce-fir dies and aspen begin to colonize the area. These changes elicited concerns from managers because of increased hazards of falling trees and fire as well as the complexities of managing a system after a disturbance. These changes provoked different strategies from managers with some focused more on mitigation and others on assisting change and still others that planned on merely observing the changes.

Sagebrush, in contrast to spruce-fir, was described as vulnerable to future climate changes, but less vulnerable to current impacts. Drought was considered the greatest climate threat to sagebrush, and in particular to the water resources and springs that were critical to the sagebrush system. Current and past droughts were critical to people's understandings of climate, but there was a long history of droughts on the landscape, so it was harder to tease climate change apart from variability. Interviewees used reference years to help them understand and interpret climate. Interviewees regularly cited key reference years, such as the droughts of 2012 and 2002, when discussing future impacts of climate. This suggests that conceptions of future hazards and climate are structured and bound by past experiences and extremes.

When discussing climate change impacts to the targeted landscapes, interviewees often referred to climate-related proxies, rather than to climate itself. Climate change vulnerability was discussed in terms of beetles and fire for spruce-fir, while drought and species loss were used to imply climate effects for sagebrush. Impacts and vulnerabilities were discussed and accepted, but not explicitly tied to the underlying driver (climate change on the whole). Localized climate processes are often easier for people to digest and integrate into their local knowledge of a place, but it is important to recognize which proxies are used for which targets, and the larger implications of such perceptions for design of useful climate information.

This focus on components and proxies is quite different from the way climate change is typically measured and presented. Traditional climate information includes projections about metrics such as precipitation and temperature, but these are not what are "felt" by local communities or fit into their understanding of climate vulnerability. Furthermore, climate information often focuses on means (monthly, yearly), but the ranges and extremes are more telling of a future climate and its impacts. This suggested that people are much more sensitive to impacts of climate changes, and tangible landscape processes, than to climate change as a whole. How people understand and perceive climate can help in the design of more useful climate information and support new approaches to communicating information.

Focus Issues:

The targeted landscapes are important to interviewees because of the activities that take place in those systems, rather than the inherent value of the targets themselves. The goal of this research project was to integrate the social analysis into the ecological and climate analysis to reflect the interdependent nature of these social-ecological systems, but it was challenging to elicit social dynamics with ecological targets. People felt a greater connection to the *activities* that took place in the targets rather than to the targets themselves. For example, focusing on an activity like grazing may capture a very similar landscape and system as the sagebrush landscape, but it centers on a set of values that are socially vulnerable and therefore salient to people. Discussions that remained focused on the target, rather than the related activity, address the ecological importance narrowly, but did not provide insight into the *social* importance. This suggests that targets designed around important activities rather than ecosystems may be more relevant to managers, users, communities, and the public.

Additionally, water resources emerged as an important issue in the Gunnison Basin that was not fully captured in the two targeted landscapes. Water often evoked greater threat and concern than either of the two terrestrial system targets. Target selection included feedback from the Gunnison community, but interview responses suggest that water resources are vulnerable and greatly influence both sagebrush and spruce-fir. Water also inculcates a strong social vulnerability and importance. Water resource vulnerabilities were locally expressed through their ecological impacts that could alter landscape systems and aesthetics, and through their social implications that could affect activities such as recreation and tourism (Blue Mesa reservoir, Crested Butte ski resort, etc.), grazing and municipal supplies. They were also discussed regionally as the community greatly feared how the needs of outside communities, perhaps also affected by climate change, would restrict their local water supplies. Threats such as calls on the river, new municipal water rights and trans-mountain diversions made the actions of outside communities salient to Gunnison.

Management and Engagement:

While land managers discussed potential impacts of climate change, almost all interviewees reported that climate change was not part of their larger, agency management plans. This was likely a product of the era they were created; most were decades old and were slated for revisions. While most of the long-term plans did not include climate change because of their age, the short term plans often did not include climate because of their scope. Interviewees reported it was difficult to include climate in short to mid-term decisions (5-10 years) because climate change is thought of on a longer scale, and shorter timeframes might detect climate variability rather than change.

> "That's a tough question just because I'm not sure that the agency has come out and said "This is what the XYZ will be for our goals for spruce fir", you know we talk about resistance and resilience and those kinds of things, but I don't know that anyone's come down upon high and said "our goal and our objectives will be this", so I'd say no, [our goals aren't realistic in the context of climate change]"

Access to information, and the type of information, plays an important role in how land managers incorporate climate change into decisions. Interviewees were asked what type of information they needed to better integrate climate into management and where they would access such information. They discussed information needs, and while many were interested in more climate information, none of them felt completely uneducated about climate change. In fact, Gunnison land managers have developed strong knowledge networks that facilitated access to new science and better sharing of information between agencies. Many reported having resources and access to information within their

> "The Forest Service has a climate change performance scorecard that each forest has to answer a series of 10 questions and we've been working on this for the 3rd year, by 2015 the agency wants every agency to say "yes" to over 70% of the questions. And the performance scorecard, part of that includes basic knowledge, providing training to the workforce, incorporating climate change into decisions, developing adaptive strategies, working in collaboration with public universities and research, and there's a big chunk of sustainable operations involved"

Information Needs
• Understanding human behavior and social processes intertwined with resource management • Strategies for relationship building • More localized information in future climate and impact projections • Sagebrush specific information • Defining best available science • Certainty of models outputs • Recreation carrying capacity • Forecasts on a range of time periods • Trainings on how to use tools/models

agency, from outside agencies, and with non-governmental partners. Managers received science and new information that was digested and disseminated through agency research centers and universities, and they used connections across agency boundaries as well.

Interviewees felt that the Gunnison land management community was closer and better integrated than many of their counterparts elsewhere. They gave many examples of working with other agencies on a common goal and sharing information and project funding. While the Basin has historically had good interagency interactions, this also may be one byproduct that resulted from the threat of the sage-grouse listing. In response to legal consequences, the community created a number of cross-agency groups to focus on the sage-grouse issue, and this helped to build stronger relationships that otherwise may not have formed. While sage-grouse listing is perceived as a serious threat to the community, it may have built a greater capacity to respond to climate change through the stronger relationships and experiences with collaboration.

Relationships between the public and agency managers were not as well formed, and represent an opportunity for increased capacity. Many land managers discussed the challenge of communicating and engaging with the public as an obstacle to decision-making, and felt this was especially salient for decisions regarding climate change. None of the managers interviewed were skeptical of climate change, but they felt that public skepticism made it harder to get buy-in and public approval of their climate related management decisions. A lack of trust between agencies and local community members meant that interviewees felt that every decision was scrutinized, and often challenged, and that this took away from their capacity to effectively manage resources.

Capacity to address the social issues of resource management and manage the public's use of resources was often discussed as more important than the science and management, and participants felt ill-prepared to effectively engage the public. Most of their training focused on the technical aspect of resource management, and many claimed that public land agencies select for people who didn't want to have to work with people. These factors work together to make communication and trust-building a daunting task for managers, and many wanted strategies that could address that self-proclaimed deficiency. Yet, this was not observed in interview and focus groups, as most managers were competent communicators, despite the contrasting narrative. While managers claimed this deficiency, it may be more

> "That trust component that social capacity is really important and you've got to understand human nature. You are, you are not a natural resource manager, you're a human nature manager, and that's the reality of it. So you know, from an organization like mine becomes a challenge because I've got some good technical experts who don't necessarily have that skillset in negotiating political savvy, emotional [interactions]"

representative of agency discourse than practice. This sentiment was not limited to climate adaptation, but managers felt that adaptation would require stronger relationships with the public as compared with current management because the strategies to respond to this new problem would diverge from historic management policies.

Uncertainty and perception

A greater understanding about how people understand climate change can provide insight into their decisions and better guide the provision of climate information. Participants tended to perceive climate change through extremes and variability rather than shifts in mean conditions. This departs from how climate change is often understood, as a single trajectory of global *warming***.** Interviewees expressed a nuanced understanding of climate change and future climate, which recognizes a range of effects and the challenge of predicting those effects. Specifically they discussed extremes and greater variability of climate, and how that would be increasingly difficult to plan for and manage.

The historic and future range of variability is understood and bounded by previous climate experiences. Interviewees discussed how the Basin already experienced significant climate variation and they expected climate change to make extremes more extreme. They regularly referenced extreme drought years (2002, 2012) and high precipitation years (1986, 2008). When impacts of climate were discussed, people often invoked reference years and conditions, speaking of "more 2002's" or a greater oscillation between "2008's" and "2012's." This both roots future projections in lived experiences making their impacts tangible, but also limits future possibilities to past experiences and makes it challenging to imagine beyond prior extremes

> "I think the uncertainty around climate is no different than the uncertainty in any other resource we've managed."

Climate uncertainty elicits a range of responses from land managers, especially as it intersects with decision-making. Some interviewees felt a sense of dread and paralysis, others expressed a neutral curiosity about future systems, and still others expressed confidence. People were comfortable making decisions with climate uncertainty when it was framed as a disturbance. Managers regularly make decisions about disturbances that are steeped in uncertainty (fire, beetles, drought), and recognize that their understandings of future ecological conditions are only partial. To manage for disturbances they must try to create resiliency in the landscape and invest in protective efforts, but they cannot control large, landscape-scale disturbances. Often, they must respond quickly during or after disturbances. When climate change is viewed similarly, it fits within current management frameworks and managers' skill sets. Framing climate change as a large-scale disturbance does not require managers to have certainty on the scope and scale of its impacts, but rather move forward in decision-making with recognition of uncertain future conditions.

> "It's the politics around climate that make it seem different and scary, but from any natural phenomena, or ecosystems stand point, it's no different than the resource we're dealing with, characterize the impacts, package the information and describe it."

Framing climate impacts as a disturbance may be a strategy to aid managers, and one that works with their current management frameworks and approaches. Some managers are already framing climate impacts this way and more managers may benefit from this approach. It could translate climate from an unimaginable and unmanageable challenge into a type of issue they have confidence with and experience working on. A disturbance framing may combat the feelings of inexperience surrounding climate change and may help free it from the politics that also make it hard to engage with. Even those who were already framed climate as a disturbance were quick to acknowledge this was not a silver bullet and that management challenges exist with all disturbances.

Adaptation and Management

Land managers discussed different approaches about how to adapt to climate change and make decisions under uncertainty; however, they favored approaches that allowed them to focus on what was more certain within a range of uncertainties. Even managers who were comfortable with uncertainties favored a straightforward and defined management goal rather than one that was undefined and open-ended. Two, somewhat countervailing, themes emerged in their favored approaches: specific and set goals were needed for management, and processes with increased flexibility and re-evaluation were the strongest for managing under uncertainty.

> "I guess a number of us saying, 'What does a climate change strategy look like, what do you do?' Well because you can do a lot of paper stuff that is meaningless. 'What do you do on the ground? What does the land owner do?'"

Managing for a "range of future conditions" is often discussed as a strategy for climate adaptation decision-making, but interviewees did not respond well to the idea. There was a mix of reactions that ranged from excitement and support, to confusion, to resistance and critique. The non-supportive reactions were spurred by confusion about what a "range of future conditions" meant and frustration that it was not a practical management goal and could not readily be implemented. When asked about that approach, many were confused as to what it meant and asked for further definition. They were not familiar with the concept and furthermore were unsure how it translated into actual management prescriptions or how their agency would even support it. Others responded strongly against the notion. To some it was unrealistic and others misunderstood what it meant. The feasibility and practicality of planning for a range of future conditions was questioned, and to many it sounded like increased paperwork and a bureaucratic headache. Some were frustrated by the idea, stating that it was probably something that researchers came up with who were detached from management, or that it did not make sense and was going to be another burden added to their decision process. A minority did respond well to the idea, with some saying it would be a useful goal, to others suggesting that they already did this through use of historic range of variability and NEPA processes. These responses suggest that managing for a "range of future conditions" is not an accessible strategy to most managers and might conflict with conceptual frameworks of how to make decisions. Instead, one set goal was the favored management approach.

Managers wanted one clear management goal, even if that goal needed to be amended later. It was suggested that a useful approach to managing for a range of future conditions was to consider all the decisions and then choose one goal that represented the middle ground between extremes. Even with uncertainty, managers preferred to set a clear goal, one that was measurable and that management strategies could be geared to, rather than have a range or an undefined goal. People did recognize that goals may prove to be unobtainable with such great uncertainty, but believed that adaptive management (regular re-evaluations of goals) could address that.

Different Responses to Managing for a Range of Future Conditions:

> "Managing for a range of future conditions, I think we're not there yet, and I'm uncertain as to what the agency could do at this point to support it. I think this is frankly, a key area, and it'll come with the type of work [this project is] developing. How do you consider a range of climate scenarios in the future? How do you analyze [climate scenarios]? What are the potential impacts we can be looking at and considering?"
>
> "That is absolutely true. We should try to manage for a range of future conditions out there and so I think part of that is trying to look at what do we think those range of conditions might be in the future."
>
> "A range of future conditions, yeah I think we're kind of doing that now. That's a hard one."
>
> "I've heard about it but I'm not sure how you manage for multiple outcomes at the same time. I mean to me it makes more sense to pick a path that makes sense based on what you know today, but be flexible enough that as you get more information, you can decide to change course. You know, it's like, for an example, you know, if you're trying to make a decision on where to go to dinner, you can't go to five different restaurants at the same time."
>
> "I think that's the dumbest thing I've ever heard. Our agency in all, what would enable us to do that? Because you don't know what the situation is so, you're gonna try to manipulate the landscape in 10 different ways in case it hits any direction so you're going to have at least nine failures and nine damaged creations, if you will, so yeah, that's a really bad idea in my opinion."
>
> "You have an end goal if you want to get to, know if you're directing towards for that or away for that, but managing for million different scenarios would only kind of quagmire you and this indecision, I don't know what to do."

Assist or Resist?

While most agreed that they would prefer to have one management goal, there were tensions over what approach it should take; should adaptation assist or resist climate impacts? Management efforts could work to maintain currently functioning systems and try to protect them and build resistance to change, or they could attempt to facilitate change. One example of this was on species ranges. Managers struggled with whether to use nurseries and management prescriptions to maintain diverse species and keep systems within their historic range. Some suggested that to best adapt to climate change, they should start to plant new species and assist in shifting ranges. This highlights the complexity of management under climate change: how to approach a changing system.

Adaptive management (AM) is a popular strategy for managing under uncertainty, but participants noted that a gap exists between theory and practice. AM requires flexibility to respond in a timely manner, flexibility that current financial constraints, regulations (NEPA), and agency guidelines do not facilitate. Managers often cannot respond quickly to changes or disturbances and they worried this would become an increasing problem with climate adaptation. Furthermore, a critical component of AM is experimentation, which includes failures, but managers described a risk-adverse culture that did not tolerate failure. There was pressure from the public for the "right" management prescription and this translated into the agency promoting conservative management.

Managers need accurate and current baselines for adaptive management, but lack the necessary funding and capacity for consistent long-term monitoring. This is a significant challenge to implementing adaptive management and another gap between theory and practice. Monitoring projects rarely get funding, especially the long-term funding required to construct baselines and to understand the impact of management prescriptions. Permittees discussed this same gap in monitoring and baselines, and suggested it was an opportunity to utilize local knowledge. Ranchers spent significant time on their permits and built a deep, and long-term baseline knowledge of the system that they thought could be useful in light of the funding and capacity challenges for monitoring.

Barriers to Adaptation

While uncertainty about future climate presents challenges, a lack of information is not the most critical barrier to implementing adaptation strategies in the Gunnison Basin. Interviewees had experience and familiarity with climate science and strong networks to obtain additional knowledge (agency research branches, agency specialists, TNC, RMBL,WSCU). Many barriers exist within and outside of the agencies that may have a greater impact on implementing climate adaptation strategies than scientific uncertainty. All are important to recognize when designing adaptation strategies.

Type:	**Financial**	**Structural**	**Social**	**Other**
Themes:	Insufficient budgets; restrictions on how funds can be used; lack of monitoring funding; depressed local economies; lack of professional development funding	Laws and regulations; diverse land ownership; cumbersome bureaucratic processes; lengthy planning processes; highly mobile agency employees; lack of staffing capacity; uncertainty about "best available science"	Special interest groups; public perception of the environment; challenges with public engagement and communication; overuse and maintenance of partnerships; politics that resulted in stakeholder fatigue or non-diverse community engagement; short-term memory of landscape change; lack of trust between agencies and the public; limited local control of resource management and decisions; skepticism of climate change	Scale of processes and interventions (often a mismatch); confusion about the best approach to change (resist or assist);

Adaptation barriers and challenges in the Gunnison Basin can be grouped into three main categories: financial, structural and social. Financial barriers are obvious, and related to availability, quantity and timing of funding. Structural barriers refer to issues that are part of a larger, often formal, system such as laws and governance, institutional guidelines and restrictions, and agency processes. Social barriers include interpersonal interactions, relationships between agencies and the public, and public beliefs.

Selected Barrier Quotes (from resource managers across agencies):

Financial Barriers	
Theme	**Quotation**
Low budgets	"I would say it's a real challenge right now with the budgetary constraints and the kind of projections of what where we're going with budgets right now. The BLM, at least in my experience, does not have enough people and money to do what we're supposed to do, let alone what we'd like to do. So that's a struggle."
Funding restrictions	"Money isn't always the issue, it's some of these fiscal constraints and caps, like I can only spend $25,000 on one contractor when I know he's qualified to do the work, you know. But I have $50,000 of work funds this year."
Professional development funding	"We don't have funding to go to conferences; those are always good places too. Maybe not always to learn the information but definitely make contacts with people who have the information and find out what kind of research is happening, and that's something that the BLM and I think the other agencies too, are getting less and less support to send its people to conferences or even giving us the time to go to them, I mean really, we're so strapped for time that I haven't been to a professional conference other than just taking annual leave and going on my own, for years."

Structural Barriers	
Theme	**Quotation**
Laws and government regulations	"Most of our district is Roadless or Wilderness, we can't manage that area. That's part of the issue, a lot of the areas we cannot actively manage because they're Roadless and wilderness and we have to obey that. To manage them we need roads but we simply don't have that."
Red Tape	"It's you know, sadly, paperwork intensive as opposed to on the ground solutions. If we had money that we could quickly put on the ground we would achieve so much so quickly, but it's all paperwork, and a lot of laws require that. And some of that is internal."
Highly mobile agency employees	"Very difficult to go from an entry-level position to a management position in one office, you're gonna have to transfer. I don't know if it's formal policy, but a lot of agencies it's informal policy. As far as providing a broad base of skills, and not becoming entrenched in an area that works but as far as being able to make good land management decisions, makes it difficult I think. "
"Best available science"	"You know, we make our decisions based on the best available science, and that's something we're required to do, at least at the Forest Planning level, but I think it actually carries forward into project levels, so we try to base our decisions on best available science. I think that oftentimes best available science is based on history that it is based on uncertainty."

Social Barriers	
Theme	**Quotation**
Special interest groups	"The land management agencies have to deal with special interest groups pushing, no matter what they decide, so they have some pressure no matter. There's always a special interest group that's unhappy no matter what the decision."
Public perception of the environment	"Not targeting climate change because there's a lot of skepticism up here, if you say "climate change" up here to some of these folks, you're automatically a granola-crunching hippie who yeah drives a Subaru."
Short-term memory of landscape change	"It's unprecedented in the memory of people... They think it's always been this way, people have a very hard time visualizing change so because we have limited space where things can be done, the management of spruce-fir is mostly going to be done from a public safety perspective."
Relationships & lack of trust with the public	"So there's lots of challenges and then just the fact that people, there's a still of big distrust that the Forest Service that could possibly be good for the landscape. There's opposition to seeing any kind of management to be done. Consequently we have the Colorado Roadless Rule, which ties our hands for being able to respond to changes on the landscape. So lots of challenges. People move here because they see this beautiful landscape and "not in my backyard, I don't want to see anything happen".
Local control	"There seems to be a shift from trusting, they expect everybody in these positions has to have a huge amount of education, you know the requirements to get one of these jobs are very precise and overwhelming. And they're taking away that trust that [our agency] used to be a locally-managed. We trust our employees. Now everybody's kind of pulling back to "Our employees are not the smartest so let's give them the template they need to use."

KEY FINDINGS

Adaptive and flexible management:

- Adaptive Management (AM) is a popular strategy for managing under uncertainty, but a gap exists between theory and practice because managers do not have the flexibility to respond quickly or adequate baselines to evaluate management strategies.
- Interviewees did not respond well to the idea of managing for a "range of future conditions" because of confusion over what it meant and frustration over how to implement the strategy.

Uncertainty and Variability:

- Uncertainty elicits a range of responses from land managers from dread to curiosity to confidence; people were comfortable with future uncertainties when they were framed as disturbances.
- Climate change was understood through extremes and variability rather than a simple focus just on increasing temperatures.
- The historic and future range of variability is understood and bounded by previous climate experiences, with regular references to extreme drought years and high precipitation years.
- A lack of information is not the most critical barrier to implementing adaptation strategies in the Gunnison Basin.

Public Influences:

- Interviewees did not deny climate change, but saw public skepticism as a barrier to implementing climate adaptation.
- Recreation pressures (and conflicts) are growing in the Basin and this is compounding the challenges of climate change.

Capacity:

- The threat of an ESA listing for the Gunnison sage-grouse may have built community capacity for adapting to climate change.
- Capacity to integrate the human dimensions of natural resource management was often discussed as more important than the science and management, and participants felt ill prepared to effectively engage the public.
- Interviews highlighted a range of barriers for climate adaptation and climate decision-making that can be placed into three main categories: financial, structural, and social.

Perception and Environmental Understandings:

- When discussing climate change and the targeted landscapes, interviewees discussed climate related proxies, such as wildfire or beetles, rather than climate itself.
- The targeted landscapes are important to interviewees because of the activities that take place in these ecosystems rather the inherent value of the targets themselves

Climate adaption under a range of scenarios: Natural resource manager focus groups in the Gunnison Basin

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Executive Summary:

Resource managers need to consider climate change in their management decisions and long term planning. Yet, while they are increasingly being tasked to incorporate climate change, many barriers and challenges exist that complicate integrating climate information and producing robust adaptation strategies. Climate change information is often at the global scale and projected over long time periods and this makes it difficult for managers to integrate it into local management plans with shorter timescales. Furthermore, the uncertainty of *how* climate will change, especially in hard-to-model mountainous landscapes, increases the difficulty of this task. To help address this challenge, localized climate scenarios were developed for the Gunnison Basin as a tool for resource managers to facilitate thinking about climate adaptation strategies.

This report summarizes the findings from four, scenario-driven focus groups of natural resource managers. Managers were asked to consider how to incorporate a range of future conditions into resource decisions. The scenarios specifically keyed into two target landscapes due to their social and ecological importance in the Gunnison Basin: spruce-fir forests and sagebrush shrublands.

The focus groups produced a number of key findings about planning for a range of future conditions, and potential adaptation strategies at a local scale:

- *Perceived Risk:* Participants largely agreed that a scenario with high variability in precipitation and temperature would be the greatest challenge for management. Furthermore, managers thought that scenarios without clear warming and drying trends, such as moderate temperature increases or high variability, would be harder for the public to recognize, which could undermine adaptation efforts.
- *Spruce-Fir and Sagebrush Landscapes:* Participants recognized that both target landscapes were undergoing change and that they could not manage for current conditions. Spruce-fir was already undergoing significant and rapid change and participants expected future disturbances to be longer in duration and higher magnitude. The sagebrush shrublands were considered ecologically vulnerable to climate change, and due to the strong dependence on this landscape by the ranching community, also socially vulnerable.
- *Potential Strategies:* Participants generated several strategies in response to scenarios; many were not novel, but instead used and built on previous practices. This indicates that managers might already have many of the tools and much of the knowledge needed to respond to a changing climate, and they discussed

utilizing existing management strategies and borrowing exemplars from other locations. However, increased flexibility in terms of funding, procedures, and management practices would improve managers' ability to plan for a range of future conditions.

- *Conflict and Cooperation:* Participants interpreted potential changes through existing conflicts, with little discussion of new ones; this may indicate that climate change is not so different from other types of social-ecological changes, or that people have a hard time imagining subtle changes and altered future conditions. Participants felt the Basin has local capacity for cooperation, and they preferred bottom up approaches such as collaboration fostered by locals rather than mandated, top-down adaptation protocols.
- *Climate Science and Scenarios:* Overall participants reported that the scenarios helped them interpret climate change impacts locally in the Gunnison Basin and consider a range of future conditions. However, participants requested more information about current baselines and the status of human communities be incorporated into the narratives. Future work should also consider how to promote thinking beyond past experiences.

These findings can help climate scientists understand how to better design useable climate science and also inform resource managers, and researchers, in how to develop and support climate adaptation strategies in the Gunnison Basin and beyond.

Introduction:

Natural resource managers have a challenging task managing for multiple goals and diverse users, and a changing climate complicates this already difficult job. The American West is already facing myriad climate change impacts, including higher temperatures and more water shortages, both of which are predicted to increase in intensity (Seager et al. 2007; Garfin *et al.* 2013). Changes in temperature and precipitation are in turn impacting ecological and social systems. This project used a scenario-based focus group process to engage natural resource managers in the Gunnison Basin in the development of adaptation strategies that respond to tangible landscape-scale changes as well as a range of futures possible under a changing climate. The process was designed to integrate landscape-scale projections and uncertainty into climate planning.

Large, undeveloped landscapes provide critical and represent opportunities to employ landscape-scale adaptation strategies. However, challenges remain regarding how to manage undeveloped landscapes in the face of climate change and uncertainty.

Climate models, or multiple models in an ensemble, can generate information that is challenging for natural resource managers to engage with, interpret, and use to inform decisions. In many cases, model information is provided as changes in averages, rather than ranges, and is focused on temperature and precipitation instead of other important climate and terrestrial metrics. Modeled data are also often at a regional scale, which can create a mismatch between the scale that managers and the public plan for and the information given to guide that planning. Further, while there are some processes that climate scientists are more confident in (e.g. global to regional temperature trends), great uncertainty exists about how climate change will affect particular places. Downscaled models are useful, but changes in scale carry increases in uncertainty. Mountainous environments, like those in the American West, are particularly challenging to predict because topography can shape weather patterns but Global Climate Models use coarse data that smooths sharp relief (Cozzetto *et al.* 2011; Rasmussen *et al.* 2011).

To address these challenges Imtiaz Rangwala, of the Western Water Assessment, and Renee Rondeau, of the Colorado Natural Heritage Program, spearheaded the development of narrative scenarios based on climate models and other biophysical data. Three narrative scenarios were developed for a 20-year timeframe to reflect three different plausible futures for the Upper Gunnison Basin. These scenarios bring together different data sources to paint a picture of how climate might impact the biophysical environment and people of Gunnison Basin, to make projections more detailed, tangible, and useful to managers. By producing three scenarios that describe a range of possible futures for the Gunnison Basin, managers were able to confront key differences in how their landscapes might change and think through how to manage under that uncertainty. Focus groups explored how scenarios might be used in decision-making.

This report highlights the findings from the scenario-based focus groups conducted during the summer and fall of 2014, which were part of a larger interdisciplinary, multi-landscape research project, the Southwest Colorado Social-Ecological Climate Resilience Project (SECR), funded by the Department of Interior's North Central Climate Science Center (NCCSC). SECR project partners[1] and stakeholders aimed to facilitate climate change adaptation that contributes to social-ecological resilience, ecosystem and species conservation, and sustainable human communities in both the Gunnison and San Juan Basins.

Project Goal

The social science component of the SECR project examined decision-making under uncertainty and the use of narrative climate scenarios as a tool. Further, this research is focused on two targeted landscapes selected for the Gunnison Basin: the spruce-fir forests and the sagebrush shrublands. The Gunnison Climate Working Group (GCWG), a collaborative group of community members representing land and water managers, ranchers, county officials, university scientists and others, selected these landscapes because they will likely be affected by climate change, and community members see them as important for both social and ecological values. The two landscapes cover approximately one million acres within the Upper Gunnison Basin, with the sagebrush occupying the lower elevations and the spruce-fir extending to higher elevations.

Methods:

Four scenario-based focus groups were conducted in the Gunnison Basin between July and October 2014. Out of the 72 climate model outputs generated, Rangwala and Rondeau selected a model output with high temperature increases and precipitation decreases as the *Hot and Dry* Scenario. The *Warm and Wet* Scenario had mild

[1] Colorado Natural Heritage Program, The Nature Conservancy, Colorado State University, Mountain Studies Institute, University of Colorado, University of Montana, U.S. Geological Survey, Western Water Assessment, University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES), National Oceanic and Atmospheric Association (NOAA), and the Gunnison Climate Working Group.

temperature and precipitation increases, and the *Feast or Famine* Scenario had large oscillations between extremes, primarily strings of years with very high and very low precipitation.

The three scenarios represented different possible future climates for the Gunnison Basin, and researchers developed narratives for each model output to make their local environmental impacts more explicit for decision makers. The text of each narrative scenario was limited to two pages to make them manageable. Rangwala and Rondeau used a number of strategies to make narratives not only both technically accurate and maintain a high level of detail, but also accessible to a broad range of users. Comparisons to analog climates provided participants real world, local examples of what a new climate would feel like. Analogs included different towns that had climates similar to projections, or focused on previous climate events, like significant droughts. Similar scenarios have been used by the US National Park Service (Chaplin *et al*. 2007) and researchers studying decision making under uncertainty in the western United States (Murphy *et al*. 2015, Wyborn *et al*. 2014).

Changes in temperature and precipitation were translated into landscape level impacts to flora, fauna and ecosystem processes, such as increased invasive species or increased wildfires. Additionally, scenarios tried to capture inter-annual variability and extreme events.

Table 1. Scenario Descriptions and Implications

Scenario Title	Climate Description	Select Ecological Implications
Hot and Dry	Warmer and drier across all seasons with perennial drought	Sagebrush stands will likely convert to grasslands, aspens will be unable to recover from drought, spruce-fir stand species composition will shift and species may migrate to higher elevations
Warm and Wet	Warmer across all seasons, earlier snowmelt, with more winter precipitation (as snow and/or rain)	Maintain current stands, but the condition will degrade, increase in invasive species such as cheatgrass
Feast or Famine	High inter-annual climate variability with hot, dry years followed by cool, wet years, more floods and droughts	Increase in fire severity and intensity due to build up in wet years, fire danger in dry years

Focus group participants included a wide range of natural resource managers working in the Upper Gunnison Basin. Managers from federal, state, and local agencies were invited to participate and focus groups included representatives from the U.S. Forest Service, Bureau of Land Management, National Park Service, Colorado State Forest

Service, Colorado Parks and Wildlife, and the Natural Resources Conservation Service. Participants included experts in forestry, wildlife biology, range management, botany, fire management, and hydrology. Additionally, participants ranged from line-officers to specialists. The design intentionally mixed participants so that each focus group would have representatives from different agencies and specialties.

All managers who were interviewed earlier in the research project were invited to participate, along with new participants who were recommended by interviewees and other contacts. Three of the focus groups were conducted in Gunnison; one was held in Montrose. Overall, 18 resource managers participated in the focus groups, in groups of 3, 4, 5, and 6 individuals.

Each session started with an overview of the project directives, discussing and signing informed consent forms, introductions to the group, and ground rules. Next, participants read the *Hot and Dry* Scenario. After all of the participants finished reading the scenario, general feedback was solicited and a series of questions (see Appendix 1 for focus group questions) were asked about participants' responses to the scenario. Steps were repeated for *Warm and Wet* Scenario and the *Feast or Famine* Scenario. At the end of the focus groups, participants were asked to share their feedback about experiences with the scenarios and the process of thinking through uncertainty.

Each focus group was conducted by the author and lasted two hours. All focus groups were audio-recorded and transcribed verbatim to assist in analysis. Transcripts were then coded using Nvivo software with explicit (water resources, barriers, etc.) and implicit (risk, fear, frustration, etc.) codes. Coding was used to identify themes and facilitate analysis.

Key Findings:

1. Risk Perceptions:

Scenario-Specific Feedback

The three scenarios elicited very different responses, offering useful insights into the risk, vulnerability, adaptation and perception of Gunnison Basin managers. The *Hot and Dry* Scenario and *Feast or Famine* Scenario matched the personal climate experiences closely and current climate observations could easily fit into or lead to either trajectory. Many participants expressed that the *Hot and Dry* and *Feast or Famine* Scenarios were "already starting to happen."

Each scenario carried different risks with the *Feast or Famine* Scenario being considered the greatest threat and the *Warm and Wet* Scenario considered the most benign. The majority agreed that the *Feast or Famine* Scenario was the greatest threat because of management challenges associated with a highly variable system. It was feared that the oscillation between the two extremes would lead to people constantly being blindsided and promote reactionary, triage-oriented management. However, opportunities may exist with highly skilled management that harnesses resources in feast years and conserves during famine years. The *Warm and Wet* Scenario was generally considered the "best case scenario," but participants discounted its probability of occurring, in part because it did not match their own personal climate observations and conflicted with meta-narratives of climate change.

One of the greatest factors that contributed to perceived risk was the trajectory of change and how clearly it could be interpreted. Managers discussed that even a predictable, but less ideal climate (like the *Hot and Dry* Scenario that has significant water resource limitations) is preferable to a climate with high variability because it was so difficult to craft effective management strategies. Participants worried that it would be much harder for the public to recognize the changes in the *Warm and Wet* and *Feast or Famine* Scenarios. This would make it much harder to obtain public support and financial resources for climate adaptation plans. There were minor disagreements about threat level because a few individuals thought that the *Hot and Dry* Scenario carried the greatest risk with its constant lack of water resources, but most agreed it would be easier to manage for, even if it was a more severe departure from the current climate.

2. Spruce-Fir and Sagebrush Landscapes:

All three narratives described anticipated changes to the two landscapes due to climate change, and this helped managers think about the management needs and possible threats to the targeted landscapes. Participants discussed the main risks of each scenario and what implications it would have on the larger system.

Spruce-Fir:

The descriptions of future spruce-fir were questioned more than other landscapes because participants thought that there would be very little spruce-fir forest left by 2035. A total transformation was expected within this landscape and people commented that the system would forever be changed after the on-going beetle disturbance and that it would not return to this recent past state in their lifetime. Many suggested that attempting to manage for the recent past conditions was not realistic and it would only become harder to restore spruce-fir landscapes. A reduction in spruce-fir would likely increase aspen groves, and have recreation impacts and wildlife implications because of altered thermal dynamics and habitat conditions. To respond to changes, participants said they would need to be prepared for longer duration and higher magnitude disturbances such as the beetle infestation and wildfire. Connectivity between the few existing patches of spruce-fir "islands" and newer generation was discussed as a critical management goal. Additionally, there was debate over whether managers should resist changing ranges by planting saplings in historic ranges or assisting migration and planting at higher elevations, which was similar to the interview results (Clifford 2015). Some participants worried that these changes could increase conflict, as there were greater pressures on the alpine landscape from recreation (skiing) and wildlife.

Sagebrush:

The climate changes outlined in all scenarios would impact the sagebrush landscape and have cascading impacts through ecological and human communities, so discussions of sagebrush often quickly migrated to discussion of local economies and wildlife. One of the largest concerns – especially from the *Warm and Wet* Scenario – was invasive species, namely cheatgrass. Participants feared that a warmer environment would make the sagebrush landscape more susceptible to invasive and generalist species. Invasion of cheatgrass would reduce the value of shrubland for wildlife and ranchers and be difficult to fight; it would require significant work from private landowners.

Furthermore, longer and more extreme droughts were thought not only to be able to change the distribution of sagebrush, but to be intense enough to kill the species and push past system flexibility. These changes were expected to have large impacts on the Gunnison sage-grouse and on the ranching economy. If the sage-grouse[2] were listed as endangered it would result in a number of land use restrictions challenging land management and local ranching operations. Even without a listing, participants worried that climate changes may affect the sagebrush landscape enough to endanger the ranching operations and possibly push them past their coping capacity. This could lead to large numbers of ranches going out of business, which would impact the local culture as well as the landscape if ranches were subdivided and developed, further fragmenting the landscape.

While many risks to sagebrush were identified, some changes may not be as threatening, and some could even be considered positive, at least in relation to other climate impacts. Some level of drought could be beneficial to the landscape because it might create successional processes and a mosaic landscape that would offer more local level diversity. Furthermore, unlike the spruce-fir landscape, which has limited space for upward migration due to its high elevation, sagebrush does not have spatial limitations and could migrate upward to higher elevations. This possibility raised questions about the rate of change in the system: would the changes occur too fast for sagebrush to adapt? This was a major concern and facilitating adaptation consistent with rate of change would be a key role for resource managers.

3. Potential Strategies

At the end of each focus group, and after all three scenarios were reviewed, the researcher asked participants what types of strategies they could use in response to the changes described in the scenarios. They were asked to think about responses to each of the scenarios individually as well as responses that would be robust in response to the range of possibilities exhibited by the scenarios.

Many of the strategies discussed were not novel practices, but rather built on existing strategies and plans employed by land managers, often with increased resources, intensity or flexibility. Adaptive management, collaborations among agencies, intensive seedling planting and regular revisions of management plans were all suggested. Prescribed fire and timber harvesting were considered important strategies especially as they pertained to future fire risk. This indicates that many climate adaptation strategies can fit within existing management frameworks and may not require managers to design totally new approaches.

[2] The focus groups were conducted before the sage-grouse was listed. On November 24th, 2014 the US Fish and Wildlife service determined the Gunnison sage-grouse required protection under the Endangered Species Act as a "threatened species."

However, current strategies would be greatly facilitated by increased funding, capacity and flexibility. Managers spoke about a number of barriers that inhibit current strategies and would further inhibit climate adaptation. The amount of funding and the strict temporal guidelines for grants and financial resources made it challenging to respond to change and unanticipated events. Many lamented that they had to apply for project funding years ahead of time when it was hard to determine what the landscape needs would be. Additionally, lack of funding and capacity made it challenging for managers to implement strategies at the scale and intensity they wanted to, and to maintain up-to-date monitoring to inform management decisions. Flexibility, in all dimensions, was important to managers because it would allow them to better practice adaptive management and would allow them to respond creatively, quickly and effectively to management challenges arising from climate change. Addressing current barriers to flexibility is a clear strategy to serve climate adaptation.

Comprehensive List of Strategies Generated in Focus Groups:

- Increased and flexible funding
- "No regrets" strategies like the wetland restoration structures
- Borrowing ideas and best practices from other sites
- Assisting plant migration through seeding
- Seed banking
- Prescribed fire
- Investing in fire fighting and mitigation
- Changing agricultural species (e.g. grasses)
- Private land conservation to maintain landscape connectivity
- Flexible funding schemes and grants
- Updated infrastructure
- Power to make local level decisions
- Mapping and monitoring (ecosystem health and species distribution)
- Collaborative, inter-agency groups focused on climate change issues (like the GCWG)
- Cross boundary management
- Pooling of resources across agencies
- Look to case studies outside the basin for approaches
- Manage for bad years
- Increased flexibility for grazing permits

Some of the focus groups discussed a strategy of increasing landscape "resiliency." Discussions were largely focused on a particular example: the Gunnison Climate Working Group and The Nature Conservancy efforts to build simple restoration structures[3] to slow and store water in riparian areas and wetlands within the sagebrush landscape. Building rock structures represents a "no regrets" strategy that would serve all three scenarios well, especially as they address what managers felt was the most critical resource in the system: water. Many discussed how much they appreciated a concrete

[3] The Gunnison Climate Working Group has been implementing a multi-year project building simple yet innovative restoration structures to help riparian and wetland habitats retain water and help the Gunnison sage-grouse and other wildlife species adapt to a changing climate
For more information see: http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/colorado/colorado-simple-structures-help-wildlife.xml

example of how a climate adaptation strategy could be designed and employed because it felt like such an abstract idea beforehand. Additionally, it was part of a process that worked across agency lines and in partnership with private landowners. Participants suggested additional rock structures as a strategy that addressed all scenarios.

In addition to current management practices, participants discussed adopting new climate adaptation strategies from other field offices and looking to other case studies to see what approaches work. They spoke of the importance of sharing information across agency lines locally, but also reaching out to other districts, especially other high alpine, mountainous locations like Montana, or even other countries. Looking to case studies would allow managers to gain knowledge from experimentation and could be achieved with limited capacity due to staffing and financial constraints. This would require increased communication between districts, which often operate in isolation, and would prevent everyone from trying to "reinvent the wheel."

The primary focus on current management options, or small changes to current management practices, raises several questions. Does this indicate that new and transformative strategies are not required to address climate change? Or, is this indicative that it is challenging to think beyond the current management toolkit for new management possibilities? The answer to this question, which is beyond the scope of this report, is likely a combination of the two, but can help provide insight into climate adaptation strategy development and decision-making. Regardless, managers were able to brainstorm how to utilize current strategies and in some cases include new strategies to respond to a range of future condition.

Spruce-Fir and Sagebrush Focus

Participants were asked follow-up questions about what strategies they would use specifically for the spruce-fir and sagebrush landscapes. Each focus group had a mix of specialties, so some focused more on one landscape over another, and many of the strategies generated were not new approaches, but were in line with their current management. Strategies for spruce-fir included: maintaining genetic diversity, allowing disturbances, and maintaining connectivity. The strategies for sagebrush included: protection from grazing, increasing groundwater infiltration, and decreasing the spread of noxious weeds.

While they were able to generate specific ideas for the target landscapes, participants thought about landscape strategies more broadly and often thought at the scale of the Gunnison Basin. Narratives gave specific information about the target landscapes, but participants generated ideas that crossed political and ecological boundaries and saw strategies and broad approaches to climate impacts in the Basins.

4. Conflicts (and Cooperation):

Conflict is often discussed as one of the social consequences of climate change, but this research found that participants generally did not expect new conflict; climate change was primarily interpreted through existing social conflicts. Participants were asked to identify threats or potential conflicts that would be associated with each scenario. While a few new conflicts were discussed as potential results, the reliance on previous conflicts illustrates how people interpret scenarios and understand them through their previous experiences, and suggests that they may struggle with trying to anticipate new dynamics.

This can be understood as a strength but also a potential limitation for integrating climate into decisions. It may indicate that climate changes are not so different from other disturbances or social-ecological changes, or that people have a hard time imagining the unimaginable or unseen. Furthermore, this finding illustrates how climate transforms into a social process and how the interpretation of climate information is not objective and based on statistics, but formed and shaped by the previous experiences of the individual. The same scenarios can elicit different levels of perceived threat, conflict, or optimism.

Potential Conflicts:

Potential conflicts were greatly influenced by the agency and expertise of participants, type of scenario and individual experiences and beliefs. However, general themes emerged about the type of conflicts participants anticipated.

- Management: The stress of climate change on resources could potentially pit different agencies against each other and strain relationships when managing complex landscapes with disturbances (e.g. fire, beetle) or legal issues (e.g. ESA). Participants recognized that changes would transcend agency boundaries and require coordination, but different management agencies have different goals and approaches to management that could be challenging to reconcile. Furthermore, different agencies have access to different levels of funding and participants worried that some agencies and projects might be favored over others. This might be exacerbated by disparity between the funding levels and institutional support of different agencies.

- Multiple Uses: Accommodating multiple (and divergent) uses was already challenging for managers and they felt like this mandate would be increasingly problematic with climate-stressed resources. Struggles between stakeholder groups for access to and use of resources would become heightened. Many thought that they would need to say more "no's" and this would restrict access and their ability to compromise. While there are many stakeholders that could be embroiled in conflict, three interests emerged as particularly susceptible in the Basin: ranchers, recreationalists, and wildlife[4]. Each of the three were assumed to be in direct conflict with each other and likely to create management challenges.

- Altered geographies: Altered ranges and geographies is a conflict that was largely new and outside the personal experiences of participants. Managers were worried that ranges projected to shift due to climate change would disrupt the tenuous balance between the stakeholders and different uses. Recreation, wildlife, plant species and demographics were all expected to experience a change to their historic range and the new ranges might increasingly overlap, creating strain on resources and pitting different uses against each other.

[4] including the management plans and laws.

Trans-local connections:

Climate change does not only affect Basin residents through direct impacts but can also be felt through trans-local connections; climate impacts to other parts of the West may be important drivers of, for example, migration and water resource conflicts. Issues of migration and population change outside of the Basin could create conflicts over resource management within the Basin and this was especially pertinent to water resources. Participants discussed how increased temperatures and climatic changes in more vulnerable places, e.g. Texas or the Colorado Front Range, may drive increased migration to the Basin and further burden resources. Similarly, climate changes and droughts outside the Basin could strain water resources and spur new diversions and water calls that would limit water use in the Basin. Human migration patterns and legal frameworks connected disparate localities in a shared climate risk that operates in nested scales. Trans-local connections could transfer climate impacts from places with greater vulnerability to the Gunnison Basin. This was especially worrisome because managers have little to no jurisdiction over resource use outside of the Basin that could severely impact resources inside the Basin.

Water Resources:

Water resources evoked the greatest sense of threat in the climate scenarios showing that it was an extremely vulnerable system important to social and ecological communities. Participants viewed their environment as hydrologically limited and less flexible to changes of precipitation than temperature; many felt that if water stayed consistent that the Basin could survive, albeit with challenges due to increases in temperature. Water resources were discussed in response to all scenarios and were important to ecological and social systems. Almost all the conflicts were directly or indirectly connected to water resources and the stresses from reduced runoff. While most of the risk and potential conflicts were discussed in terms of drought and water shortages, participants acknowledged that an unpredictable system with extremes could also generate harmful impacts.

Reservoirs:

Reservoirs emerged as an increasingly important water resource element with climate change. In response to climate changes, people expected their management to become more complicated and for more reservoirs to be built. This could make it increasingly challenging to maintain naturally functioning or flowing rivers and likely have many impacts on ecological and human systems as an indirect effect of climate change. Reservoirs could be needed to keep water in the high country if snow melted off earlier and they may play an increasing role in flood management, as people expected the melt to be more "flashy." Many discussed that water storage through snowpack in the high country is ideal because of its timing (it slowly melts and provides a more constant supply of water) and because it retains water (unlike reservoirs which can loose water to evaporation).

Collaboration:

While scenarios elicited feelings of threat and worries about potentially exacerbated conflicts, participants were still largely optimistic about cooperation and collaboration in the Basin. The Basin may be able to avoid some of the potential conflicts because it has already proven that it is successful in working across agencies and stakeholder groups. Gunnison Basin managers were proud of their communities' ability to work collaboratively, and many stated that relationships in the Basin were much better than in previous locations they had worked. Past experiences may highlight important capacities for future resource challenges.

Droughts and years with extreme snowpack have always occurred in the Basin, and the community has created local, voluntary and context-specific solutions to address associated resource challenges. A few participants cited the example of voluntary fly-fishing restrictions during the drought of 2012. As water levels decreased, the Basin's fishers stopped using the lower stretches to help maintain fish populations. This was not a product of government regulation or restriction, but rather self-regulation of nongovernment actors. Additionally, managers spoke of the joint EA (Environmental Assessment prepared under the National Environmental Policy Act (NEPA)) on salvage timber that the USFS and BLM were submitting together. Large landscape challenges like beetle kill, fire, and the federal listing of species already required agencies to collaborate.

Self-regulation and local agency control seemed to be much more favorable approach than top-down regulation for collaboration between actors. This was especially clear at the time the focus groups were conducted, in the attempts to avoid a Gunnison sage-grouse listing under the Endangered Species Act (ESA). Several community groups united to avoid a federal listing. Many worried that if the Gunnison sage-grouse was listed, it would undermine and discourage future voluntary, collaborative efforts. Conversely, the threat of the listing—and the local, collaborative planning in response—may have strengthened social ties across agencies and stakeholders and built capacity to respond to climate change.

Examples of cooperation indicate that the community has built capacity and has experience cooperating on a common goal, but also that this behavior is largely in response to imminent threat (often of regulation) or in response to a disturbance. Organizing around threats has built strong social ties and networks that can be utilized in future decision processes, but collaboration in response to threats may have its limitations as to what types of community issues can be addressed. It may be challenging to apply this response to climate change because the threat is not as explicit as a regulation or visible as beetle kill, yet it will require similar, if not greater, collaboration. The trajectory of climate change, and the ability for people to see a trend, will likely influence how it is responded to; the *Feast and Famine* Scenario may make it harder to identify the "threat" or trend and more challenging to foster community collaboration. However, a collaborative group, the Gunnison Climate Working Group, already exists and is planning for short and long-term climate impacts, which indicates that the capacity built through previous threats may be applicable to climate change.

5. Climate Science and Scenarios:

Climate Science

Participants responded positively to the scenarios, their level of detail, and their Gunnison contextualization, but wanted more information about specific processes or additional systems to capture a more dynamic future. Precipitation information that explains general trends in quantity was not enough; people wanted information about the intensity of precipitation because strong pulses would have different impacts than typical rain patterns. Many were concerned that the system would become "more flashy" and were especially interested in differentiating forms of precipitation (snow or rain).

Another request was to include people in the scenarios. Most felt like scenarios captured a plausible future well, but they said it was hard to evaluate them without information about what people were doing in the Basin. They were especially interested in population size, migration patterns and resource use. A significant part of a resource manager's job is managing the use of resources for and by people, so it was challenging to think about management without information about the human population. Those participants felt that excluding people made the scenarios less robust and only captures a small piece of what the future might look like.

While many participants are familiar with baseline conditions in Gunnison, some needed more information about current systems to understand the magnitude of the described changes. In an effort to keep scenarios short and readable, information that was not deemed essential was excluded. Some participants were unsure of baselines outside of their specialty, and so it was harder to understand how much a described change would alter the system. For example, a few were unsure what magnitude of change would occur from decreasing precipitation one inch annually. Most participants did not need this information and groups were able to answer questions collectively, but detailed footnotes may prove helpful for disseminating the scenarios to other groups with different backgrounds.

Participants thought that the scenarios depicted realistic impacts for the basin in light of climate change, but many questioned the rate of change. Scenarios were written with specific attention to ecological targets and all discussed changes to spruce-fir. Projected spruce-fir changes were slower than participants envisioned. A number of people commented that the spruce-fir changes projected 20 years out were already occurring and that there would barely be any spruce-fir left in 20 years. Interestingly, other comments were that the rates of change in other aspects of the scenarios were unrealistically fast. It was hard to believe that some of the changes described would take place in just 20 years; participants suggested that some changes may take longer and that some were already occurring.

The narrative form, local landmarks, and use of comparative reference years made scenarios more accessible, but they also limited the range of imagined futures. Climate was bounded through past experiences, and both the narrative scenarios and participants used past extremes as reference years to interpret information. Reference years were a useful strategy in helping make future projections more accessible. When people read that there would be more years like 2002 and 2012, they knew what it meant; they knew how that scenario translated into landscape changes. This both works to make climate projections tangible and fit within knowledge systems and it limits the possible range of options, which could detract from adaptation planning. Part of thinking about uncertainty and impacts of climate change must be to think about events that depart from past weather and climate. Future attention could be given to how to promote thinking about events that are unlike past events and do not correspond to reference years.

Process and Participation

Access to climate science was not the only valuable part of the focus groups for participants; they also found the process and interactions with others to be useful. Most had thought about climate change, but focus groups provided contextualized information on how climate change might impact the Basin and helped "start a conversation." A number of participants explained how important this step was for their understanding of how to "do" adaptation. Many remarked that they understood adaptation conceptually, but were challenged by how to perform adaptation and move from vulnerability analysis to implementation.

One of the greatest benefits to participants was using the focus groups as an exercise to think in new ways about the environment in which they worked. The scenarios guided managers' discussions and facilitated thinking about new management strategies outside of traditional approaches. Managers spoke about having so many duties and responsibilities that they rarely had time for "thought exercises," to re-think how they approach issues, or to give time to explore hypothetical situations. They felt time-stressed and appreciated the opportunities to think at new scales. The scenarios asked participants to think on longer time scales than is usually required in their work, which is driven by annual or 5-year management plans, and feedback indicated that they appreciated moving the focus from a single species or system, to look at the Basin scale and multiple intersecting systems.

Participating in the processes with colleagues from different agencies was a benefit in and of itself, and it further built local capacity. Participants appreciated conversations with managers with different specialties (both within and outside of their home agencies) because it helped them think beyond their specific focus (i.e. grazing, recreation, forestry, etc.) and think about how different systems and species would interact. This indicates that the scenarios alone might not provide the same benefit. Instead, management is a social action that requires engagement between agencies and beyond the target resource.

Conclusion:

This report discusses a number of findings that relate to management decisions, climate information, uncertainty, scenario processes and localized impacts of climate change. The exercise of thinking through multiple, possible, future climate scenarios shows the complexity of decision making and the barriers to planning with uncertainties. Along with a number of specific findings that help understand the dynamics in the Gunnison Basin, some of the findings touch on larger themes that apply to climate adaption for resource management generally.

This research suggests that managers may not need completely new skills, tools, and knowledge to adapt to climate change. Managers already have a suite of knowledge and strategies that can be harnessed to adapt to climate change, but they may need to change how they think about the future by integrating new perspectives, like planning for a range of future conditions. This report highlights that the regulatory landscape affects how strategies can be mobilized by the way it divides up landscapes, allocates funding, requires protocols, and uses standardized procedures. Yet, increased flexibility may be important to facilitate climate adaption, especially when planning for uncertainty. Furthermore, the risks and threats of climate change not only affect the ecology and natural environment, but also affect social dynamics. Integrating both types of systems, physical and social, is important for understanding which scenarios pose the greatest threat.

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Appendices

Appendix 1: Focus Group Questions

Focus Group Questions (questions in italics can be skipped if there isn't enough time)

1. What's your initial reaction to this scenario?
2. What's particularly concerning about this scenario?
   a. *How might this scenario impact management of public lands in the Gunnison?*
   b. *How might this scenario impact the local ranching community?*
   c. *How might this scenario impact the broader community?*
3. *What kind of problems/disputes/conflicts arise in this scenario?*
4. *What kinds of opportunities are present in this scenario?*
5. What types of management strategies would you consider to deal with this scenario?
   a. How about management strategies to specifically address changes in sagebrush areas?
   b. How about management strategies to specifically address changes in spruce fir areas?
6. What are the barriers to implementing the strategies you've described?
7. Who needs to work together or collaborate to effectively respond?
8. How does this process help you think about making management decisions in the face of change and uncertainty?

Appendix 2: Scenarios

Scenario 1: Hot and Dry

In this scenario annual temperature increases approximately 5^0 F by 2035. To put that in perspective, Gunnison's temperature becomes similar to the current climate of Ridgeway, CO. By 2035, every summer will be warmer than 2002 and 2012 – years when we experienced excessive heat waves. At elevations below 7,000 feet, for at least two weeks during the summer, nighttime lows will not dip below 68^0 F (a typical tropical night), and summer will expand by a month. **Annual precipitation will decline by 10%, and the combined effect of warming and lower precipitation will result in nearly 45% decrease in annual runoff. There will be a large increase in the frequency of extreme drought years.** Roughly every fifth year, we experience droughts similar to 2002 and 2012 (in these years, precipitation was 40% below average).

FIRE

Not every year will be an exceptional fire season but average fire frequency, intensity, and size will increase. The average fire season will lengthen by one month and the average fire frequency will increase up to 12 times while the total area burned in any given year will increase 16 times[1]. The largest burns will be in coniferous forests, including spruce-fir, lodgepole pine, mixed-conifer, and ponderosa pine. Once burned, these areas are likely to transform into aspen, shrublands, or grasslands. The growing season will increase by three weeks, however, with less precipitation the understory herbaceous growth (fine fuels) will decrease which may reduce fire risk in the sagebrush. If a fire occurs in the lower elevation sagebrush zone the site will transform into grassland or rabbitbrush/grassland rather than return to a sagebrush system. There is a good chance that the "new" grassland will be dominated by cheatgrass. Note that sagebrush requires at least 7.5 inches of annual precipitation, and the large water stress in this scenario will make it difficult for the low elevation sagebrush to regenerate.

DROUGHT

In this scenario, Gunnison's annual precipitation declines and becomes similar to the current precipitation of Del Norte[2]. Spring snowpack will decline by 10% and spring temperatures will increase by 4^0 F. This combination of a reduced snowpack and warmer spring temperatures will reduce the available water during the growing season. Trees and shrubs (especially sagebrush) rely on winter and spring snows. The snowpack allows for deep soils to remain moist during the growing season, therefore a reduced snowpack associated with a warmer and drier spring will negatively impact vegetation with deep roots (most trees and shrubs). Summer precipitation will decrease by 20% and have a large negative impact on vegetation, especially shallow rooted plants (mostly grasses and forbs). Snowline shifts up by 1200 feet and could impact the lower elevations of the Crested Butte ski resort. In addition, the average timing of snowmelt will shift a full three weeks earlier from temperature increases and more frequent dust-on-snow events (which will occur every year). Higher than average peak spring flows followed by lower summer flows will reduce the amount of water available for fish, riparian vegetation, migratory birds, and grazing animals, especially during summer. Endangered fish would most likely suffer from lower in-stream flow and increased stream temperature. Less precipitation in winter and summer will significantly decrease surface water and shallow ground water. Seeps, springs, and mesic meadows associated with shallow groundwater will decline and species composition will be greatly altered. We will likely see a shrub invasion into mesic meadows and a decline in nearby aspen stands.

INSECTS

Tree mortality due to insect and disease outbreaks will greatly increase with a hot and dry climate, more so than in any other scenario. The current spruce-bark beetle infestation will likely expand and cause significant mortality in the mature trees[3]. Species that rely on mature spruce-fir forests, such as Lynx, Boreal owl, Snowshoe hare, and Pine marten, will decline due to lack of food and shelter. Aspen trees at lower elevations will experience die-back associated with increased temperatures and decreased soil moisture. However, aspen stands at upper elevations may increase as coniferous trees decline due to fire and beetle kill.

Scenario 2: Warm and Wet

In this scenario, annual temperature increases 2^0 F by 2035. To put this in perspective, temperatures in Gunnison will resemble current temperatures in Cimarron. **Summer will expand by a week. Annual precipitation will increase by 10%** (in terms of soil moisture and stream flows a 5% increase in precipitation is needed to offset a 2^0 F increase in temperature with its associated higher rate of evapotranspiration). Drought years, such as 2002, will occur every 15th year, similar to today's frequency. However, the intensity and severity of droughts will increase because of higher temperatures.

CHANGE

While the water stress from 2^0 F temperature increase will be offset by a 10% increase in precipitation, ecosystems will change in measurable ways. For example, the ratio of warm season to cool season grasses will change, and we could see declines in western wheat grass, needle and thread grass, while blue grama and galleta grass expand. The snowline will shift upwards by 600 feet. As a result, the current vegetation in the 8,500-9,000 feet elevation band will begin to shift from mixed conifer or aspen to ponderosa pine. Due to increased precipitation, overall runoff will increase by 10%, while warmer temperatures mean that peak runoff will occur a week earlier. In this scenario, heat waves similar to 2002 (5^0 F above normal) will occur once every decade. Fire risk in this scenario is the lowest of any scenario but fires will be present, and intermittent dry conditions may cause severe fire hazards because of high fuel loads. These high fuel loads are a result of increased winter, spring, and summer precipitation producing more foliage. A 2^0 F increase in temperature will increase the fire frequency up to 4 times and the annual area burned by 6 times[1].

WEEDS

We will have greater than normal winter snowpack above 10,000 feet and spring, summer, and fall precipitation will increase at all elevations. The increase in year-round moisture coupled with a moderate increase in temperature will promote invasive species (more so than any other scenario). Current invasive species such as leafy spurge, knapweed, and yellow toadflax will expand into low to montane elevations and new invasive species such as Japanese brome or purple loosestrife will likely move into the area. Rangelands will become degraded by invasives, and knapweeds and leafy spurge expand into rangelands that have never had a serious weed problem. Further, invasive species will out-compete the native vegetation and create a high density of fine fuels for fires, especially at the lower elevations.

WATER

We will still experience droughts; however, they will be less frequent than in the other scenarios. Disease and insect outbreaks are expected to be lower than the other scenarios, however, insect outbreaks will still increase, as the droughts that do occur will be more intense than the droughts experienced during the 20th century. When we do experience a beetle outbreak, the recovery time may be quicker than in the other scenarios. Seeps, springs, and other groundwater dependent wetlands will increase or experience very little change. There will be some drought years that impact low elevation wetlands, but for the most part, wetlands will benefit from the years of increased annual precipitation. Higher elevation wetlands will do exceptionally well and possibly expand due to the greater snowpack above 10,000 feet. Higher soil moisture will likely eliminate or reduce invasive species in wetlands.

Scenario 3: Feast or Famine

In this scenario, annual temperature will increase approximately 3^0 F by 2035. To put that in perspective, Crested Butte's temperature will be similar to the current temperature of Lake City. Average annual precipitation does not change; however, we will experience **larger year to year fluctuations in precipitation, with some very wet years and some intense drought years,** as compared to our current climate. Winter precipitation will increase, but precipitation will decline in the other seasons. When droughts occur, they will be more intense than present but generally less than two years long. Once every decade we will experience a drought similar to the 2002 and 2012 droughts (years when precipitation was 40% below average).

FEAST

The growing season will expand by 2 weeks and during wet years vegetation growth will be exceptional with trees, shrubs, and ground cover greatly increasing. The frequency of severe El Nino and La Nina events will double to an average of once every seven years. We experienced severe El Nino years in this region in 1982/83 and 1997/98 with annual precipitation at roughly 20% above average. Invasive species will do well under El Nino conditions but decline in La Nina conditions (drought years). The annual fire risk is lower in this scenario than the hot and dry scenario. Large fluctuations between wet and dry years will increase fuel growth during wet years. This means that when a fire does occur, the severity, intensity, and size could be very high, and in a bad fire year the average fire frequency will increase up to 8 times and the area burned will increase 11 times[1]. Year to year, summer monsoons will be more variable than they are currently. Large spring floods will be more likely as earlier rain on snow events will cause abrupt snowmelt. Dust-on-snow events, coupled with warmer spring temperatures, will also increase the chance of spring flooding, especially during El Nino years. The largest flooding events will generally occur from heavy monsoon precipitation. During these floods, there will be severe erosion in small streams as water runs over banks and culverts.

FAMINE

Intense droughts will more frequently follow extreme wet years. Bark beetles will expand during these drought years, causing extensive conifer mortality. The difference between this scenario and the hot and dry scenario is that multi-year droughts will be less likely in this scenario, so bark beetle dieback may not be as severe as in the hot and dry scenario. It is important to note that most conifer forests can regenerate more easily following beetle outbreaks than fires because bark beetles do not kill the young trees. However, insect kill in mature trees will diminish seed production. This reduction in seed crop will hurt the animals that rely on conifer seeds. In the event that a fire occurs after a beetle outbreak, tree regeneration is nearly impossible due to a lack of a nearby seed source and nurse plants. The large fires associated with drought years will result in younger forests, more open structure, more early successional species, and more invasive species. Large landscape scale disturbances, such as fire and insect outbreaks, will fragment coniferous forests and negatively impact Lynx, Snowshoe hares, Pine martens, and other species that rely on large intact functioning forests, while possibly being a benefit to those species that prosper from a more open forest canopy.

Seeps, springs, and other groundwater dependent wetlands will experience a moderate decline, especially below 8,500 feet, where spring precipitation will fall as rain rather than snow. Increased evapotranspiration, driven by higher temperatures, will reduce soil moisture and streamflow. Consequently, species that can handle drier soil conditions, for example sagebrush, shrubby cinquefoil, and rabbitbrush will flourish; invasive species such as cheatgrass and knapweed will likely increase, especially at the lower elevations. Juniper establishment in the sagebrush is likely during wet years that follow a drought year.

1. Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science 313: 940-943.
2. Rangwala 2014 pers. Com.
3. Colorado State 2013. 2013 Report on the health of Colorado's forests; caring for Colorado's forests: Today's challenges, tomorrow's opportunities.

Appendix I. Social Ecological Response Models Methods Overview

Situation Analysis and Diagram: Methods Overview

Background

A Situation Analysis assesses the important ecological, socioeconomic or political factors and trends affecting the ability to meet management and conservation goals. These factors may act as constraints or provide opportunities for making progress toward goals. Key factors include direct and indirect threats, opportunities and enabling conditions.

The analysis describes the current understanding of a project's ecological status and trends, and the human context. A clear understanding of what is happening within a large-scale landscape is critical for developing strategies that make sense for the specific conditions.

A Situation Analysis probes the root causes of critical threats, degraded species and vegetation, and other values to make explicit the contributing factors — the indirect threats, key actors and opportunities that enable successful action. By understanding the biological and human context, the team can develop appropriate goals and objectives, identify intervention points, and design adaptation strategies.

A Situation Analysis answers:

- What factors, positive and negative, affect our conservation targets and ability to achieve our goals?
- Who are the key stakeholders linked to each of these factors and what motivates each of them?
- What ecosystem services and human wellbeing targets (livelihoods) are provided by the landscape
- How will the targets, factors, and ecosystem services be affected by climate change?

The process of creating a Situation Analysis helps us:

- Articulate and test the logic of our thinking
- Identify the most critical factors that cause threats
- Summarize compelling evidence concerning trends in these factors
- Highlight key stakeholders and opportunities
- Focus on what is most important

- Identify intervention points for developing the most appropriate strategy

A common understanding can bring together:

- Different visions of what will be accomplished through conservation work
- Different perspective of the project's context
- Disparate knowledge and understanding of trends in socioeconomic, political and ecological factors
- A wide variety of assumptions about these trends and what is most important to address
- A range of perspectives about leverage opportunities
- Multiple definitions or uses for the same term

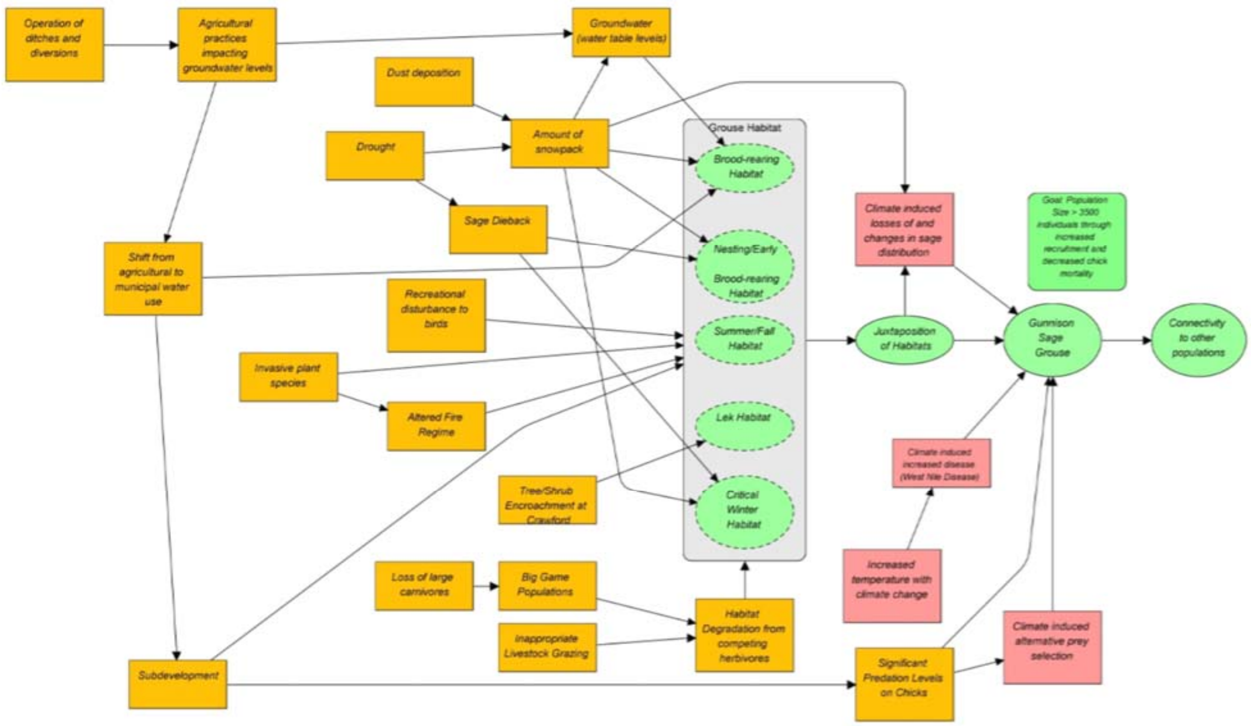
Method

1. Diagram the current condition of the system describing the socioeconomic, political and ecological factors
2. Add in the climate change scenario and determine whether any additional factors need to be added. Discuss whether any of the existing factors significantly increase or decrease with the climate change scenario in mind.
3. Identification of intervention points. Where is action needed?
4. Identification of the high level strategies that are needed at the intervention points.

A Situation Diagram is a box and arrow model that shows the linkages between the conservation values, threats, and other factors. By creating a diagram, intervention points become clear.

Example

Developed for Gunnison sage-grouse at the Gunnison Basin Climate Change Adaptation Workshop for Natural Resources Managers held in 2009.



Additional resources and information about the Situation Diagram process can be found at the website below:

Conservation Measures Partnership. 2013. *Open Standards for the Practice of Conservation Version 3.0.* http://www.conservationmeasures.org/wp-content/uploads/2013/05/CMP-OS-V3-0-Final.pdf

Gunnison Basin Climate Change Adaptation Workshop for Natural Resource Managers (2010) http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/Colorado/science/climate/gunnison/Pages/Climate-Change-Adaptation-Workshop-for-Natural-Resource-Managers-in-the-Gunnison-Basin.aspx).

Chain of Consequences: Method Overview

Background

Established by Secretarial Order 3188 in 2012, the Department of the Interior (DOI) Strategic Sciences Group[1] (SSG) provides the DOI with the capacity to rapidly assemble teams of experts to conduct science-based assessments of environmental crises affecting DOI resources, and provide results to leadership as usable knowledge. To do this, SSG "crisis science teams" effectively act as "pop-up think tanks" to identify the potential short- and long-term environmental, social, and economic cascading consequences of the crisis, and determine intervention points.

Method[2]

Through facilitated discussion, the team of experts builds *Chains of Consequences.* This process is used by the SSG and was developed by its predecessor, the DOI Strategic Sciences Working Group in 2010. The process involves four main steps:

1) Establish the scope (ecological and geographic area of interest, focal time period) and define assumptions.
2) Develop detailed Chains of Consequences that illustrate important cascading effects on the coupled natural-human system.
3) For each element in a chain, assign a level of scientific uncertainty (see example below).
4) Identify potential interventions at points in the chain at which scientists, policy makers, and others might take specific actions to significantly alter the outcomes of the cascade.

Example[3]

Chains of Consequences developed by the SSG Hurricane Sandy crisis science team determined that overwash and breaches of barrier islands were certain to occur as a result of the storm (assigned an uncertainty value of 5), leading to advance of bay shoreline (beach growth as a result of sand redeposition following the storm; assigned a value of 5), and to the probable creation of new habitat (assigned a value of 3). This information was used to develop *interventions* such as mapping and measuring the protection services of key ecosystems such as dunes and wetlands). Interventions were delivered to decision-makers during briefings and in the final SSG Hurricane Sandy report.

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[1] For more information on the Department of the Interior Strategic Sciences Group, please see www.doi.gov/strategicsciences

[2] Department of the Interior Strategic Sciences Working Group, 2012, Mississippi Canyon 252/Deepwater Horizon Oil Spill Progress Report Department of the Interior, Washington, D.C., 58 p. Available online at: http://www.doi.gov/strategicsciences/publications/index.cfm

[3] Stoepler, T. and Ludwig, K. 2015. Strategic science: new frameworks to bring scientific expertise to environmental disaster response. *Limnology & Oceanography Bulletin*.

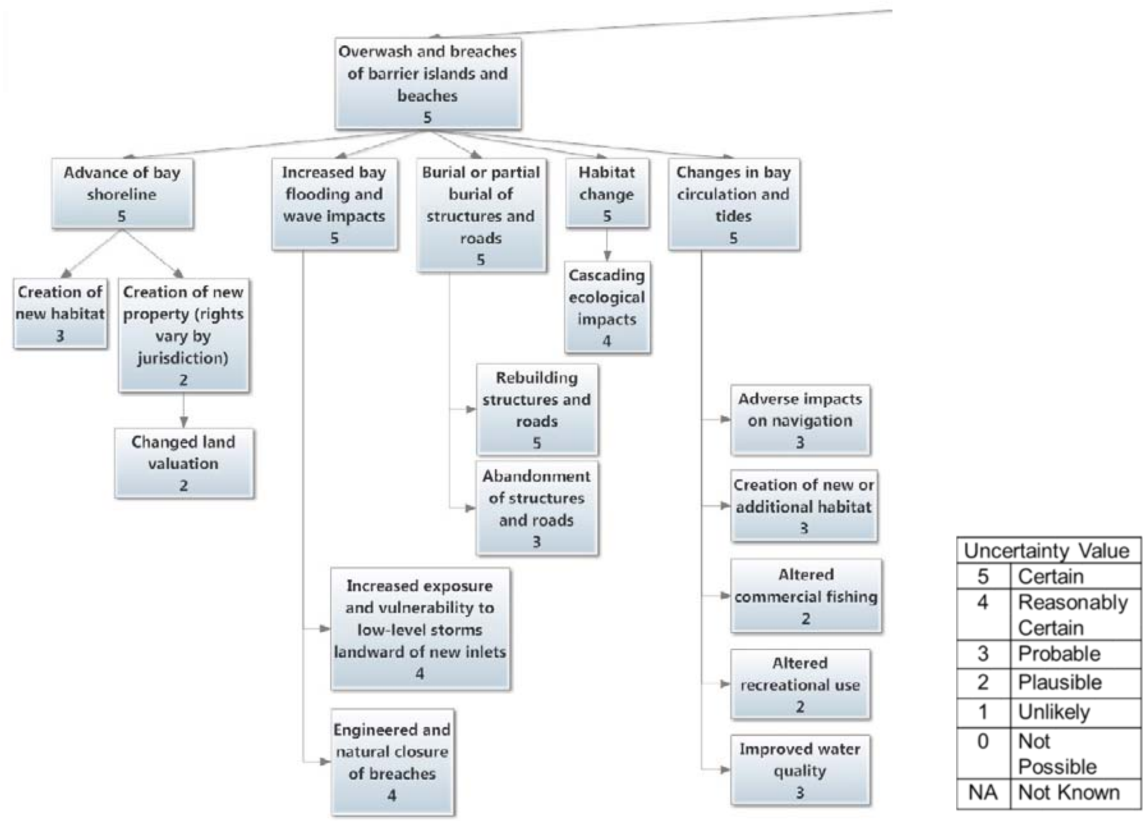


Figure I-1. Example Chains of Consequences developed by the SSG Hurricane Sandy crisis science team: Changes in coastal geomorphology as a result of Hurricane Sandy. *Credit: Department of the Interior, 2013*.

APPENDIX J. SITUATION ANALYSIS DIAGRAMS

In the following diagrams, the conservation target components of each landscape are shown as ovals within a green box. Direct threats or impact categories are represented as pink rectangles, and are influenced by a variety of factors shown as orange rectangles. Strategies or interventions are represented as yellow hexagons. The eventual “human wellbeing” targets are depicted as ovals grouped within a brown box.

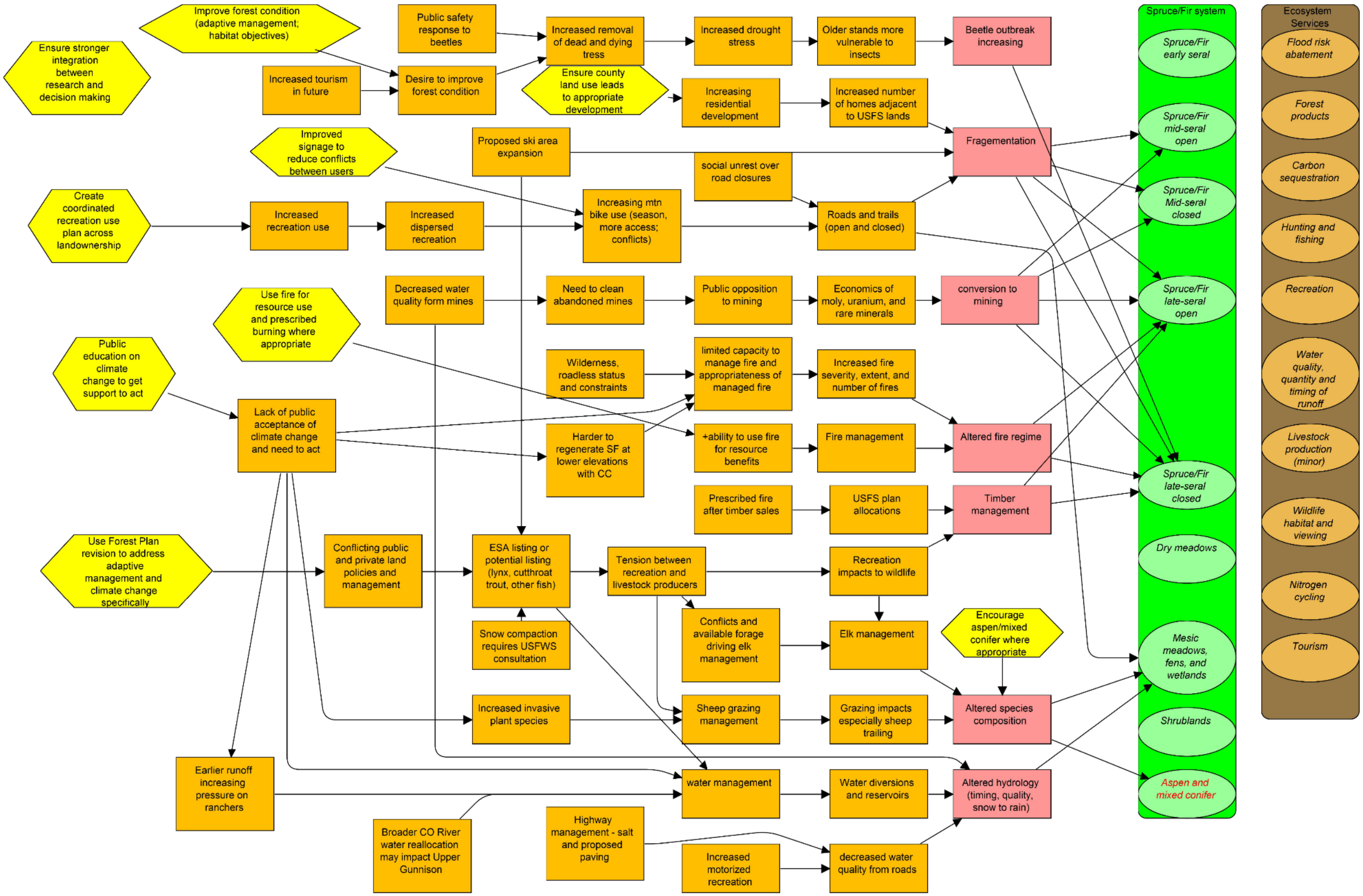


Figure J-1. Situation Analysis for Spruce-Fir (Group 1)

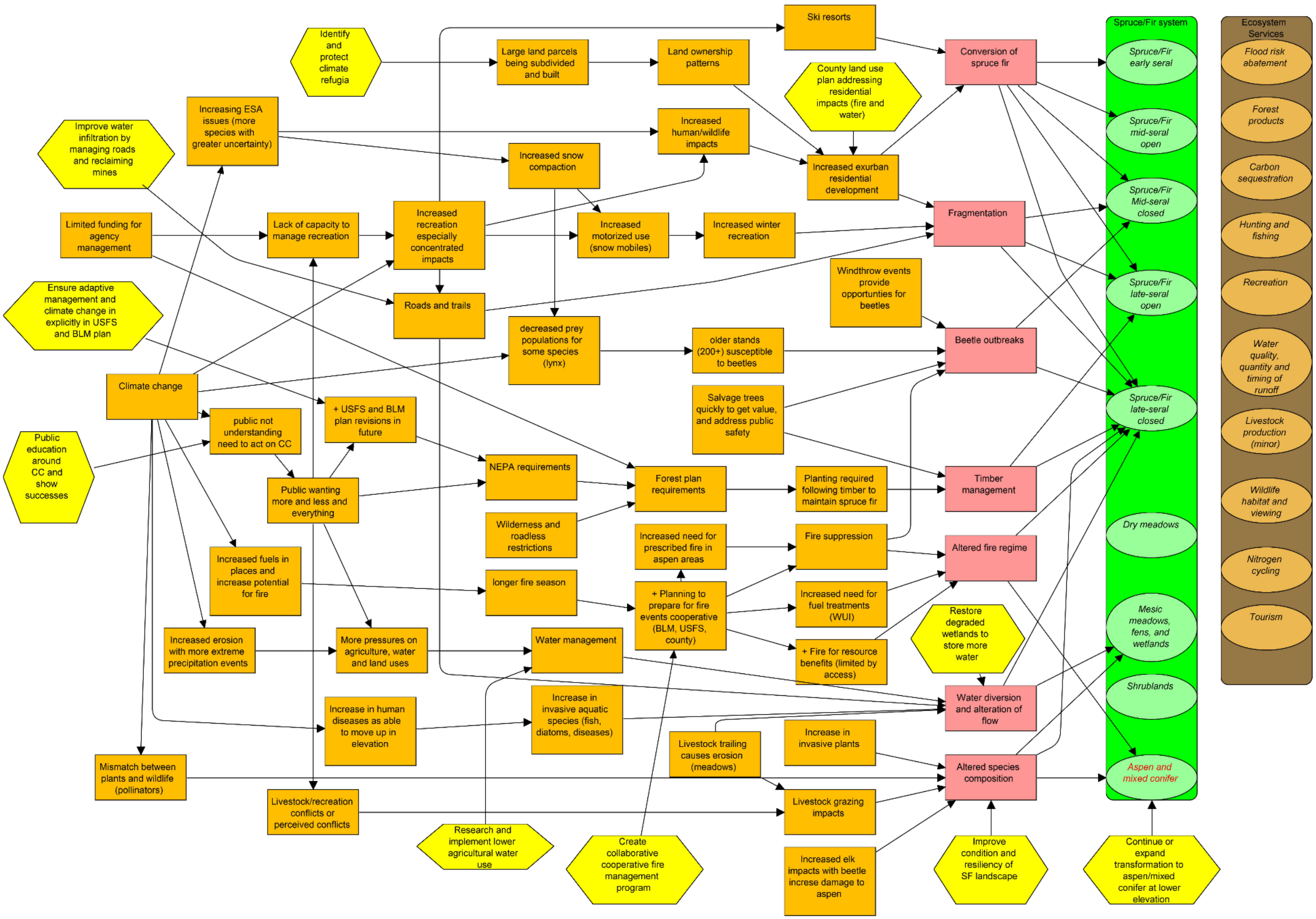


Figure J-2. Situation Analysis for Spruce-Fir Landscape (Group 2)

APPENDIX K. CHAIN OF CONSEQUENCES

The following Chains of Consequence were developed by participants at a workshop in Gunnison on April 23, 2015. The four diagrams illustrate important cascading effects of severe wildfire and insect outbreaks on the coupled natural-human spruce-fir system for the Feast and Famine Climate Scenario. The green boxes indicate ecological consequences, the yellow boxes indicate social-economic consequences, and the numbers on the arrows indicate interventions (see list of potential interventions in the lower left corner).

Note: This Appendix is formatted to print on 11'' x 17'' paper.

Figure K-1. Spruce-Fir Landscape, Wildfire, AM group.

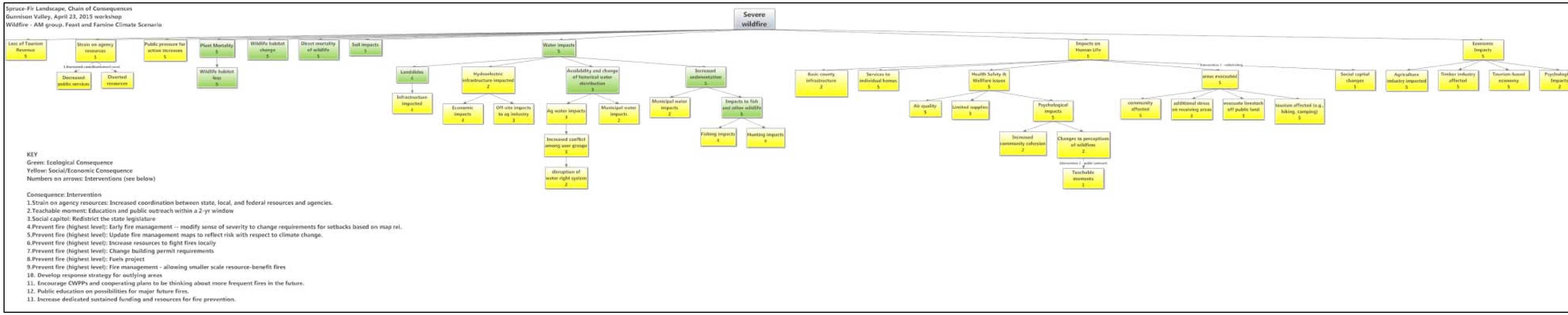


Figure K-2. Spruce-Fir Landscape, Wildfire, PM group.

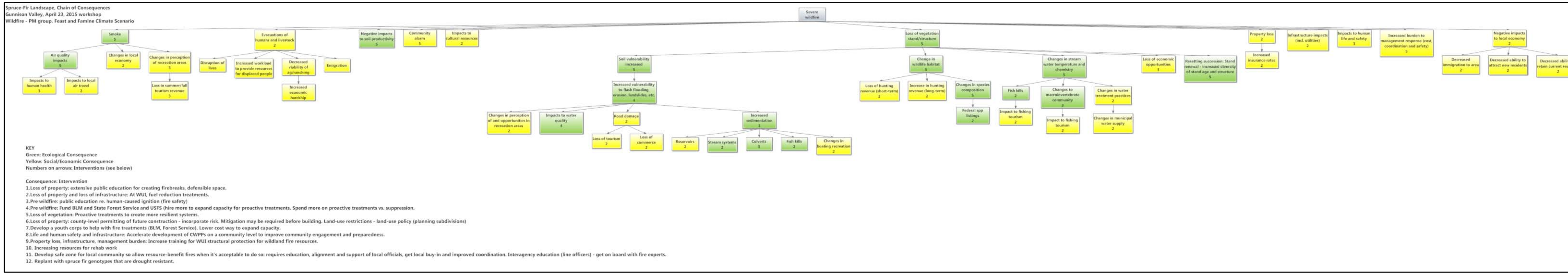


Figure K-3. Spruce-Fir Landscape, Insect Outbreak, AM group

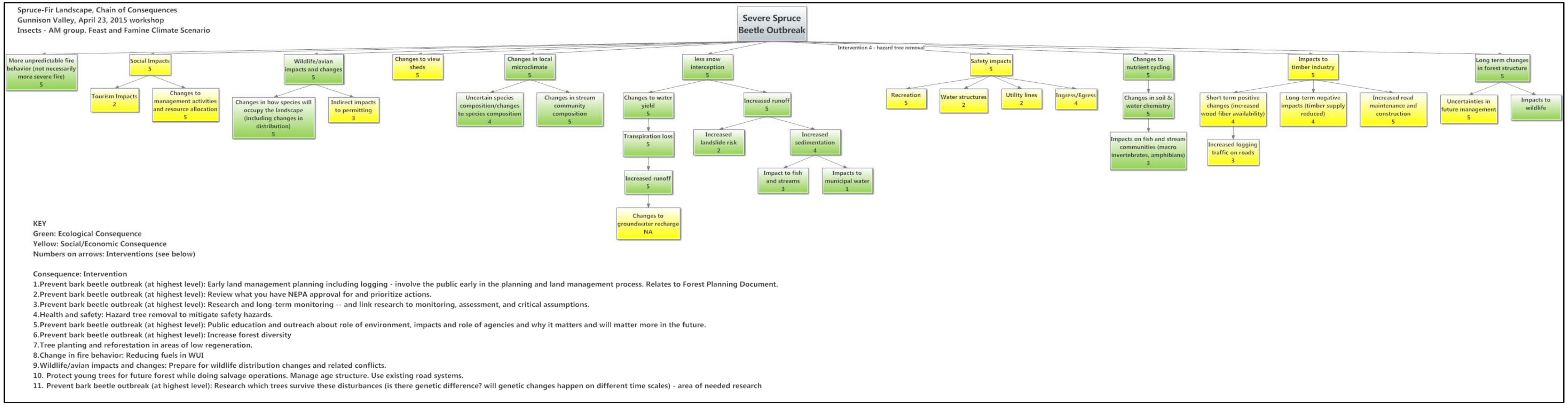
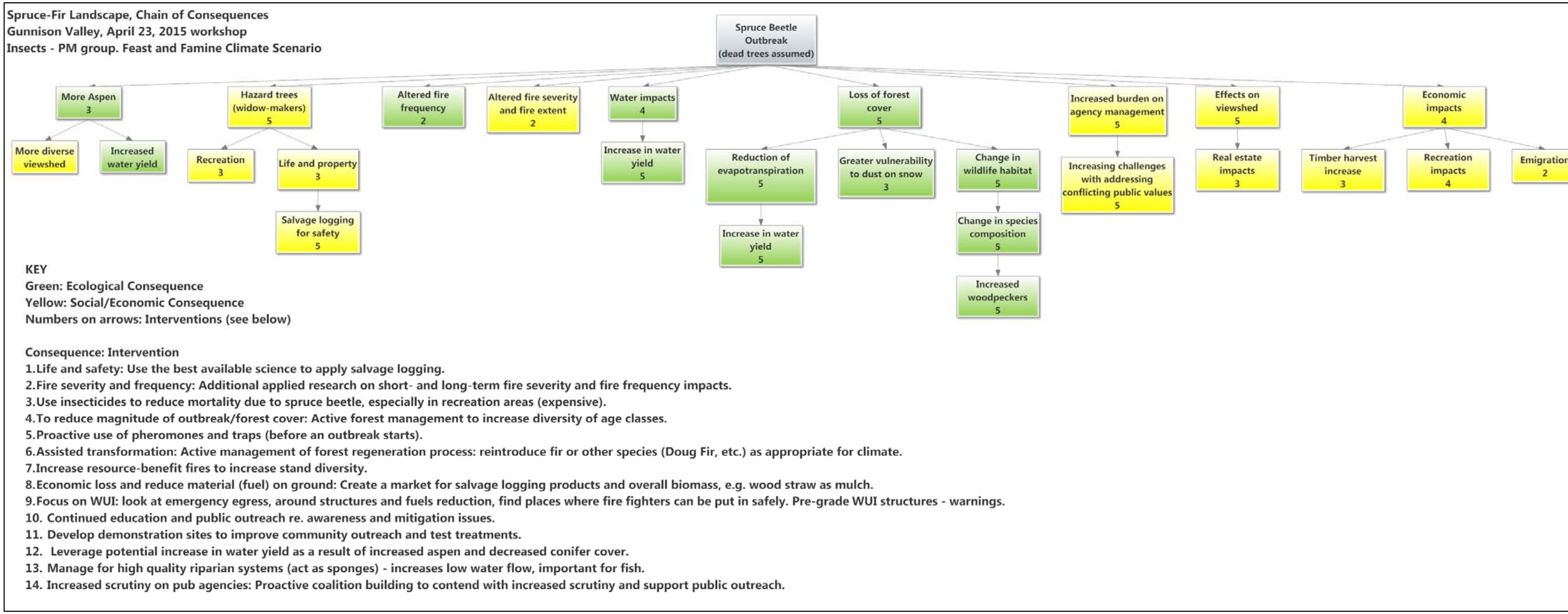


Figure K-4. Spruce-Fir Landscape, Insect outbreak, PM group.



Appendix L. Impacts and Actions (Interventions) Associated with Three Climate Adaptation Strategies

The following tables (1-3) summarize the impacts and actions associated with the three strategies that we focused on during our February, 2016 adaptation workshop and were the focus of the final workshop in April, 2016.

Table L-1. Impacts and actions identified for the "Identify and Protect Persistent Areas" strategy

Impact	Action	Strategy
Forest mortality	Identify and protect spruce-fir refugia	Identify and protect refugia
Loss of old growth	Identify and protect spruce-fir refugia	Identify and protect refugia
Increased wildfire risk	Identify and protect spruce-fir refugia	Identify and protect refugia

Table L-2. Impacts and actions identified for the "Proactive Treatment for Resilience" strategy

Impact	Action	Strategy
Severe wildfire	Plant tree species of spruce-fire genotypes that are drought resistant	Proactive treatment for forest resilience
Forest mortality/insects	Forest management: Proactively use beetle pheromones and traps before outbreaks start; especially for blow down areas	Proactive treatment for forest resilience
Forest mortality	Forest management: Protect young trees for future forests while salvage logging	Proactive treatment for forest resilience
Lack of knowledge: disconnect between research and management	Increase integration between research and decision making	Proactive treatment for forest resilience
Impact on human safety, life and property	Use best available science for salvage logging	Proactive treatment for forest resilience
Altered succession	Improve forest condition through adaptive management & flexibility in new USFS plan revision and BLM RMP	Proactive treatment for forest resilience
Beetle/Insects	Prioritize actions and NEPA approval review to prevent beetle outbreak	Proactive treatment for forest resilience
Forest mortality	Forest management: Manage age structure (use existing roads)	Proactive treatment for forest resilience
Forest mortality/insects	Forest management: Improve condition and resilience of spruce-fir landscape (decrease basal area, increase size and age class diversity) e.g., plant trees and reforest areas with low regeneration to increase diversity of age classes and species diversity, to prevent	Proactive treatment for forest resilience

Impact	Action	Strategy
	beetle outbreaks and reduce magnitude/loss of forest cover	
Forest mortality	Forest management: Proactively manage forest regeneration, reintroduce fire and plants	Proactive treatment for forest resilience
Increased fire risk	Create a market for salvage logging products and biomass, e.g., wood straw as mulch, to reduce economic loss and reduce fuel on ground.	Proactive treatment for forest resilience
Forest mortality	Identify and protect spruce-fir refugia	Identify and protect refugia
Severe wildfire causing loss of spruce-fir forests	Forest management: Expand transformation to aspen at lower elevations, encourage aspen/mixed conifer transition where appropriate	Assist/allow transformation
Drought: warming causing altered tree species composition	Plant tree species that can survive future climate scenarios and assist migration	Assist/allow transformation

Table L-3. Impacts and actions identified for the "Assist and Allow Transformation" strategy

Impact	Action	Strategy
Severe wildfire causing loss of spruce-fir forests	Forest management: Expand transformation to aspen at lower elevations, encourage aspen/mixed conifer transition where appropriate	Assist/allow transformation
Drought: warming causing altered tree species composition	Plant tree species that can survive future climate scenarios and assist migration	Assist/allow transformation