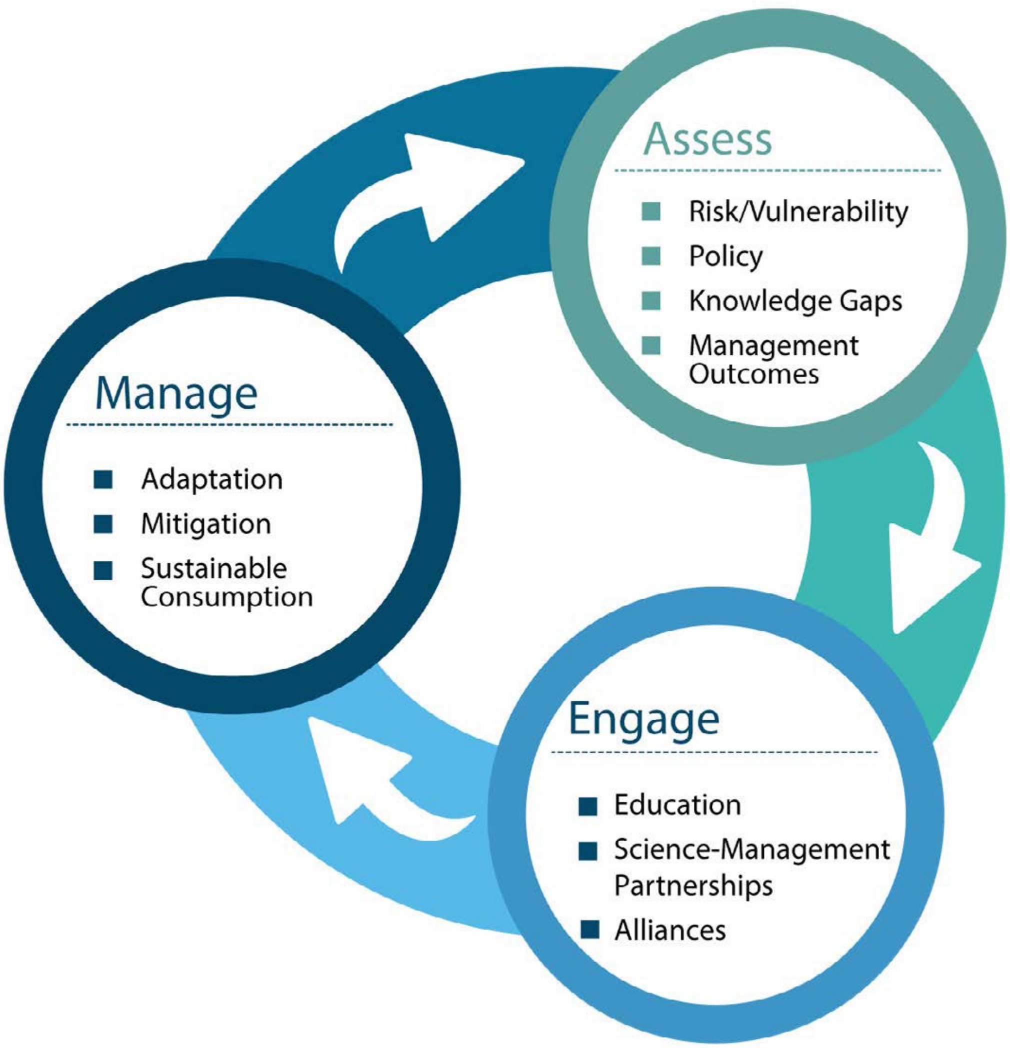
Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Southwestern Region | April 2023

Regional Climate Adaptation Strategy

Integrating Existing Tools, Science, and Collaborative Outcomes for Climate Adaptation, Mitigation, and Socioeconomic Vulnerability v9



Cover image: Graphic of the assess-engage-manage framework of the USDA Forest Service and the agency's Climate Adaptation Plan (USDA Forest Service 2022).

Summary

Ecosystems of the US Southwest are undergoing substantial and rapid change in response to changes in temperature and precipitation of the 21st century with recent observations to corroborate ongoing change (Brusca et al. 2013, Guida et al. 2014, Parks et al. 2019). Several climate vulnerability assessments indicate that most of the region will be significantly impacted by current climate trends and more arid conditions (Seager et al. 2007, Notaro et al. 2012, Friggens et al. 2013, Wyndham et al. 2018), with uncharacteristic fire and other catalysts able to trigger sudden and lasting change in ecosystem conditions (Coop et al. 2020). Climate vulnerability, ongoing and potential impacts, and limited management capacity point to a clear need for a coherent climate adaptation strategy.

This adaptation strategy provides guidance and a workflow to help managers incorporate climate adaptation and set priorities in project and program planning, and to narrow *adaptation options* for the consideration of project-level tactics. This strategy integrates climate adaptation options of *Resilience*, *Resistance*, and *Transition* (Millar et al. 2007, St-Laurent et al. 2021, Falk et al. 2022) as categories of management **intent**. While *restoration* may sometimes be appropriate, as with climate refugia, most circumstances of vulnerability and the optimization of ecosystem services warrant climate-smart approaches given the velocity of change in the Southwest. The strategy was developed to advance climate-smart management for the continued delivery of ecosystem services (Stein et al. 2014). For Forest Service units, the strategy responds to the agency's National Climate Adaptation Plan and the Southwestern Region's Climate Action Plan. **This strategy aims to minimize reinvention and instead rely on existing resources including: the knowledge and collaboration reflected in key adaptation strategy references and workshop outcomes (Peterson et al. 2011, Elias et al. 2015, Swanston et al. 2016, Wyndham et al. 2018, Comer et al. 2019, TAMT 2019, Anderson et al. 2021, Stevens et al. 2021, Janowiak et al. 2022, Sample et al. 2022); the expertise and experience of Southwest resource managers represented in Forest Plans and other land management strategy and guidance; and a synthesis of scientific research and data sources on contemporary climate trends for the Southwest**. This strategy was written as a seamless solution among dimensions of desired conditions and land management plan implementation, vulnerability and resource assessments, monitoring, and the goals and issues of local resource programs, project teams, and stakeholders. Also acknowledged is that plant populations are contracting or shifting on the landscape but that desired condition descriptions remain useful with vegetation type projections. A regionwide socioeconomic vulnerability assessment and environmental justice mapping are used as an objective means of integrating information on the vulnerability of local communities.

This **adaptation strategy includes four main sections**: 1) an introduction and summary of national, agency, and regional priorities and direction; 2) description of the Forest Service Strategic Framework for Responding to Climate Change; 3) a climate adaptation workbook in six steps including a substantial section on potential climate impacts; and 4) a set of appendix resources including a *quick guide* to the workbook steps. The adaptation workbook was developed from 'Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers' (Swanston et al. 2016), a product of the Forest Service's Northern Research Station and the Northern Institute of Applied Climate Science. A worksheet is included in Step 4 of the workbook and in Appendix B to guide the thought process in identifying adaptation options and desired conditions. Some tactical-level guidance is included in Step 5 of the

workbook and will be further developed as part of a separate partnership with managers and scientists of the region.

The core of the strategy reflects a **workbook process based on the science-management partnership for adaptation (Swanston et al. 2016) in six steps**: 1) DEFINE location, time frame, and management goals using established management plans and other sideboards, integrated landscape prioritization and fine-filter questions; 2) ASSESS climate change vulnerabilities and potential impacts and ecosystem responses, reviewing basic climate change science while ranking the vulnerability of natural resources; 3) EVALUATE management objectives under the climate vulnerabilities, goals, and issues for a given area; 4) IDENTIFY adaptation options and desired conditions for resolving ecosystem characteristics (= indicators of ecological integrity) to climate change; 5) IMPLEMENT strategy into projects or management plans using adaptation tactics; 6) MONITOR, LEARN, and COMMUNICATE effectiveness of on-the-ground management using monitoring observations, evaluation, and the Forest Service Climate Action Tracker (scorecard) process to inform future adjustments and share knowledge in a science-management community of practice. The selection of adaptation options and tactics is guided by management objectives, the Fire Menu (Sample et al. 2022), Indigenous knowledge including A Tribal Climate Adaptation Menu (TAMT 2019), and other resource. Options and tactics are also based upon ecosystem trajectories that are substantiated through **multiple lines of evidence including research on vulnerability and potential impacts, uncertainty in research and climate forecasts, and field validation.** It is important to be aware that most landscapes of the Southwest are highly modified by land use and multiple human-related actions including past resource management as the context for determining climate vulnerability and adaptation responses but that **in some cases non-climate factors will be more important than climate change.**

While the general concepts of this strategy are applicable to all natural ecosystems, additional strategy considerations for soils, heritage resources, recreation, infrastructure, and other resources will be developed separately. By design, this regional strategy is intended to apply to administrative units across the Southwest and build on established guidance including:

- USDA Action Plan for Climate Adaptation and Resilience (USDA 2021);
- USDA Forest Service Climate Adaptation Plan (USDA 2022);
- Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers (GTR-NRS-87-2; Swanston et al. 2016);
- Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options (PNW-GTR-855; Peterson et al. 2011);
- Adaptation Strategies and Approaches for Managing Fire in a Changing Climate (Sample et al. 2022); and
- Indigenous knowledge reflected in tribal engagement and workshop outcomes and in resources such as the Tribal Climate Adaptation Menu (TAMT 2019), the National Congress of American Indians (NCAI 2022), the Climate Adaptation Plan for the Navajo Nation (NNDFW 2018), and other available tribal resources (Petzold et al. 2020).

The strategy adapts important content of these key resources particularly the workbook of Swanston et al. (2016) and content of Peterson et al. (2011) into a strategic approach compatible with regional land management planning and with minimal added complexity and terminology. We recognize that National Forests of the Southwestern Region are under the policy of newly revised Forest Plans within a paradigm of *restoration* (e.g., Mast et al. 1999) and that many Plan components have been written with sufficient flexibility to incorporate *climate adaptation* and that the plans have already addressed climate adaptation to an extent (e.g., USDA Forest Service 2020). The guidance presented here is compatible with existing policy and stakeholder agreements and is structured to leverage the exploration, expertise, and collaboration built into land management plans for long-term ecological integrity.

Key Words

Climate change, climate adaptation strategy, adaptation options, ecosystem characteristics, environmental justice, resilience, resistance, transition.

Contributors

Max Wahlberg is Ecologist for the Deschutes National Forest in Bend, Oregon.

F. Jack Triepke is Regional Ecologist for the Southwestern Region of the USDA Forest Service in Albuquerque, New Mexico.

Anita Rose is Regional Air Program Manager and Climate Change Coordinator for the Southwestern Region of the USDA Forest Service in Albuquerque, New Mexico.

Amy Waltz is Director of Science Delivery for the Ecological Restoration Institute at Northern Arizona University in Flagstaff, Arizona.

Bryce Esch is Research Coordinator for the Ecological Restoration Institute at Northern Arizona University in Flagstaff, Arizona.

Tzeidle Wasserman is Ecologist for the Ecological Restoration Institute at Northern Arizona University in Flagstaff, Arizona.

Jessica Halofsky is Director of the USDA Forest Service Western Wildlands Environmental Threat Assessment Center and the USDA Northwest Climate Hub in Olympia, Washington.

David L. Peterson is emeritus Research Scientist with the USDA Forest Service Pacific Northwest Research Station and Affiliate Professor at the University of Washington in Seattle, Washington.

Elizabeth Sorells is Natural Resource Specialist for the Gila National Forest in Silver City, New Mexico.

Don Falk is Professor at the University of Arizona School of Natural Resources and the Environment, with joint appointments at the Laboratory of Tree-Ring Research and the Institute of the Environment in Tucson, Arizona.

Dave Breshears is Professor at the University of Arizona School of Natural Resources and the Environment in Tucson, Arizona, and leads the Extreme Global Change Ecology lab.

Dan Ryerson is Science Delivery Specialist for the Southwestern Region of the USDA Forest Service in Albuquerque, New Mexico.

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Contents

Introduction – National and Regional Priorities

In a February 15, 2008, letter to the National Leadership Team, Forest Service Chief Gail Kimbell acknowledged the role and importance of climate change for land management and the Forest Service. Chief Kimbell characterized the agency's response as "one of the most urgent tasks facing the Forest Service" and stressed that "as a science-based organization, we need to be aware of this information and to consider it any time we make a decision regarding resource management, technical assistance, business operations, or any other aspect of our mission." In 2021, Chief Vicki Christiansen reiterated the urgency of the agency's climate response, including it with the 'Five National Priorities for the Forest Service':

> *Climate change threatens the very ability of the Forest Service to fulfill our mission by undermining the health, diversity, and productivity of the Nation's Forests and Grasslands. Our core purpose of sustaining nature to support life demands that we respond to climate change as a national priority. We recognize the global nature of the threat from climate change to the sustainability and integrity of our Nation's ecosystems, watersheds, and water supplies, all critical to the health and well-being of the people and communities we serve. A robust climate change response aligns accordingly with our core values of conservation, interdependence, safety, and service.*

Climate change represents one of the most complex and unique challenges for natural resource management. At a time when land managers are working hard to restore and rebalance landscapes after more than a century of fire suppression, climate stressors pose an existential threat to the mission of sustaining the nation's forests and grasslands.

In recent decades there has been increased recognition by federal and state agencies for the need to adopt a climate adaptation paradigm for the delivery of ecosystem services from public lands. In October of 2008 the Forest Service introduced a 'Strategic Framework for Responding to Climate Change' for planning, followed by the release of the Forest Service Global Change Research Strategy in 2009 (FS-917a), and the National Roadmap in 2011 (FS-957b). From the Roadmap:

> *Americans rely on their forests and grasslands for a wide range of benefits – for provisioning services such as water, wood, and wild foods; for regulating services such as erosion, flood, and climate control; and for cultural services such as outdoor recreation, spiritual renewal, and aesthetic enjoyment. These services are connected and sustained through the integrity of the ecosystems on these lands.*
>
> *Climate change places those ecosystems at risk. Most of the urgent forest and grassland management challenges of the past 20 years, such as wildfires, changing water regimes, and expanding forest insect infestations, have been driven, in part, by a changing climate. Future impacts are projected to be even more severe. Managing America's forests and grasslands to adapt to changing climates will help ensure that they continue to produce the benefits that Americans need, while helping to mitigate the effects of a changing climate and to compensate for fossil fuel emissions through carbon storage in healthy forests.*

The Forest Service response to the USDA 2010-2015 Strategic Plan included the introduction of a Performance Scorecard, now referred to as the Climate Action Tracker, to monitor and incentivize progress in climate adaptation at the local level. The Tracker was updated in 2022 (v3.0).

In 2012, the Planning Rule for National Forest System lands was issued, stating:

> *In the assessment for plan development or revision, the responsible official shall identify and evaluate existing information relevant to the plan area for the following: system drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change [§219.6.b.3].*

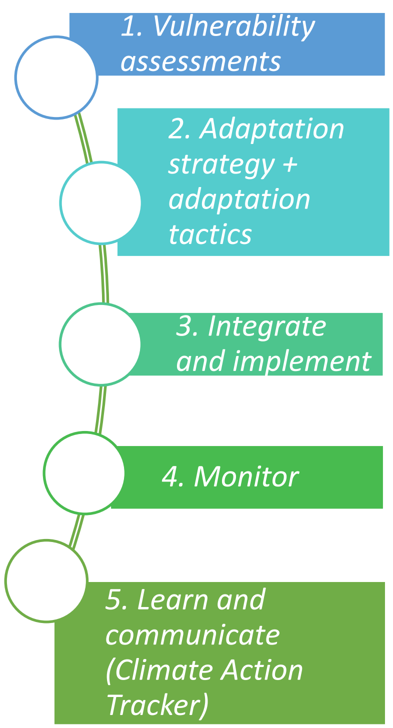
In order for the Southwestern Region to respond to federal, Department, and agency direction and to protect and enhance the ecosystems that provide life sustaining ecosystem services, management must be informed and guided by an understanding of the threats and impacts of a changing climate. Much has been learned over the past two decades by the scientific community about these threats, and land managers are interested in developing and employing means to try and combat them. Extended duration and extreme drought, record heat, flooding,

and unprecedented fire seasons are converging stressors reflecting the climate crisis for ecological integrity and ecosystem sustainability in the Southwest. The Forest Service is working with the Ecological Restoration Institute (ERI), at Northern Arizona University, other regional universities, and several partners for a coordinated response to the climate trends.

Strategic Planning Framework for Responding to Climate Change

Framework Overview and Status in the Southwestern Region

In response to national and regional priorities, the Southwestern Region has implemented the agency's *Strategic Framework for Responding to Climate Change*, a five-part framework for planning that the Region began implementing ten years ago (Figure 1).



1. Climate Vulnerability Assessments: The Southwestern Region has completed three regionwide all-lands assessments including a socioeconomic vulnerability assessment (SEVA) (Borchers et al. 2021, Hand et al. 2018), a climate change vulnerability assessment for upland vegetation types (CCVA) (Triepke et al. 2019), and an aquatic-riparian vulnerability assessment (ARCCVA) (Wahlberg et al. 2022). Vulnerability assessments for the region suggest that the majority of lands and many communities are highly vulnerable to changing climate, but that the degree of vulnerability differs by location and other factors. Vulnerability forecasts have been corroborated by independent observations and assessments.

2. Adaptation strategy and tactics: The Region is working with ERI to create an adaptation strategy based on agency policy and existing vulnerability assessment work. This strategy will be a streamlined resource for programs and project teams that highlights vulnerability assessment findings and emphasizes key geographic areas, vegetation types, and adaptation options. Site-level guidance will be developed similar to previous agency handbooks (e.g., Handler et al. 2017) to help identify existing and potential stresses and possible tactics for implementation and management activities. ERI will be hosting work sessions for managers and scientists to improve the adaptation strategy and tactical guide

3. Integrate and implement: The Region will continue working with ERI and other partners to apply the climate action framework and its component parts, including the integration of the adaptation strategy with project planning, and developing appropriate tactics for implementation. Forest pilots and demonstration projects can be used to advance implementation.

4. Monitor: The Forest Service has identified monitoring elements for climate, vulnerability, and project effectiveness with the revision of all Forest Plans in the Region. Several corporate and Forest-level data sources provide continual means for monitoring climate impacts, carbon patterns, and project effectiveness.

5. Learn and communicate (Climate Action Tracker): The new Climate Action Tracker (scorecard) provides a consistent and objective means to assess progress in the application of the adaptation framework and is focused on growth and shared learning rather than unit-level rating.

Figure 1. Strategic Framework for Responding to Climate Change and current status of each component in the Southwestern Region of the Forest Service.

Adaptation Strategy Goal

This strategy has been written in response to the Forest Service's climate framework to provide land managers a concise reference for resource programs and project teams, with concepts, tools, and contextual guidance for developing climate-smart management. This document represents guidance and not policy, with the goal of developing climate smart management that integrates with existing planning policy, collaboratives, and other regional and agency initiatives. The strategy is designed to support landscape and broader planning in a stepwise manner through a workbook process (Table 1 and Appendix A) while building on multiple lines of evidence for the selection of adaptation options, desired conditions, and tactics. Separate tactical-level guidance will be available to help assess stress, adaptive capacity, and appropriate actions at the site level. By its strategic focus and its reliance on on-the-ground conditions, the strategy lends itself to *condition-based NEPA*, those projects designed to respond to specific conditions within an analysis area without traditional fixed treatment units that can constrain adaptive management and unforeseen circumstances. The strategy is intended to provide an ordered solution for project teams and management planning focused on ecosystems and environmental justice to make the most of available science and local knowledge as a means of optimizing success, minimizing risk, and making best use of limited capacity for active management.

Table 1. Crosswalk of the Strategic Framework, the Climate Adaptation Workbook, and the conventional plan-to-project model.

Strategic Framework for Responding to Climate Change	Climate Adaptation Workbook	Plan-to-Project Model
Vulnerability Assessments	**Step 2**: ASSESS climate change vulnerabilities and potential impacts	**Monitor and Evaluate**
Adaptation Strategy and Tactics	**Step 1: DEFINE** location, time frame, and management goals **Step 3: EVALUATE** management objectives - Integrated Landscape Prioritization - Fine-Filter Questions **Step 4: IDENTIFY** adaptation options and desired conditions	**Proposal Development** – Issue identification – Existing stakeholder agreements – Purpose and need – Develop management alternatives – Proposed action – Environmental Analysis
Integrate and Implement	**Step 5: IMPLEMENT** adaptation strategy into projects or management plans using adaptation tactics	**Implementation** – Decision – Appeals – Notification – Silv Rx, fuels planning, allotment plans
Monitor **Learn and Communicate**	**Step 6: MONITOR, LEARN, and COMMUNICATE** climate impacts, the effectiveness of on-the-ground management, and Scorecard progress	**Monitor and Evaluate**

The strategy was developed as a seamless solution with the resource manager planning model, Forest Service policy, initiatives, and desired conditions, and data sources and conventions of the Southwestern Region including the R3 Ecosystem Analysis Framework (Triepke et al. 2016). It is designed to bring together an understanding of climate vulnerability at multiple scales to best inform appropriate management options and tactics to address the desired conditions of key *ecosystem characteristics* (see Step 4). This document provides a cohesive strategy for climate adaptation while maintaining flexibility at the local scale to pair appropriate adaptation options and tactics to conditions on the ground.

For now, the strategy is focused mostly on ecosystems and affected communities and less so on individual species or individual economic sectors. Nonetheless the workbook process is applicable to other resources and values when applied appropriately and with additional filters and information. Refinement and implementation of the climate adaptation framework and climate adaptation strategy is only possible with participation and contribution by leadership and staff of all administrative units along with the help of partners. This strategy will be updated in the future with additional local and Indigenous knowledge and new science.

Climate Adaptation Workbook

(adapted from Swanston et al. 2016)

This section is the workbook process for resource programs and project teams to enact climate adaptation strategy and translate available science, spatial information, and manager-stakeholder goals into tangible actions for planners, practitioners, and decision makers. It is designed to accommodate a diversity of objectives, vegetation types, spatial scales, and levels of decision making (e.g., planning, problem solving, implementation) (Peterson et al. 2011, Janowiak et al. 2014, Swanston and Janowiak 2012). The workbook is summarized in a quick guide in Appendix A. The workbook steps augment the R3 Ecosystem Analysis Framework process of assessing structure, composition, process, and connectivity (Barrett et al. 2010, Triepke et al. 2016, Weisz et al. 2009) and draws upon geographically specific information on climate and socioeconomic vulnerability to develop purpose and need, management alternatives, and annual planning through the filter of climate adaptation options. In most instances, adaptation options can be integrated effectively with desired conditions of existing management plans (see desired condition worksheet example; Appendix B). The following workflow is designed to leverage scientific information and local knowledge to maximize likelihood of success and minimize risk as an optimization of limited capacity for active management.

To prepare for the workbook process, it is recommended that teams review the climate adaptation strategy and workbook steps and gain a sense of the application of adaptation options of Resistance, Resilience, and Transition (RRT) for a given landscape (example in Appendix D). It is also helpful to have a sense of other sideboards including existing management plans and adaptation strategy (Appendix E), Forest Service Plan components and 5-year plans, stakeholder agreements, and other prioritization schemes such as Shared Stewardship or the Fireshed Registry, and to organize information by vegetation type, specific elements or ecosystem characteristics (= indicators of ecological integrity), or by key management topics.

DEFINE Location, Time Frame, and Management Goals (Workbook Step 1)

The first workbook step involves defining the location and timeframe for a project or program and an initial look at management goals. In this step, consider established management plans (Appendix E), stakeholder arrangements, and other existing sideboards to carefully identify an area of interest for the workbook process (Peterson et al. 2011, Swanston et al. 2016). The *integrated landscape prioritization* outlined below can assist in selecting target landscapes based on the combination of climate vulnerability patterns and some initiatives such as the Fireshed Registry (Evers et al. 2020). After gaining a better understanding of climate vulnerability and impacts in Step 2, the initial management goals will be narrowed to specific objectives in Step 3. Because Step 1 serves as a starting point for subsequent workbook steps, location and time frame should be as specific as possible.

Description of Workbook Items

Project or program area – Name the area of interest. Describe the geographic location of the area and provide a spatial layer(s) of the boundary for GIS. The integrated landscape prioritization and fine-filter questions that follow can assist in identifying location and management goals.

Management goals – List the management goals for the project area. Management goals are broad, general statements, usually not quantifiable, that express a desired state for the landscape and collaborative processes to achieve. Management goals reflect existing management plans and climate adaptation strategy (Appendix E), Watershed Restoration Action Plans (WRAPs), stakeholder agreements, and major issues and ecosystem services provided (e.g., municipal watershed, listed species habitat, domestic grazing). They provide important context to consider climate vulnerability and specific objectives (steps 2 and 3) and potential change (Step 4).

Vegetation types (Ecological Response Units), watersheds, streams, communities, or specific elements – List the area, specific vegetation types, ecosystem characteristics, or other elements or management topics that are relevant to the area of interest. Because this information is tied to management objectives of Step 2, you may want to subdivide areas based upon management units, settings, pasture or allotment boundaries, subwatersheds, or other features.

> *Note: Current conditions are sometimes departed from desired conditions. In Step 4, desired conditions are identified and often assume shifting site potential and conversion under climate current climate trends so that desired conditions also address the changing and future climate of a given area. Step 4 includes a worksheet process for identifying desired conditions under both past and future climate conditions.*

Time Frame – List the approximate time frame for project development, implementing management actions, and for achieving management goals and objectives. As a default, identify a point in both the short term (10 years or less) and the long term (30 or more years) for goals and objectives.

Integrated Landscape Prioritization

Integrated landscape prioritization can be used to inform Step 1 while providing an **opportunity to address environmental justice** through the integration of the Socioeconomic Vulnerability Assessment (SEVA; Borchers et al. 2021). The prioritization scheme combines existing initiatives including Watershed Condition Classification (WCC), Fireshed Registry, Shared Stewardship, range condition trends (RAP 2022, RPMS 2022), and climate vulnerability assessment in a coarse filter one-stop shop by the following criteria:

- Inclusive of current prioritization schemes, no reinventing
- Climate smart
- Simple, transparent
- Consistent with Forest Plans and desired conditions of the Southwestern Region
- Inclusive of all vegetation types (Ecological Response Units)
- Preference for regional data of known quality
- Readily updated with new information

Integrated prioritization provides a transparent and tractable alternative to complex, resource-intensive, and subjective optimization models that have been used for prioritization and vegetation treatment placement (Wei et al. 2008, Ager et al. 2010, Krofcheck et al. 2019). The integrated landscape prioritization is divided into three realms of forest-woodland, watershed resources, and rangelands that combine SEVA and other resources and tools relevant to each realm (Table 2). Box 1 illustrates the integrated landscape prioritization concept for watershed resources.

Table 2. Inputs to each realm of an integrated landscape prioritization.

Inputs	Forest-Woodland	Watershed Resources	Range
Watershed Condition Classification		X	
Aquatic-Riparian Climate Change Vulnerability Assessment (ARCCVA)		X	
NM Shared Stewardship	X	X	
Fireshed Registry	X	X	
Majority landscape fire-adapted forests-woodlands	X		
Majority landscape accessible by road	X		
Climate Change Vulnerability Assessment (CCVA)	X		X
Environmental Justice - Socioeconomic Vulnerability Assessment (SEVA)	X	X	X
Plant production trends			X
Bare soil trends			X
Perennial-annual grass cover trends			X

Box 1

Integrated Landscape Prioritization for Watershed Resources in Arizona and New Mexico National Forests

Table B1. Prioritization Factors - WCC, ARCCVA, environmental justice (SEVA), NM Shared Stewardship
Modifiers - All watersheds <=33% USFS lands considered Low Priority
Comments - There are 12 watersheds not analyzed with ARCCVA that are also 'Functioning Properly'

WCF Watershed Condition Class	Low ARCCVA	Moderate ARCCVA	High ARCCVA
WCC 3 (Impaired)	High Priority	High Priority	Moderate Priority
WCC 2 (Functioning at Risk)	High Priority	Moderate Priority	Low Priority
WCC 1 (Functioning Properly)	Moderate Priority	Low Priority	Low Priority

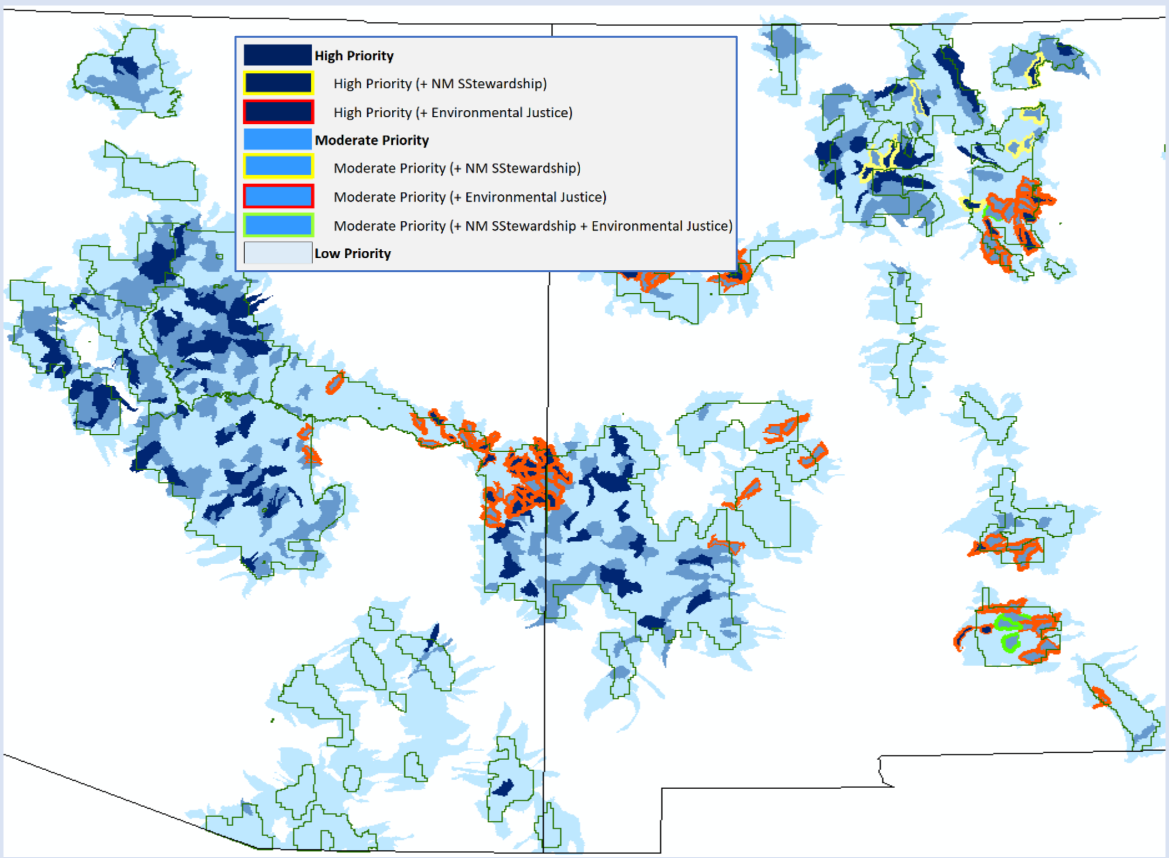


Table B2. Related planning and prioritization potentially affected – WCC, National Forest 5-year plans, Collaborative Forest Landscape Restoration Program (CFLRP), Watershed Source Protection Plan (WSPP)

Integrated Prioritization	Total Watersheds	NM Shared Stewardship[1]	Environmental Justice[2]
High Priority	147	4	29
Moderate Priority	283	9	54
Low Priority	1,117	19	229
Total	1,547	32	312

[1] Watersheds within NM Shared Stewardship priority landscapes that have watershed risk priorities 1-33

[2] High socioeconomic vulnerability (SEVA) counties used to identify watersheds for environmental justice (EJ)

Identifying priority watersheds through WCC and integrated prioritization helps to fulfill Step 1 and set the stage for writing climate-informed WRAPs (Appendix F). A WRAP is a planning document to identify essential projects necessary to improve or maintain WCC. The template in Appendix F assists specialists in documenting climate considerations and integrating climate adaptation into WRAPs.

Integrated prioritization provides a first cut (coarse filter) in lead up to more specific fine-filter questions about local priorities, resources, and feasibility. **Fine filter questions**:

- Would the work support T&E species recovery?
- Is there a Watershed Restoration Action Plan (WRAP) for priority watersheds?
- Is this watershed identified in a 5-yr plan for a National Forest?
- Would the work provide tangible benefit to tribes?
- Is there a need to protect key infrastructure?
- Would the work contribute to or implement the Strategic Framework for Responding to Climate Change?
- Has environmental analysis (e.g., NEPA) been completed for the work and are there projects ready for implementation?
- Is partner funding available at 50% match or better?

The potential exists to develop integrated prioritization for other realms such as cultural heritage (Clark et al. 2022), recreation, or engineering, using relevant inputs and questions. More socializing of an integrated landscape prioritization scheme is needed for buy-in, commitment, refinements, and to explore other realms for setting priorities.

ASSESS Climate Change Vulnerabilities and Potential Impacts (Workbook Step 2)

There will be a wide variety of climate impacts on the landscape and nearby communities and not all areas will respond alike, even under similar ecosystem conditions and climate vulnerability projections. For this reason, it is essential not only to think about broad vulnerability patterns in the region but also to consider how specific areas on the landscape could be affected. Here, climate vulnerability information is considered in six parts that include likely impacts of climate trends in the Southwest:

- Prospective climate and environmental effects (regional overview)
- Upland ecosystems
- Carbon
- Aquatic, riparian, and watershed resources
- Socioeconomic resources

This information will be coupled with local knowledge and experience to fully evaluate how specific project or program areas may be vulnerable to climate change. Because there is a great deal of variability among different locations, local understanding of site conditions will help in identifying the most promising management responses in later steps.

Prospective Climate and Environmental Effects in the Southwest

The Southwest is the most extensive arid region of the US, with most of the region receiving less than 15 inches of rain per year (Elias et al. 2015). Human communities rely on the delivery of ecosystem services from natural lands, including water supply with agriculture use far exceeding other water uses (Gutzler 2013). High-elevation snowpack and seasonal rains supply much of the regional surface water. The prognosis for the region is one of increasing vulnerability given the convergence of land use history and extended duration and extremes of drought, record heat, and unprecedented fire seasons (Williams et al. 2010, 2020).

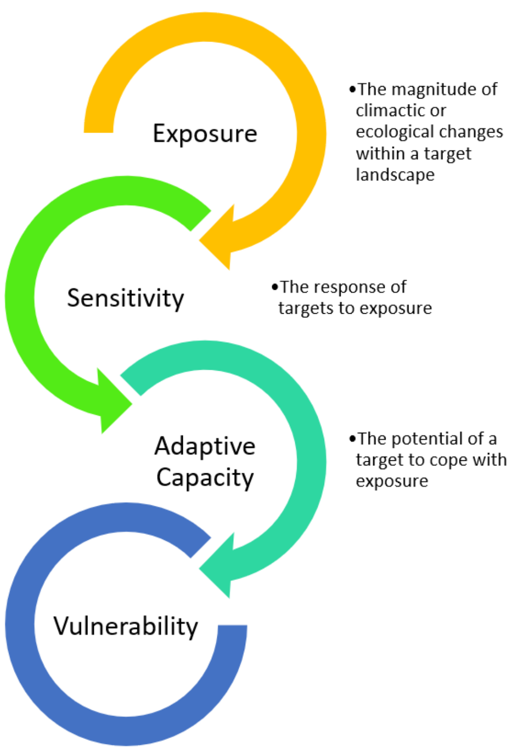
In the Southwest, several global climate model (GCM) projections indicate altered climate patterns and a continuing trend toward warmer and drier conditions (Seager et al. 2007, Gutzler and Robbins 2010, Jones and Gutzler 2016). Depending on the emissions scenario, model projections show average annual temperature increases of 1-4°F in the period 2021-2050, 1-6°F in 2041-2070, and 2-9°F in 2070-2099 (Garfin et al. 2013). By the middle of the century, the Southwest region is expected to experience 5 to 30 more days per year with a maximum temperature exceeding 95°F. Southern parts of the region could get up to 45 more days each year with maximum temperatures of 90°F (32°C) or higher when compared to the period 1976-2005 (Kunkel et al.2013, Gonzalez et al.2018). Projected hotter temperatures increase probabilities of decadal to multi-decadal megadroughts (Gonzalez et al.2018). Increases in temperature are also likely to contribute to aridification in much of the Southwest, through increased evapotranspiration, lower soil moisture, reduced snow cover, earlier and faster snowmelt, and changes in the timing and efficiency of snowmelt and runoff (Brown and Mote 2009). Additional heatwave days have occurred globally each decade since the 1950s (Perkins-Kirkpatrick and Lewis 2020).

Projections of precipitation are less certain than those for temperature; however, projections indicate that the southwestern U.S. may experience chronic future precipitation deficits, particularly in the spring but with deficits in winter precipitation and snowpack being much more concerning. Snowpack supplies a major portion of water in the Southwest, but with continued warming, models project substantial reductions in snowpack (Brown and Mote 2009). Uncertainty in the magnitude and timing of future drying is high and fewer days with precipitation may lead to increased year-to-year variability (Gonzalez et al.2018, Wehner et al.2017).

Climate models project an increase in the frequency of heavy downpours, especially through atmospheric rivers, which are narrow bands of highly concentrated storms that move in from the Pacific Ocean. Under the higher emission scenario (RCP8.5), models project increases in the frequency and intensity of atmospheric rivers. Climate models also project an increase in daily extreme summer precipitation in the Southwest region, based on projected increases in water vapor resulting from higher temperatures. Projections of summer total precipitation are uncertain, with average projected totals not differing substantially from what would be expected due to natural variations in climate, due in large part to the monsoonal dynamics that drive summer rainfall in much of the region (Gonzalez et al.2018).

About Vulnerability Assessment

Critical to assessing vulnerability and potential impacts is understanding appropriate management responses to the threats and hazards posed by contemporary climate trends. Also critical is a fundamental understanding of the vulnerability of the ecosystems or elements in question. Climate change vulnerability assessments evaluate exposure, sensitivity, and adaptive capacity of ecosystems in response to changing climates.



Vulnerability assessments provide a means for evaluating risk for both *intrinsic* and *climate-induced* risk. Intrinsic risk, existing risk not associated with climate trends, is included in many vulnerability assessments in recognition of the interplay and feedbacks between underlying threats to ecological integrity and those specifically driven by 21^{st}-century climate. Vulnerability assessments can be used across scales to relate local vulnerability to a context scale as a process of determining the best management for a given area. Because risk is often considered to be cumulative, the underlying intrinsic risks to loss in ecosystem function can elevate the potential for climate stressors to exacerbate that risk. A common example of this additive effect is the intersection of wildfire risk with increased temperature and ecological function when compared to an area with equally predicted changes in climactic conditions but without the underlying intrinsic wildfire risk. While fire effects remain largely an artifact of past land use and fire suppression, there is an increasing role in current climate trends in fire weather, protracted fire seasons, and drier fuel conditions (Williams et al. 2014, Abatzoglou et al. 2017, Parks et al. 2018, Mueller et al. 2020, Pausas and Keeley 2021).

Figure 2. Some resources available for assessment of climate vulnerability, impacts, and climate-smart solutions including the Western Wildlands Environmental Threat Assessment Center (Quigley et al. 2004), Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options (Peterson et al. 2011), Effects of Drought on Forests and Rangelands in the United States (Vose et al. 2016), the Fourth National Climate Assessment (Reidmiller et al. 2018), the Seedlot Selection Tool (St. Clair et al. 2022), Climate Adaptation Science Centers (USGS 2022), SRRT reforestation decision support tool (Rodman et al. 2022), the Template for Assessing Climate Change Impacts and Management Options (TACCIMO; Treasure et al. 2014), the USDA Southwest Climate Hub (Elias et al. 2015), and Forest Adaptation Resources (Swanston et al. 2016).

In the Southwest, high-elevation snowpack and seasonal rains supply much of the regional surface water. The prognosis for the region is one of increasing vulnerability given the convergence of land use history and extended duration and extremes of drought, record heat, and unprecedented fire seasons. Three all-lands assessments were developed for the Southwest including the Climate Change Vulnerability Assessment (CCVA) for upland ecosystems (Triepke et al. 2019), the Aquatic-Riparian Climate Change Vulnerability Assessment (ARCCVA) (Wahlberg et al. 2022), and the Socioeconomic Vulnerability Assessment (SEVA) (Hand et al. 2018, Borchers et al. 2021). Each was developed with its own organizational frame and supporting indicators. Though only the CCVA, ARCCVA, and SEVA are summarized in this strategy, there are numerous climate vulnerability and resource assessments available to the region including important assessments on specific areas or elements of the Southwest (e.g., Bagne et al. 2011, Bagne and Finch 2012, Coe et al. 2012, Friggens et al. 2013, Elias et al. 2015, Friggens 2015, Hoglander et al. 2016, Wyndham et al. 2018) (Figure 2) that can be helpful for Step 2.

Upland Ecosystems

Introduction

Current climate trends in the Southwest coupled with a broad consensus among climate modeling denote a pattern of continued warming, greater aridity and drought, and increased variability as the new climatology of the region (Seager et al. 2007). The resulting effects on regional vegetation patterns and Southwest forests are already apparent and expected to intensify in the 21st-century, under the influences of increased temperatures and changes in precipitation patterns along with indirect stressors including fire, insects, and tree disease. Under late-century climate forecasts the majority of forests are vulnerable regardless of emissions scenario, though the reduced emission scenario shows substantial benefits to reducing climate impacts (Thorne et al. 2018). Non-forest vegetation is particularly affected by lower soil water availability linked with increased temperatures and reduced precipitation. For all vegetation types increased evapotranspiration and aridity will result in lower plant productivity and changes to species composition, with related effects to habitat and forage conditions for native ungulates and livestock (Wyndham et al. 2018) and a pronounced vulnerability to familiar vegetation patterns across the region.

Regional Climate Change Vulnerability Assessment (CCVA)

The CCVA was an ecosystems-based approach to rate vulnerability by the disparity between projected and historical climate conditions (Triepke et al. 2019), similar to Comer et al. (2019) and Elias et al. (2015) in approach and in the role of vulnerability assessment in a climate adaptation framework. The CCVA categorizes local vulnerability into four broad classes: Low, Moderate, High, and Very High based on the number of standard deviations in departure between the historical climate envelope (pre-1990) and climate forecasting (2061-2090) (Figure 3). For purposes of this strategy 'high' and 'very high' are often grouped as 'high+' and collectively represent areas expected to exceed three standard deviations of the mean climate envelope conditions. Only those areas rated as low in this vulnerability assessment are expected to stay within a characteristic climate envelope.

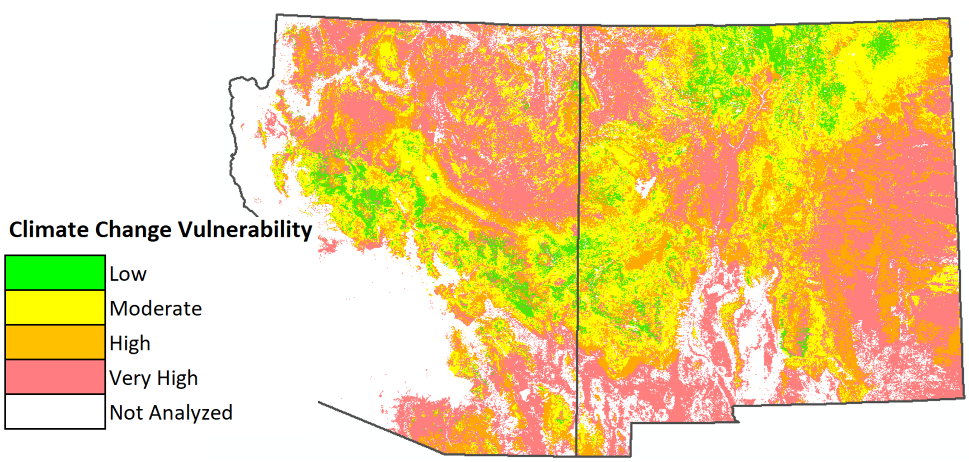


Figure 3. Climate change vulnerability assessment results for upland ecosystems in the Southwestern United States (Triepke et al. 2019).

The CCVA was stratified by vegetation types, or Ecological Response Units (Moreland et al. 2017), areas of similar site potential, historical fire regime, and succession patterns on par with LANDFIRE Biophysical Settings (Barrett et al. 2010). Ecological Response Unit (ERU) mapping provides a benchmark from which to gauge and forecast climate impacts. Climate conditions themselves drive the long-term differentiation of vegetation, soils, and productivity across the landscape (Braumandl and Curran 1992, Pojar et al. 1987) and, in the nearer term, interact with geology, soil properties, and topography to control *site potential* – particular combinations of plant functional traits (Laughlin et al. 2011), community physiognomy, and ecosystem processes that, in turn, influence disturbance patterns (Agee 1993, Laughlin et al. 2011). Site potential and climate-vegetation relationships are a central theme of the impacts section of this document (Step 2) and an area of strong science for the region. All major vegetation types in Arizona and New Mexico are represented by ERU mapping (Table 3). This mapping is generally 1:24,000 scale and, on Forest Service lands, reflect technical groupings of Terrestrial Ecological Unit Inventory (TEUI) units. Map data are publicly available for download (www.fs.usda.gov/detailfull/r3/landmanagement/gis).

Table 3. Listing of all major Ecological Response Units in the Southwest along with ERU codes and system types (forest, woodland, shrubland, grassland, or Great Plains). Subclasses are not included in this list.

Ecological Response Unit (ERU)	ERU Code	System Type
Spruce-Fir Forest	SFF	forest
Bristlecone Pine	BP	forest
Mixed Conifer w/ Aspen	MCW	forest
Mixed Conifer – Frequent Fire	MCD	forest
Ponderosa Pine Forest	PPF	forest
Ponderosa Pine – Evergreen Oak	PPE	forest
PJ Sagebrush	PJS	woodland
PJ Deciduous Shrub	PJD	woodland
PJ Evergreen Shrub	PJC	woodland
PJ Woodland	PJO	woodland
PJ Grass	PJG	woodland
Juniper Grass	JUG	woodland
Madrean Encinal Woodland	MEW	woodland
Madrean Pinyon-Oak Woodland	MPO	woodland
Montane / Subalpine Grassland	MSG	grassland
Colorado Plateau / Great Basin Grassland	CPGB	grassland
Semi-Desert Grassland	SDG	grassland
Alpine and Tundra	ALP	shrubland / mixed
Mountain Mahogany Mixed Shrubland	MMS	shrubland
Gambel Oak Shrubland	GAMB	shrubland
Sagebrush Shrubland	SAGE	shrubland
Interior Chaparral	IC	shrubland
Apacherian-Chihuahuan Upland Scrub	ACU	shrubland
Sand Sheet Shrubland	SSHR	shrubland
Intermountain Salt Scrub	ISS	shrubland
Sonora-Mojave Mixed Salt Desert Scrub	SDS	shrubland
Chihuahuan Salt Desert Scrub	CSDS	shrubland
Chihuahuan Desert Scrub	CDS	shrubland
Mojave-Sonoran Desert Scrub	MSDS	shrubland
Sandsage	SAND	shrubland
Shinnery Oak	SHIN	Great Plains
Mixed-Grass Prairie	MGP	Great Plains
Shortgrass Prairie	SGP	Great Plains

- ERU mapping available at www.fs.usda.gov/detailfull/r3/landmanagement/gis/?cid=stelprdb5201889&width=full

In general, options for active climate adaptation or mitigation measures may be more successful in areas of low or moderate vulnerability. Areas of high vulnerability may nevertheless warrant resistance measures where there are high-value elements such as threatened or endangered species habitat. The CCVA has relatively high spatial resolution (20-30ha polygons) but appropriate scales for application are on large landscape projects or broader. There is much greater uncertainty at precise locations and much greater risk of misinterpretation. **In all cases vulnerability needs to be assessed in the field prior to implementing adaptation options and tactics**. For Forest Service lands, Terrestrial Ecological Unit Inventory (TEUI; Winthers et al. 2005) data can be used to help determine vulnerability at the site level (Box 8). Environmental justice considerations are given for nearby communities with low adaptive capacity and elevated climate exposure or sensitivity (Borchers et al. 2021). Vulnerability ratings should always be corroborated with local knowledge and other observational data or scientific references. Figure 29 later in the document paints a timeline of CCVA relative to other variables and references.

Summary of CCVA Results

The CCVA resulted in a probability surface for Arizona and New Mexico that represents future climate as a potential stressor of significant change to ecosystem structure, composition, and process and represents the likelihood of climate-driven type conversion from low to high, with an inverse relationship for the system to return to its characteristic state (Comer et al. 2019). Uncertainty was also assessed by the level of agreement in vulnerability results among multiple global circulation models. Though the majority of lands fell into high vulnerability and low uncertainty (Table 4), the results varied from one ERU to the next, with cold temperate ERUs averaging higher vulnerability than mild vegetation types of lower latitudes.

Table 4. Overall climate vulnerability and uncertainty results for the CCVA.

Climate Vulnerability	% Area	Low Uncertainty	Moderate Uncertainty	High Uncertainty
Low vulnerability	6%	2%	4%	0%
Moderate vulnerability	24%	1%	16%	7%
High+ vulnerability	70%	48%	22%	0%
Total		50%	42%	8%

The CCVA indicates that only a small portion of the region (6%) is projected to remain within its historical climate envelope by the year 2090. About 70% of the region is in the high or very high vulnerability category with vulnerability patterns varying considerably among ERUs. Vegetation of upper life zones is at considerable risk to changing climate. All alpine and tundra within the region is very highly vulnerable. Alpine is inherently vulnerable to warming given its limited extent at the southern periphery of its range in the United States and given that most of the ERU is concentrated nearer the lower, warmer end of the life zone, making it susceptible to even minor temperature increases. Spruce-Fir Forest is less vulnerable than other upper life zone types, though is considerably vulnerable in southwestern and western extremities of the region. Nearly all of the Bristlecone Pine ERU occurs as high or very high vulnerability. In contrast to the other upper elevation systems, the Montane/Subalpine Grassland has the lowest overall vulnerability of any ERU. At middle elevations, the two major montane forest types – Mixed Conifer-Frequent Fire and Ponderosa Pine Forest – exhibit lower vulnerability than upper elevation systems, with each ERU having half or less of its area in high to very high vulnerability. However, vulnerability increases significantly for these ERUs as one moves southward in either state.

Among the woodland ERUs, Pinyon-Juniper Sagebrush, a cold-temperate type, has the greatest vulnerability with the vast majority occurring as high or very high vulnerability. In contrast, Pinyon-Juniper Evergreen Shrub, which occurs to the south under mild temperature regimes, has the lowest vulnerability of the woodland ERUs. The two Madrean woodland units of mild extents, Madrean Pinyon-Oak and Madrean Encinal Woodland, stand in contrast to one another at 37% and 75% high or very high vulnerability, respectively.

Grasslands make up nearly 40% of the region with most grasslands represented by semidesert grassland, Colorado Plateau/Great Basin Grassland, and Shortgrass Prairie, collectively comprising much of the low-lying valley and plains among islands of mountain topography. High and very high vulnerability categories make up more than 75% of each of these ERUs. An associate of valley bottoms and plains, the Intermountain Salt Scrub has the highest vulnerability of any shrubland system, a reasonable expectation for an ERU at the southern edge of its range.

Of the other shrubland systems, Sandsage has the greatest vulnerability. In contrast, the Interior Chaparral has the lowest vulnerability, consistent with its affinity toward mild climate regimes. The Shinnery Oak ERU is substantially more vulnerable than most other ERUs, similar to results for other Great Plains systems (Sandsage, Salt Grass Prairie). And like Salt Grass Prairie, southeastern New Mexico represents the southern extent of Sandsage range. Sagebrush Shrubland has the lowest vulnerability of shrubland types in contrast to the vulnerability forecast for other cold-temperate ERUs at their southern limits.

CCVA Uncertainty

While there is no doubt that contemporary climate trends will have a profound and lasting impact on natural resources, uncertainty exists around the pace and mechanics of change of Southwest landscapes. Uncertainty was assessed with the CCVA as another line of evidence in the selection of climate adaptation options in Step 4. Figure 4 shows the geographic pattern of uncertainty in Arizona and New Mexico according to the agreement among global circulation models. Uncertainty and vulnerability are summarized in Table 4 and figures 3 and 4. Uncertainty tends to be lower in basins and plains and greatest in complex mountainous terrain.

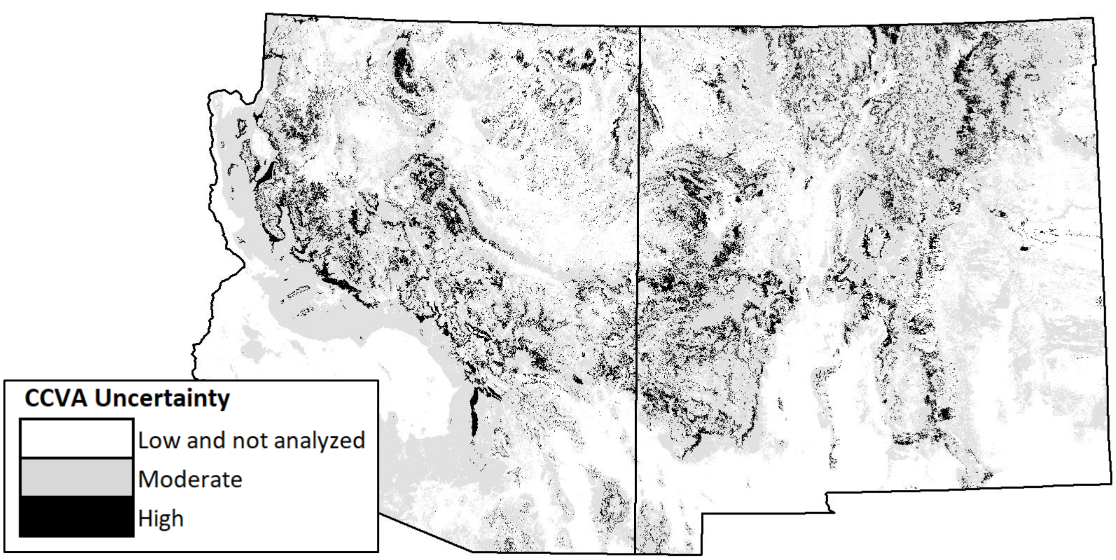


Figure 4. Uncertainty evaluation for the CCVA based on the agreement among multiple global circulation models used to forecast climate vulnerability for upland ecosystems in the Southwestern United States.

The predictive value of CCVA was tested using independent analyses and recent field observations of ongoing ecological processes. Significant statistical relationships were discovered between levels of projected vulnerability and recent wildfire severity patterns, upward tree species recruitment, and the encroachment of desert scrub into semidesert grassland. Plant production trends of the past three decades (Jones et al. 2021) were also considered and reveal an inverse relationship between climate vulnerability and productivity. The testing suggests that CCVA has value to support local adaptation strategy, set priorities, and support project-level decisions.

Desert Communities

The CCVA did not include analysis of desert units over concerns of low sample numbers for envelope models of the desert ERUs – Chihuahuan Desert Scrub (CDS), Chihuahuan Salt Desert Scrub (CSDS), Mojave-Sonoran Desert Scrub (MSDS), and Sonora-Mojave Mixed Salt Desert Scrub (SDS). Sampling only represented the northern extents of the Chihuahuan and Sonoran provinces as they occur in the US. Desert systems are especially resistant to drought stress and to variability across temporal scales (Bhattachan et al. 2014, Pockman and Sperry 2000). Nevertheless, other issues with desert systems have been identified including rapidly spreading exotic grasses (e.g., Meier et al. 2016) that need to be considered in holistic land management (e.g., USDA Forest Service 2020).

Vulnerability at Context and Local Scales

Vulnerability needs to be assessed and understood not only at the local scale but also at the broader context scale to adequately inform steps 3 and 4. The *local scale* represents areas smaller in extent such as a landscape project, watershed, Ranger District, or BLM field office, while the context scale represents *broader extents* such as Ecoregions (i.e., Ecological Sections or Provinces). *Ecoregions* are subregion- or region-scale map features (figures 5 and 6) of similar vegetation, landform, and climate patterns (Cleland et al. 2007) that can provide meaningful bounds for evaluating vulnerability at the local or the broader context scale. An ERU with high local vulnerability and low context vulnerability may warrant different management than an ERU with low local vulnerability and high context vulnerability. In order to apply climate adaptation, it is important to understand vulnerability patterns at a specific location relative to vulnerability patterns as a whole.

Though CCVA was conducted for each setting there is much greater uncertainty in the data at precise locations so that CCVA is usually summarized over much larger areas to improve certainty – local vulnerability needs to be assessed in the context of the larger landscape. For Forest Service lands, CCVA summaries have been developed for all Forests, Ranger Districts, and subwatersheds including tabular information on the vulnerability and extent of each ERU. Summaries will also be developed for the surrounding Ecoregion(s) and the Appendix D provides an example for the Coronado National Forest relative to its context Ecoregion (Figure 6).

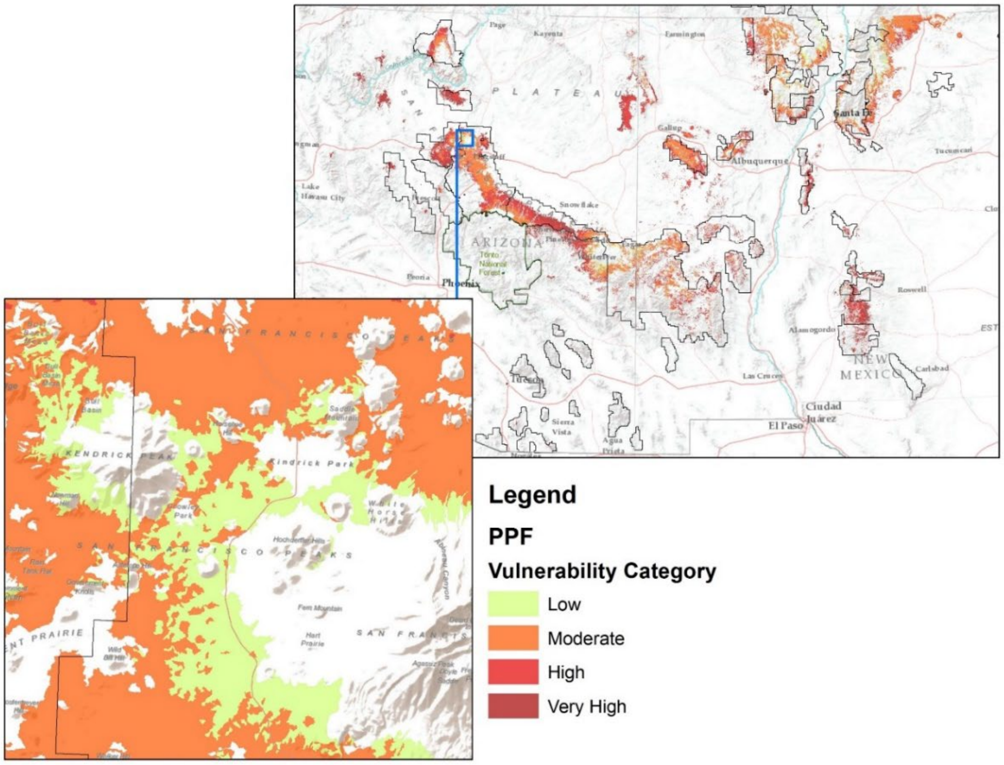


Figure 5. An example for considering vulnerability at multiple scales showing vulnerability patterns of the Ponderosa Pine Forest ERU in the Southwest at both context scale (upper image) and local scale (lower image). There are concentrations of low vulnerability areas on the Coconino NF in north-central Arizona, while the context perspective shows that the majority of the ERU is highly vulnerable.

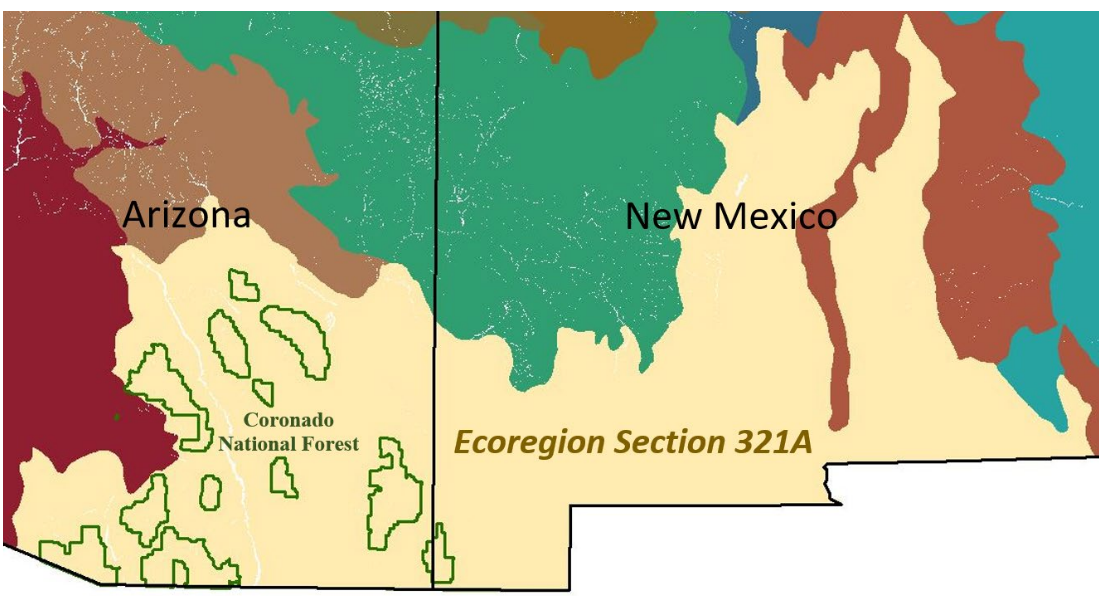


Figure 6. Shaded areas represent different Ecoregions across southeastern Arizona and southwestern New Mexico, with each Ecoregion providing context for smaller local scale units within a given Ecoregion such as the sky island unit of the Coronado NF represented by the smaller outlined areas. These local scale units occur within the context of Ecoregion Section 321A (Cleland et al. 2007).

A set of **guiding questions for context and local scales are included in Step 3** to assist in considering the relative patterns of vulnerability between the two scales, also important for Step 4.

Impacts to Upland Ecosystems and Considerations for Climate Adaptation

Below are general principles that have emerged regarding likely impacts and climate adaptation responses for upland ecosystems. This science synthesis was drawn from research in the Southwest and elsewhere in paleoecology, known life zone patterns, and from recent observations of the likely effects of 21st-century climate. Assumed in the concept of general principles is a dynamic view of ecological processes that, in combination with disturbance, is associated with rapid and irreversible change and the potential for novel ecosystem states under certain circumstances (Lynch et al. 2021; Falk et al. 2022; Guiterman et al. 2022). The synthesis represents an additional line of evidence to minimize uncertainty for managers faced with the difficult task of balancing objectives, feasibility, and limited time and resources when determining an optimal mix of adaptation options and tactics for the sustenance of ecosystem services.

All Life Zones

Life zone patterns; As climate change progresses, individual species may not maintain fidelity to specific associations or even to specific ERUs. Nonetheless, familiar life zone patterns of physiognomy, plant functional traits, and associated ecosystem processes are likely to follow climate across space and time after long lags in realignment (Whittaker 1975, Lugo et al. 1999, Elias et al. 2015). There is increasing evidence in the Southwest that life zones are indeed shifting upwards in elevation (Bell et al. 2014, Hill and Field 2021, Triepke et al. 2019) at the rate of about 15-30m per decade (Brusca et al. 2013, Guida et al. 2014, Kelly and Goulden 2008). **Consideration: Directional change in elevation can help set priorities, active adaptation, and deferral (Passive Transition). Consider likely shifts among ERUs under trends of warmer and drier conditions and assess local plant composition for sensitivity and adaptive capacity including evidence of mortality and recruitment. Legacy mapping on the spatial distribution of vegetation types should not be viewed as static and vegetation specialists will be challenged to guide managers in the interpretation of mapping in response to ongoing and projected vegetation patterns** (e.g., Figure 7).

Lags in the reorganization of life zone patterns; Given rapid shifts in site potential, changes in wildfire and postfire recovery (Coop 2022), and lags in life-zone reorganization and support features (especially soils), plant communities are likely to simplify in the coming decades in their composition, physiognomy, and dynamics. Heat and drought will drive simplification even in the absence of fire as a consequence of fewer species being able to persist, adapt, or immigrate at a given location. Some evidence shows that **mortality in plant populations at the trailing lower end of their local range is outpacing the advance at the leading edge (e.g., Brusca et al. 2013, Parks et al. 2019). Paleoecology also suggests that, on average, late seral plant indicators have a disadvantage relative to seral species in their adaptive capacity and take longer than seral species to reestablish without intervention** once climate conditions are relatively stable (Cole 2010).

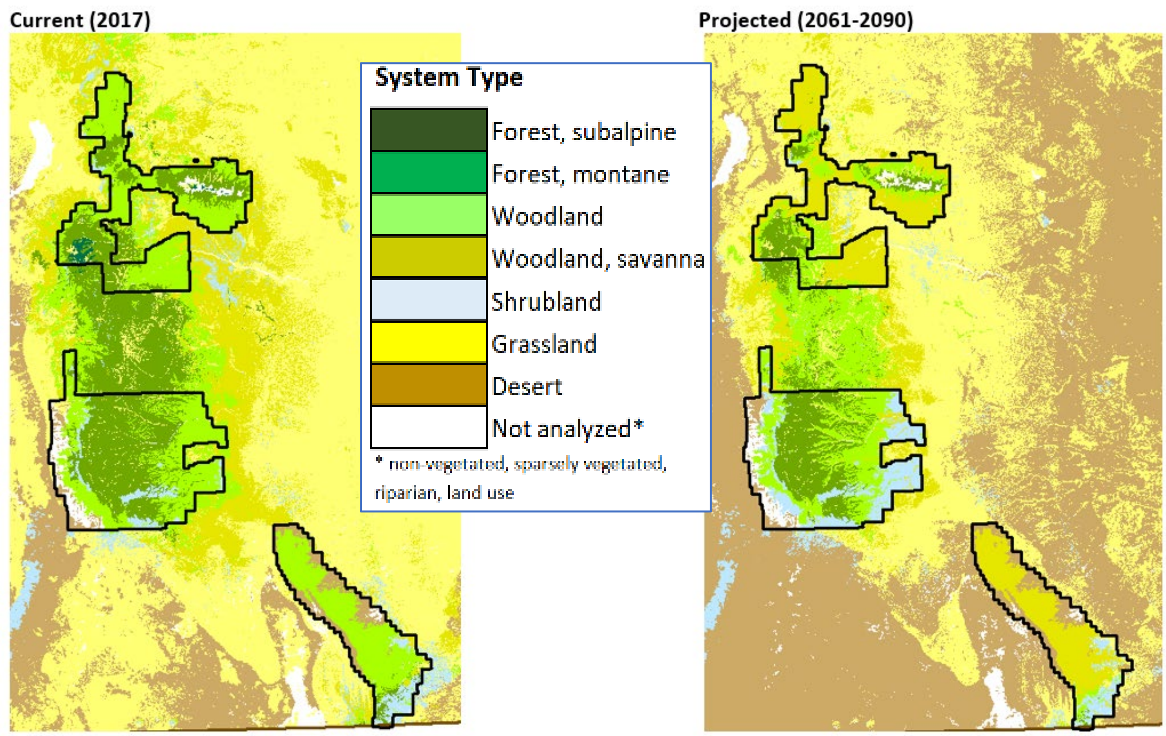


Figure 7. Ecosystem mapping for the Lincoln NF and surrounding lands in southcentral New Mexico showing current life zone distribution (left) (Moreland et al. 2017) and the projected distribution of life zones according to CCVA (right).

Species disequilibrium (legacy components); Legacy components for some species, especially older individuals of long-lived woody plant species, can thrive persist in disequilibrium within their setting in the face of changing climate, shifting site potential, and loss of regeneration potential sometimes for decades or centuries (Bell et al. 2014). These residual features represent persistence in the face of ecosystems in reorganization (Falk et al. 2022) and offer transitional potential attenuating features for more gradual transition and the perpetuation of services such as habitat and carbon sequestration. However, these same populations may lose regeneration potential, as younger individuals (seedlings and saplings) can survive only in a narrower climate space until they establish the roots and foliage needed to survive periods of unfavorable growing conditions (Law et al. 2019, Lalor 2022). In the absence of stand replacement disturbance, declines in tree species recruitment due to climate trends may be partly temporarily offset by the stabilizing effect of mature tree canopies (Dobrowski et al. 2015). **Consideration: The potential longevity of legacy components, from perennial bunchgrasses to old trees, and their value in sustaining ecosystem services should be considered in the overall approach to climate adaptation.**

Cold-temperate vegetation; There are several cold-temperate ERUs, such as PJ Sagebrush, that find their southernmost limits in the North American Southwest (Brown et al. 1998). These landscape elements are inherently vulnerable to warming trends (Boisvert-Marsh et al. 2014). Cold-temperate types are concentrated in northern extents of the region and have higher average vulnerability than warm-temperate or mild types according to the CCVA and others (e.g., Rehfeldt et al. 2006). **Consideration: Knowing if the vegetation type is cold-temperate may have value in adaptation and mitigation strategy depending on circumstances of vulnerability and on management objectives for dependent ecosystem elements such as Canada lynx (*Lynx canadensis*).**

Invasive vegetation; Many invasive plant species have inherent advantages over native vegetation, are able to readily adapt to a rapidly changing climate, and can express greater productivity relative to native species:

- Plant invaders have functional morphological or phenological traits that allow them to maintain rapid gas exchange rates and thus higher productivity in new ranges relative to native vegetation, for instance due to seasonal priority effects (Wainwright et al. 2012). Analyzing over 80 species in North Carolina, Wolkovich and Cleland (2011) found that invasive species leafed out and bloomed earlier than native species in response to an earlier growing season.
- In a common garden experiment involving 43 native and 30 invasive plant species from the eastern US, Fridley (2012) found that invasive species prolonged the window of carbon gain later into the fall as compared to native species by four weeks.
- A meta-analysis comparing trait differences between native and invasive vegetation showed that invasives have greater performance across traits of physiology, leaf-area allocation, shoot allocation, growth rate, size, and fitness (van Kleunen et al. 2010).
- A study by Funk and Vitousek (2007) showed that in environments where light, nitrogen, or water resources were limiting, invasive plants were generally more efficient than native species in using limiting resources on short timescales.
- In a study of plant resource use in forested environments (Heberling and Fridley 2013), invasive taxa expressed greater costs in leaf construction and nitrogen compared to natives, but also had greater photosynthetic energy-use efficiency and greater photosynthetic nitrogen-use efficiency such that, when integrated over leaf lifespan, invasives had a net advantage over native plant species.

Model uncertainty; Approximately 8% of the landscape is forecast as high uncertainty; that is, the CCVA indicates no agreement among the global circulation models used to project vulnerability. **Consideration: Defer active treatments in high uncertainty areas given the reduced value of CCVA in these areas and the questionable likelihood of success for treatments as additional lines of evidence in identifying adaptation options, desired conditions, and tactics.**

Magnitude of climate vulnerability (CCVA);

- High+ (i.e., high and very high categories) – About 70% of the region is considered high+ vulnerability and many areas of the Southwest already appear to be in transition**. Consideration: Zones of high vulnerability where high-value features occur (e.g., designated habitat for Federally listed species) are obvious candidates for management measures to enhance Resistance. Otherwise, areas of high vulnerability may be low priority for active management if they are already in a state of transition and given the lower likelihood of success for certain types of treatment (e.g., conventional tree planting). Areas of high vulnerability in forests and woodlands are also associated with lower fuel production and less frequency of stand replacement fire** (Diggins et al. 2010, Rocca et al. 2014, Triepke et al. 2019). All else being equal, high vulnerability projections imply less uncertainty than areas of low or moderate vulnerability. In contrast, Comer et al. (2021) suggest prioritizing active management in high-vulnerability areas consistent with a triage approach to climate adaptation where management resources might be more plentiful.
- Moderate – About a fourth of the region is considered in a state of moderate vulnerability; these areas may offer greater opportunity to proactively assist ecosystems in transition given the greater likelihood in persistence of their biotic elements. **Consideration: Zones of moderate vulnerability may be good candidates for active management and may present more possibility than high**

vulnerability areas that often coincide with trailing edge zones (Parks et al. 2019) and other ecotones that are already in transition (Figure 9).

- Low – The CCVA suggests that by late 21st century, only about 6% of the landscape will remain within its historical climate envelope, representing the best and few remaining opportunities for classic restoration. These areas of represent opportunities to manage for highly functioning ecosystems while inevitable induced transitions occur elsewhere. **Consideration: With field validation and other lines of evidence, low vulnerability extents may be opportunities for classic restoration and for creating climate refugia.**

Scarcity of management resources; Patterns of land management in recent decades coupled with increasing levels of catastrophic wildfire suggest continued scarcity of resources for active management and, therefore, the need to carefully consider location and the degree of management intervention (Chazdon et al. 2021). The adaptation strategy and integrated landscape prioritization provide default solutions for adaptation that require local assessment and validation along with the consideration of other sideboards, commitments, and available vulnerability information for the best use of resources.

Forests and Woodlands

Forest extent (all forests and woodlands); There is accumulating evidence that the extent of forested lands is being reduced in the Southwest region, along with changes in which tree species are regenerating successfully in their current location. Collectively, there is an upward shift in life zones (Bell et al. 2014, Brusca et al. 2013, Triepke et al. 2019) where wildfires can trigger rapid and permanent change in plant composition (Hill and Field 2021). On balance the paleo record shows that the current rate of climate change within the span of a century or so is equivalent to that of one or more past millennia (Axelrod 1958). Paleoecology further indicates that without human intervention ecosystems may require centuries to fully adjust to new climate patterns though there is evidence that at least some elements can adjust quickly (Clark 1998). Late-seral plant species are expected to take an even longer time to adjust (Cole 2010). Climate patterns are not expected to stabilize again until late 21st century or early the following century depending on future **carbon emission trends (IPCC 2007, 2014) with a considerable lag in acclimatization to follow. Considerations: in areas of moderate-high vulnerability, maintain encroaching tree species of lower life zones. Favor early-mid seral tree species over late-seral species given their adaptations for post-disturbance environs and warmer-drier conditions (all else being equal). Maintain tree basal area at the low end of desired ranges to mitigate water stress and support tree recruitment.** There is a growing consensus that management that reduces tree densities (Bradford and Bell 2017), especially but not only in fire-adapted vegetation types, can buffer proactively against effects of drought and warmer temperatures in either a Resistance or Transition approach (Millar et al. 2007, Falk et al. 2022). Although the influence of tree density on heat-related stress and soil moisture remains unclear, density remains a primary variable in drought-related (Greenwood and Weisberg 2008, Bradford et al. 2022) and in fire-related mortality (Ffolliott et al. 2011, Krofcheck et al. 2017, Parks et al. 2015, Strom and Fulé 2007, Strahan et al. 2015). **Management aimed at reducing stem densities and treating fuels in fire-adapted forests and woodlands that are severely departed from reference conditions remain an effective safeguard for the conservation of forests, their ecosystem services, carbon storage (Hurteau 2017, McCauley et al. 2019) and for allowing for management options across planning cycles.**

Tree planting; Step 5 and Box 8 on tree planting reflect the heightened importance for 1) forest inventory data and understanding shifting tree species ranges under current climate trends, 2) the results of recent research on regeneration potential in regional conifers (Lalor 2022), 3) a recent increase in Forest Service resources and capacity for reforestation, 4) extensive wildfires and treeless openings left by recent fire seasons, and 5) the June 23 2023 Secretary's Memorandum calling for an immediate increase in climate-informed reforestation. **Consideration: Box 8 has an initial framework for integrating climate adaptation in reforestation to improve planting long-term success. There is growing evidence that conventional tree planting strategies may be poorly suited for long-term reforestation success in areas of high climate stress; at the least, areas of high vulnerability should be deferred for planting (climate informed) until further assessments are completed.** As always, vulnerability forecasts for a given area should be verified with additional lines of evidence such as field truthing for stressors and local regeneration patterns, TEUI mapping (regeneration potential), or other vulnerability projections. There is an urgency to respond to science gaps in our understanding of tree regeneration patterns and potential management solutions for climate smart reforestation.

Forest health (all forests and woodlands); Vegetation shifts are most likely to occur after disturbance and especially in areas of high vulnerability (Triepke et al. 2019, Falk et al. 2022). Climate change will amplify many existing stressors including invasive species, insect pests and pathogens, and other disturbance factors. Forest pests and diseases are expected to become more damaging under climate change and interact with other stressors in unpredictable ways and could alter long-term carbon storage (Vose et al. 2012, Garfin et al. 2013, Joyce et al. 2014). While a warming climate has the potential to increase the number of generations for many bark beetle species in a given period, population increases and resulting outbreaks have only been documented for mountain pine beetle in the northern US and Canada and, to a lesser degree, for spruce beetle throughout its range (Carroll et at. 2003, Bentz et al. 2010). Except for some high-elevation bark beetle species, most beetle outbreaks in the Southwest are due to exacerbated drought conditions under warmer temperatures (Park Williams et al. 2013) and increased wildfire activity and not due to warmer winters. Drought-induced infestations have resulted in up to 90% mortality of overstory pinyons (Breshears et al. 2005, Greenwood and Weisberg 2008). Douglas-fir beetle outbreaks are especially associated with wildfires, particularly where there is a high percentage of fire-injured large-diameter trees (Hood et al. 2003, Powell et al. 2012). Tree mortality from wildfire and bark beetles occurred on 20% of Arizona and New Mexico forests between 1984 and 2008. Warming climate also has the potential to favor the movement of bark species northward. Northern movement of Mexican bark beetles was first documented in the Southwest in 2001 (Moser et al. 2005) but given the difficulty in distinguishing the species from southern pine beetles, Mexican bark beetles may have been present in the region much earlier. Some invasive bark beetle species, such as the Mediterranean pine engraver of warmer climates, previously isolated to urban forests may take advantage of increased temperatures and move into higher elevations of nearby native forests (Lee et al. 2008).

Fire-dependent forests and woodlands; Vulnerable fire-dependent forests and woodlands are likely to transition to other fire dependent systems, so that fire remains a viable tool for ecosystem transition and the maintenance of ecosystem services. **Consideration: Burning and surrogates that mimic historical fires and cultural burning (Mariani et al. 2022) may be more viable in fire-adapted types than in forests and woodlands that are not fire adapted, in part, due to the relative adaptive capacity of seral plant species characteristic of fire-adapted ERUs.** Some research indicates that longer fire intervals and reduced emphasis on thinning may be better tolerated in areas of high vulnerability (Diggins et al.2010), again for those instances where resources for active management are limited.

Mid-long fire interval forests (Spruce-Fir Forest, Mixed Conifer w/ Aspen); Mid- to long-interval forests of moderate and high vulnerability may be shifting towards climate envelopes familiar to fire-adapted ERUs such as Mixed Conifer-Frequent Fire. In such cases there may be higher level of risk to loss of ecosystem services and ecological integrity. **Consideration: These settings may be good candidates for proactively facilitating ecosystem realignment (Preemptive Transition) as with diversifying species selection for tree planting.** Upper montane and subalpine forests of the southern Rockies often have a more substantial component of Douglas-fir (*Pseudotsuga menziesii*) or corkbark fir (*Abies lasiocarpa* var. *arizonica*) that could allow for additional management options due to the thicker bark of these species.

Pinyon-Juniper Woodlands; Climate and associated trends in insects and smaller disturbance events are now influencing structure of PJ Woodland (persistent) more than large fires (Gray et al. 2006; Romme et al. 2009). Warmer and drier conditions associated with high vulnerability settings and low soil moisture capacity are likely limiting overall pinyon and juniper recruitment. **Consideration: Areas of high vulnerability may be more appropriate for deferring active management. Allowing pinyon and juniper to regenerate at higher elevations where these species are typically less desirable may be proactive given the presumed shifts in suitable climate in novel locals (sinks). Under the assumption of limited management resources, consider deferring activities aimed at reducing conifer encroachment into neighboring grassland and shrublands given the likely effects of climate on reducing tree cover in trailing edge forests and woodlands.**

Juniper woodlands; Juniper woodlands often occur at the lower end of the woodland life zone, beyond conditions suited to species of pinyon. Areas of vulnerable Juniper Grass ERU are likely to transition to savanna and grassland systems under current climate trends. **Consideration: Defer treatments aimed at reducing tree density in high-vulnerability settings given the likelihood of local mortality from warming trends and drought; that is, limited management resources might be better spent elsewhere where climate is less likely to effect density.** The proliferation of eastern redcedar (*Juniperus virginiana* L.) in the National Grasslands of Oklahoma could be an exception to this rule of thumb in need of closer investigation into climate trends and adaptive capacity of the species.

Oak cover types; Low rates of recruitment (i.e., evident seedling and sapling cohorts) observed over most portions of the region are likely to worsen with increased moisture stress from warming trends in addition to mortality in adult oaks resulting in an overall decline in abundance except in the most favorable settings such as riparian zones (Elias et al. 2015). In the near term, good post-fire reproduction of Madrean oaks has been observed in the Sky Islands where oaks are replacing pines or increasing in relative abundance (personal communication with Don Falk and Jim Malusa). Elsewhere in the region Gambel oak is proliferating after fires in montane forests, sometimes having persisted for more than a century. Observations in south-central New Mexico on the Lincoln National Forest suggest that Gambel oak may decline in instances of back-to-back fires (personal communication with David Baker).

Aspen (Elias et al. 2015); Aspen decline is expected to be concentrated in areas where temperature and aridity is greatest including at low elevations and south-facing slopes. More insect and disease attacks can be expected given the region's propensity for relative drought and heat extremes (Worrall et al. 2010).

Climate vulnerability and fire severity; Some evidence reveals an inverse relationship between fire severity and climate vulnerability; that is, settings predicted as high vulnerability tend to have lower fire severity based on large wildfires last two decades (Triepke et al. 2019). Likely variables include plant productivity, fuel accumulation, and fire occurrence (Diggins et al. 2010, Rocca et al. 2014). If this is the case, areas that experience warmer-drier conditions would be subject to reduced soil moisture, higher evaporative demand, and reduced productivity, with the indirect effects of reduced fuel production and fire risk. Production trends since the late 1980s (RPMS 2022) indeed suggest an inverse relationship between plant production and magnitude of vulnerability (Figure 8).

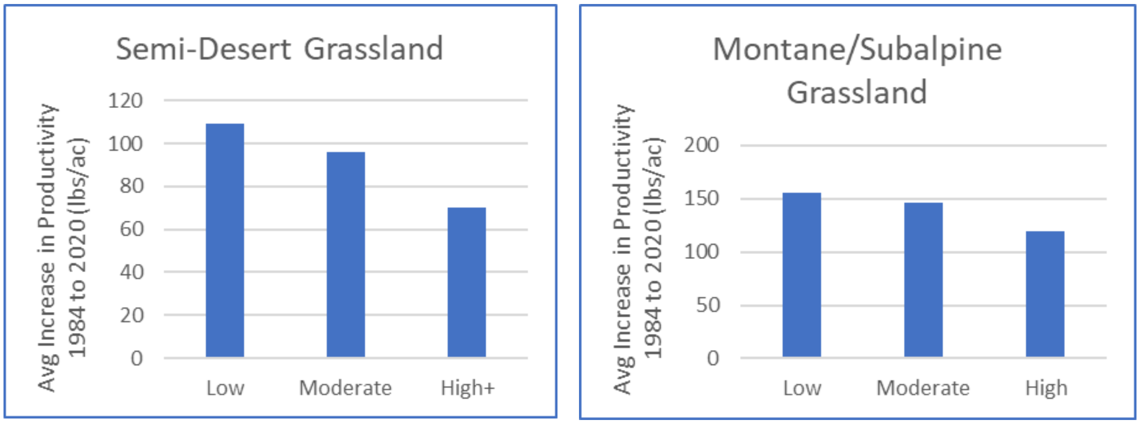


Figure 8. Relative average plant productivity among CCVA vulnerability categories from 1984 to 2020 for grassland ecosystems of the Southwest.

There is also a tendency for forests and woodlands to have the lowest canopy density in areas of high vulnerability, all else being equal (Muldavin and Triepke 2020). Stand structure and local fuel conditions, in turn, remain the primary main drivers in subsequent fire severity patterns (Parks et al. 2018). An analysis of severity data from 62 large wildfires in the Southwest between 2018 and 2020 show that stand replacement fire was far less likely to occur in open-canopied stands (-54% lower than expected) and far more likely to occur in closed conditions (62% over expected). The analysis also showed that the *location* of open-canopy stands had little to no effect on severity patterns in surrounding stands. Nor did the overall proportion of the landscape in an open stand condition affect the subsequent percentage of mixed- and high-severity fire. These results contrast with some model simulations (e.g., Ager et al. 2010, Krofcheck et al. 2019) and the literature synthesis and survey results (Jain et al. 2021) that posit the strategic locating of thinning treatments on the landscape as a means to affect larger extents than the treated areas themselves (Ager et al. 2010, Krofcheck et al. 2019); instead, the analysis results corroborate numerous observational studies linking local fuel conditions to subsequent fire effects to indicate that aggressive thinning in departed stand conditions as the most likely approach to reduce fire risk and promote long-term carbon retention (e.g., Strom and Fulé 2007, Ffolliott et al. 2011, Parks et al. 2015, Strahan et al. 2015, Krofcheck et al. 2017). **Consideration: Concentrate limited resources for mechanical treatments in areas of closed stand conditions and low-moderate vulnerability and in the relative few extents where mechanical treatment is feasible. Concentrate maintenance and cultural burning in areas of open and restored stand conditions that have lower fuel accumulations and stand structure resistant to the detrimental effects of fire.** The use of mechanical stand and fuel treatments is expected to smooth climate-induced transitions and avoid abrupt threshold responses as a means of facilitating natural adaptive processes such as changes in plant and disturbance regimes (Stephens et al. 2010).

Reburn; Fire exclusion in frequent-fire forest and woodlands has favored greater tree densities and fuel accumulations increasing the probability of high-severity fire (Romme et al. 2009, Reynolds et al. 2013, Margolis 2014). Within fire areas of the Southwest high severity patches often become dominated by shrubs and herbaceous vegetation, a state shift reinforced with long tree seed dispersal distances and reburn events (Keyser et al. 2020). There is also some evidence that subsequent fire events can further enlarge treeless patches (Stevens et al. 2021) further driven by increased fire weather severity, drought, and low fuel moistures (Collins et al. 2019). **Consideration: Reburn and fire severity and cover type shifts can affect the probability of success for selected adaptation options and tactics. In the case of tree planting, areas of low-moderate climate vulnerability may offer greater likelihood of success**, all else being equal. Consider other variables including TEUI regeneration potential ratings (USDA 2021) which considers slope, soil depth, and other soil and site characteristics (see Box 8).

Shrublands and Grasslands

Fire adapted-shrublands and invasive grasses; Fire-adapted shrublands are likely to transition to other fire-adapted shrublands of different composition (e.g., Mountain Mahogany Mixed Shrubland to Interior Chaparral). **Consideration: Fire could remain a safe management tactic in these settings with the caveat that where introduced grasses occur positive feedbacks may form with fire increasing the cover of invasive grasses while decreasing woody vegetation through repeat fire** (Brooks and Matchett 2006), these areas susceptible to decreasing ecological integrity and ecosystem services.

Shrubland transition; The distribution of shrubland types is especially driven by edaphic properties and, with some shrub types (e.g., ACU, GAMB, IC), by steeper slopes and recurring fire so that shrublands are likely to transition to other shrublands assuming a local shrub component with the adaptive capacity or ability to migrate. **Consideration: Shrublands can be a good candidate for Passive Transition when their adaptive capacity is unknown in relation to repeat fire, mowing, or herbicide treatments often used to reduce shrub cover and favor grass cover, but that may favor ruderal vegetation due to soil conditions and 21st-century warming trends**.

Aridland shrubs; Climate vulnerability assessment of these types suggests that herbaceous production may decrease in many areas and that the shrub component itself may exhibit increased rooting depths and productivity with greater precipitation variability over time, and with increased differential rooting depths between the two life forms (Gherardi and Sala 2015, Wyndham et al. 2018). Under drought conditions grasses are reduced in abundance which, in turn, allows the transfer of additional water to soil depths exploited by the shrub component with the overall effect of steady passive transition from grassland to shrubland vegetation or to desert scrub in southern extents of the region. Increased carbon in the shrub layer may partially offset the loss of carbon and provisioning services in grasslands. **Consideration: Current precipitation patterns add to land-use pressures that favor the ingrowth and encroachment of shrubs into vulnerable grasslands, especially at the grassland-desert ecotone (Figure 9), so that Passive Transition is likely preferable to classic restoration at reducing shrub vegetation.**

Grassland to shrubland conversion; Vulnerable semi-desert grasslands, though fire-adapted, are likely to transition to desert scrub associated with low fire frequency, so that fire and herbicide treatments aimed at classic restoration and scrub reduction may be counterproductive to the maintenance of ecological integrity and services (Buonopane et al. 2005) including carbon sequestration expected under warmer temperatures and increased variability in precipitation (Gherasrdi and Sala 2013, Petrie et al. 2015). The most vulnerable Colorado Plateau/Great Basin Grassland and Shortgrass Prairie settings are likewise susceptible to conversion to shrub types. While warming trends will likely favor increased shrub cover in arid grasslands of the region, land use and grazing remain the dominant factor in woody encroachment (Caracciolo et al. 2016). Nevertheless, **many vulnerable semi-desert grasslands and trailing edge zones of Shortgrass Prairie and Semi-Desert Grassland are likely already in climate-induced transition and may be good candidates for Passive Transition.** The CCVA suggests considerable expansion of both Chihuahuan and Sonoran provinces with **large expanses of grassland in southern Arizona and New Mexico likely to transition to desert scrub (Figure 9). Consideration: Treatments aimed at resisting change may do more harm than good to ecological function in the longer term. At the least, consider deferring conventional restoration in high vulnerability zones**, instead focusing limited resources in low-moderate vulnerability areas where such treatments are more likely to be successful in the long term.

Forage; Increased evapotranspiration will result in lower plant productivity over time along with species composition shifts, with both processes affecting shrubland and grassland habitat and forage conditions for native ungulates and livestock (Wyndham et al. 2018). Mitigating for these patterns will be essential to ecological and socioeconomic stability. **Consideration: Changes in stocking rates, timing, and intensity of livestock use and changes in livestock breeds are general recommendations to cope with changing vegetation patterns and increased climatic stress. Soil survey mapping from the NRCS (non-Forest Service lands) and TEUI (Forest Service lands) can provide base forage production rates pending on-site visits, while the Rangeland Analysis Platform (RAP 2022) and Rangeland Production Monitoring Service (RPMS 2022) provide estimates of production trends over time. The vulnerability assessment of Wyndham et al. (2018) for major aridland types in southern Arizona and New Mexico offers a summary anticipated impacts for several rangeland attributes (Appendix C). The CCVA indicates location and magnitude of vulnerability as an inference of the likelihood of type conversion in the coming decades.** Ecological Site Descriptions (ESDs) and state-and-transition models (https://esis.sc.egov.usda.gov/) can help land managers understand ecosystem dynamics and potential climate adaptation measures (SRM 1995, Creque et al. 1999).

Figure 9. Semi-Desert Grassland vegetation near Deming, New Mexico, with encroaching scrub. This is a trailing edge area of high vulnerability with the expansion of the Chihuahuan Desert in southern New Mexico and relatively rapid conversion of Semi-Desert Grassland.

Plant composition (adapted from Wyndham et al. 2018); Continuing changes in plant composition are expected with ongoing climate trends and will vary geographically within the region, with use varying by forage availability and grazing preferences of livestock and wild ungulates (Polley et al. 2013, Petersen et al. 2014). Many rangelands are susceptible to the introduction and spread of invasive annual grass species, particularly in winter-dominated precipitation zones in much of Arizona. Red brome, cheatgrass, and other invasives are expected to increase in abundance (Boyte et al. 2016). These areas are vulnerable to novel fire regimes, habitat loss for native plants and animals, and declines in forage production and impacts on livestock operations. The added heat stress on the cattle themselves will also likely impact production (Howden et al. 2008, Reeves et al. 2017). **Consideration: Modifications to stocking rates, intensity, and timing along with changes in pasture rotation, rest, and livestock breeds are among potential adaptation measures** for rangeland management.

Drought (adapted from Wyndham et al. 2018); Drought and climate variability are key drivers of ecosystem condition and the composition, distribution, and productivity of rangeland vegetation. System response to drought can be evaluated through an understanding of abiotic (Ecological Site) and biotic (states or phases) variables. Although grazing strategy can influence plant community dynamics and long-term rangeland production, climate variability has the greater influence over aridlands (Biondini et al. 1998). The spacing, duration, and magnitude of precipitation events along with temperatures have been shown to influence soil moisture patterns and ecosystem responses to drought. Gremer et al. (2015) showed that soil moisture alone explained 40-60% of the variance in grass cover. Evaluation of how soil properties mediate impacts of climate on plant communities may enhance our ability to predict rangeland community dynamics. Timing of precipitation, not just the total amount, is critical to the condition of perennial grasses in the American Southwest. While plants in arid and semiarid ecosystem usually respond more strongly to larger storm events or a series of events, small pulses of rain, even as small as 5 mm, may alleviate stresses that accumulates during dry periods and maintain physiological processes (Huxman et al. 2004). **Consideration: Site conditions can predispose impacts or, conversely, mediate for drought by their landform, productivity, rooting and soil depths, salt content, and other variables. Appendix C includes tabled values from Wyndham et al. (2018) for site variables linked to vulnerability, including production, for many Ecological Sites found in southern portions of the region.** Site properties can amplify or buffer plant responses to drought by their influences with the timing and amount of available water. For instance, soil surface texture affects the runoff or infiltration of precipitation, with less loss associated with coarse-textured soils.

Heat waves and grasslands; Grassland ecosystems make up about 38% of the region, the majority of which are degraded owing to past land use (Fletcher and Robbie 2004). While some grassland restoration efforts are underway, such management is likely to be more successful with an understanding of vulnerability and an eye towards landscape prioritization and climate adaptation. In the last few decades, heatwaves have increased in frequency and intensity with further increases expected (Perkins-Kirkpatrick and Lewis 2020). Experimental recent research on heatwaves in grasslands has improved our understanding of the efficacy of restoration and planting under these circumstances (Young et al. 2022) and shows that while grass plugs used in the experiment survived heatwave conditions, aboveground production was reduced. **Consideration: The loss in grassland productivity due to heat waves could result in less biomass for a feedback loop of burning and increased grass production that, in turn, favors subsequent fine-fuel production and fire. Land managers can proactively compensate for production loss due to heatwaves and drought by planting more grass plugs during initial restoration**.

Desert

Climate vulnerability of desert systems; Plant species of deserts are resistant to drought and extremes of stress and climate variability (Pockman and Sperry 2000, Enright and Miller 2007, Bhattachan et al. 2014). Climate vulnerability is inherently low in these systems and some projections suggest that Chihuahuan and Sonoran deserts may expand in the Southwest (Rehfeldt et al. 2006) as depicted in by

CCVA in Figure 30. For some desert plant species even small changes in climate and its variability may be beyond the adaptive capacity of some species that are expected to suffer declines over shorter time scales (e.g., Guida et al. 2014, Pillet et al. 2022).

Deserts and invasive grasses; Despite low inherent vulnerability to warming and drying trends, desert systems in the Southwest are not without issues. Invasive grasses in many locals of Arizona have substantially altered the structure, composition, and processes of plant communities, with positive feedbacks involving increased grass cover, fire frequency, and shrub mortality that collectively favor the proliferation of invasive grasses and further type conversion (Meier et al. 2016). Research is needed to evaluate the long-term prognosis of effects of warmer temperatures and aridity on the sustenance of invasive vegetation in deserts of the region; it should not yet be assumed that a warmer climate will impede or reduce the spread of invasive grasses.

Carbon

Introduction

Climate, disturbance, management, and environmental factors affect many ecosystem processes that influence carbon dynamics in upland ecosystems. Climate change introduces additional uncertainty about how upland vegetation – and vegetation carbon uptake and storage – may change in the future. Climate change causes direct alterations of the local environment, including temperature and precipitation, and indirectly affects a wide range of ecosystem processes (Vose et al. 2012), including vegetation growth, regeneration, and mortality. Because disturbance regimes are projected to shift with climate change, understanding past trends is not sufficient to fully understand vegetation carbon dynamics in the future.

Global carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions are projected to increase through 2100 under even the most optimistic emission scenarios (IPCC 2014). Some models project future increases in forest productivity when the CO_2 fertilization effect is included in modeling (Zhang et al. 2012). However, the effect of increasing levels of atmospheric CO_2 on forest productivity is likely to be transient and can be limited by the availability of nitrogen and other nutrients (Norby et al. 2010). Moreover, rising temperatures and atmospheric moisture demand will likely offset any benefit of increased partial pressure of CO_2. Thus, increases in plant productivity under elevated CO_2 could be offset by carbon losses from climate-related stress, disturbance, or rising temperatures.

Given the complex interactions among forest ecosystem processes, disturbance regimes, climate, and nutrients, it is difficult to project how ecosystems and carbon trends will respond under novel future conditions. The effects of future conditions on ecosystem carbon dynamics may change over time. For example, as climate change persists for several decades, critical thresholds may be exceeded, causing unanticipated responses to some variables like increasing temperature and CO_2 concentrations (Loehman et al. 2018). The effects of changing conditions will almost certainly vary by species and vegetation type. Some factors may enhance vegetation growth and carbon uptake, whereas others may hinder the ability of vegetation to store carbon. Some modelling studies suggest that in the fire-prone Southwest, restoration (thinning and low-intensity prescribed fires) might help to reduce loss of ecosystem carbon under differing climate projections (Hurteau 2017, McCauley et al. 2019). Even under low probability wildfire scenarios (1 in 50 to 1 in 100), carbon stocks were greater in stands that were treated than in control stands (after 40 to 50 years) due to a reduction in wildfire severity in these stands (Hurteau et al.2010, 2016). However, studies at large spatial and temporal scales suggest that there is a low likelihood of high-severity wildfire events interacting with treated forests, negating any expected C benefit from fuels reduction (Restaino and Peterson 2013).

Carbon Flux and Storage

Carbon uptake and storage are some of the many ecosystem services provided by forests, woodlands, shrublands, and grasslands (Swetnam and Falk 2015). Through the process of photosynthesis growing plants remove carbon dioxide (CO_2) from the atmosphere and store it in forest biomass (plant stems, branches, foliage, roots) and much of this organic material is eventually stored in forest soils. This uptake and storage of carbon from the atmosphere helps modulate greenhouse gas (GHG) concentrations in the atmosphere. Estimates of net annual storage of carbon indicate that forests in the US constitute an important carbon sink, removing more carbon from the atmosphere than they are emitting (Pan et al. 2011a). Forests remove the equivalent of about 12 percent of annual US fossil fuel emissions or about 206 teragrams (10^{12}) of carbon after accounting for natural emissions such as wildfire and decomposition (EPA 2015, Hayes et al. 2018).

Landscapes are dynamic systems that naturally undergo fluctuations in carbon storage and emissions as plant communities establish and grow, die with age or disturbances, and re-establish and regrow. When trees and other vegetation die either through natural aging and competition processes or disturbance events (e.g., fires, insects) carbon is transferred from living carbon pools to dead pools which release carbon dioxide through decomposition or combustion (fires). Management activities include timber harvests, thinning, and fuel reduction treatments that remove carbon from the forest and transfer a portion to wood products. Carbon can then be stored in commodities (e.g., paper, lumber) for a variable duration ranging from days to many decades or even centuries. In the absence of commercial thinning, harvests, and fuel reduction treatments, forests will thin naturally from mortality-inducing disturbances or aging, resulting in dead trees decaying and emitting carbon to the atmosphere, although carbon storage tends to stabilize in old-growth forests.

Following natural disturbances or harvests, forests and woodlands regrow and take up and store carbon from the atmosphere. Over the long term, as forests regenerate they tend to accumulate the same amount of carbon that was emitted from disturbance or mortality (McKinley et al. 2011). Although disturbance and stress, forest aging, and management are often the primary drivers of forest carbon dynamics in some ecosystems, environmental factors such as atmospheric CO_2 concentrations, climatic variability, and the availability of limiting nutrients, such as nitrogen, can also influence growth and carbon dynamics (Caspersen et al. 2000, Pan et al. 2009).

The IPCC has summarized the contributions of global human activity sectors to climate change in its Fifth Assessment Report (IPCC 2014). From 2000 to 2009 forest and other land uses contributed just 12 percent of human-caused global CO_2 emissions. The forest sector contribution to GHG emissions has declined over the last decade (FAOSTAT 2013, IPCC 2014, Smith et al. 2014). Globally, the largest source of GHG emissions in the forest sector is deforestation (Pan et al. 2011a, Houghton et al. 2012, IPCC 2014), defined as the removal of trees to convert forested land to other land uses that either do not support trees or allow trees to regrow for an indefinite period (IPCC 2000). However, the US is experiencing a net increase in forested lands in recent decades because of fire suppression and the reversion of agricultural lands back to forest and regrowth of cut forests (Birdsey et al. 2006), a trend expected to continue for at least another decade (Wear et al. 2013, USDA Forest Service 2016).

Carbon assessment involves determining the amount of carbon stored on a given landscape and how impacts from stress, disturbance, management, and growth influence carbon storage over time. For forested landscapes this type of assessment often relies on recent US Forest Service reports including the Baseline Report (USDA Forest Service 2015) and the Disturbance Report (Birdsey et al. *in press*). Both reports relied on Forest Inventory and Analysis (FIA) and several validated and data-driven modeling tools to provide nationally consistent evaluations of forest carbon trends across the National Forest System (NFS). The Baseline Report applies the Carbon Calculation Tool (CCT) (Smith et al. 2007) which summarizes available FIA data across multiple survey years to estimate forest carbon stocks and changes in stocks at the scale of National Forests from 1990 to 2013. The Baseline Report also provides information on carbon storage in harvested wood products (HWP) and an evaluation of the influences of disturbances and management activities using the Forest Carbon Management Framework (ForCaMF) (Healey et al. 2014, Raymond et al. 2015, Healey et al. 2016). This report also contains estimates of the long-term relative impacts of disturbance and non-disturbance factors on carbon stock change and accumulation using the Integrated Terrestrial Ecosystem Carbon (InTEC) model (Chen et al. 2000, Zhang et al. 2012). Additional reports, including the most recent Resource Planning Act (RPA) assessment (USDA Forest Service 2016) and regional climate vulnerability assessments (Triepke et al. 2019) are used to help infer future forest carbon dynamics. Collectively these reports incorporate advances in data and analytical methods, representing the best available science to provide comprehensive assessments of NFS carbon trends. Forest and woodland carbon stocks in some locations may be greater than historic norms owing to fire suppression (USDA Forest Service 2015); as such, land managers may seek a balance between restoration and reducing the risk of uncharacteristic catastrophic wildfire through thinning and prescribed fire which, in turn, reduce tree-to-tree competition for water and thereby increase resistance and resilience to climate change (Allen et al. 2015, Sun et al. 2015, Vose et al. 2016). Despite some uncertainty in annual carbon stock estimates there is a high degree of certainty that overall carbon stocks on forested lands have been decreasing from the 1990s.

Although estimates vary considerably by forest type (Johnson and Kern 2003), on average about a third of forest carbon stocks are stored on the forest floor and in soil organic carbon to a depth of about a meter (excluding roots), representing the second largest carbon pool. Another quarter of forest carbon stocks are stored in the aboveground portion of live vegetation including all live woody vegetation at least one in in diameter. Recent methods for measuring soil carbon have found that the amount of carbon stored in soils generally exceeds estimates from the CCT model (Domke et al. 2017). Annual changes in carbon stocks can be used to evaluate whether a landscape is a carbon sink or source in a given year. A negative value for a given landscape indicates a carbon sink: that is, the area is absorbing more carbon from the atmosphere (through growth) than it emits via decomposition, removal, and combustion. A positive value indicates a source: a landscape that is emitting more carbon than it is taking up. The CCT estimates from the Baseline Report are based on FIA data which may infer changes in the total forested area from one year to the next. Changes in forested area may affect whether forest carbon stocks are increasing or decreasing. Trends on forested landscapes of the Southwest since the 1990s suggest net carbon losses or carbon stability according to the given landscape (Figure 10). Differences in carbon density between units may be related to differences in impacts by disturbance and management regimes, or inherent differences in biophysical factors that influence growth and productivity such as climate conditions, elevation, and vegetation types.

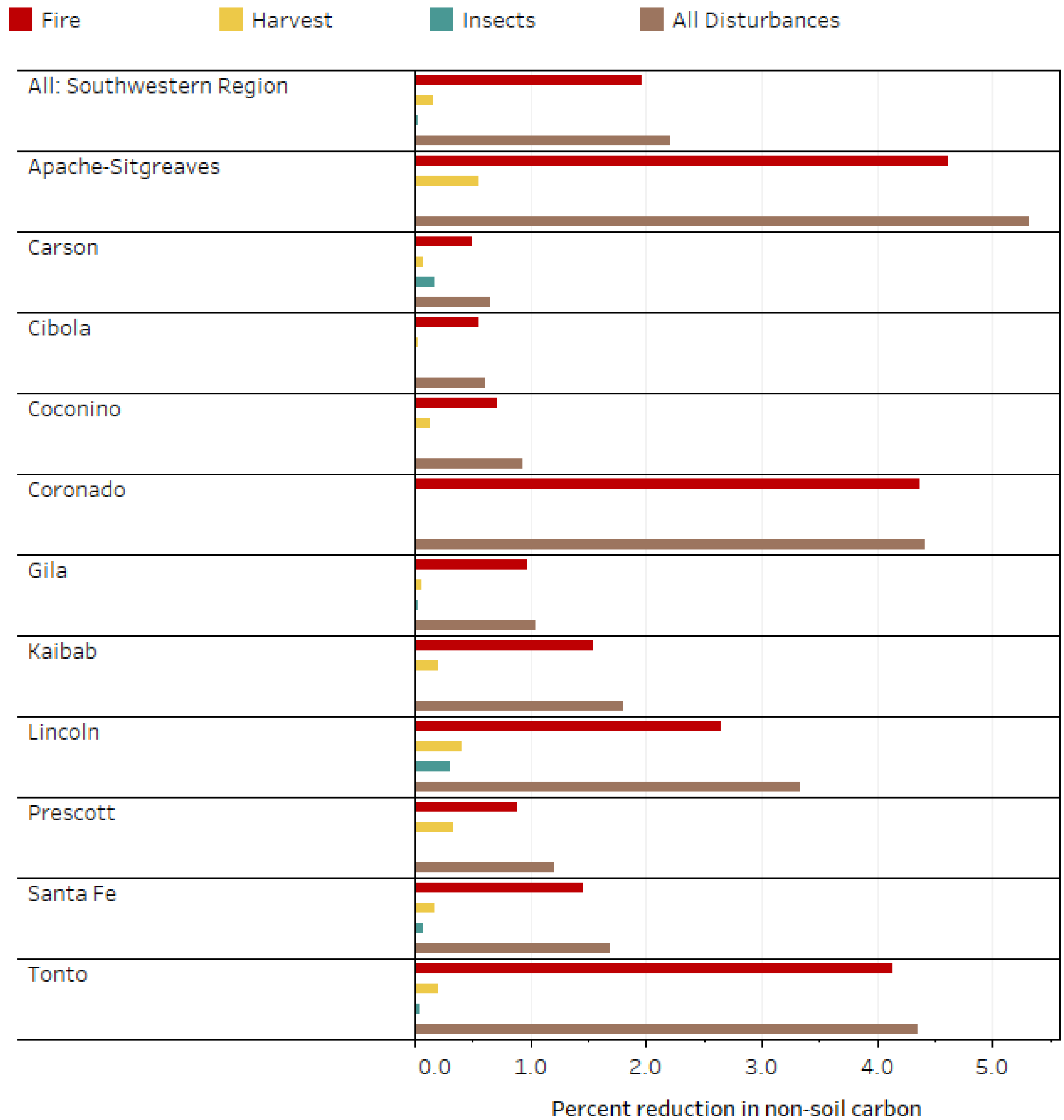


Figure 10. Impacts to carbon stores on each National Forest of the region between 1990 and 2011 relative to a hypothetical baseline with no disturbance, as estimated using ForCaMF and CCT.

Carbon in Harvested Wood Products

Although harvest transfers carbon out of forested ecosystems most of that carbon is not lost or emitted directly to the atmosphere, sometimes being stored in wood products for a variable duration depending on the commodity produced. Wood products can be used in place of other more emission intensive materials like steel or concrete, and wood-based energy can displace fossil fuel energy and result in a substitution effect (Gustavsson et al. 2006, Lippke et al. 2011). Much of the harvested carbon that is initially transferred out of the forest can also be recovered with time as the affected area regrows.

Carbon accounting for harvested wood products (HWP) contained in the Baseline Report was conducted by incorporating data on harvests on national forests documented in cut-and-sold reports within a production accounting system (Smith et al. 2006, Butler et al. 2014). This approach tracks the entire cycle of carbon, from harvest to timber products to primary wood products to disposal. As more commodities are produced and remain in use, the amount of carbon stored in products increases. As more products are discarded, the carbon stored in solid waste disposal sites (landfills, dumps) increases. Products in solid waste disposal sites may continue to store carbon for many decades.

In National Forests in the Southwestern Region harvest levels have remained low relative to other regions in the US. An upward trend of timber harvesting starting in the 1940s and continuing through the 1960s caused a steady increase in carbon storage in HWP. Timber harvesting declined through the 1970s and 1980s but peaked in the 1990s. Storage in products and landfills peaked at about 9.7Tg carbon in 1994. However, because of a significant decline in timber harvesting in the late 1990s and early 2000s (to 1930s levels) carbon accumulation in products in use began to decrease. In the Southwest the contribution of National Forest timber harvests to the HWP carbon pool is less than the decay of retired products, causing a net decrease in product-sector carbon stocks. In 2013 the carbon stored in HWP was equivalent to approximately 1.6% of total forest carbon storage associated with National Forests.

Impacts of Disturbance on Carbon Stocks and Fluxes

The Disturbance Report builds on estimates in the Baseline Report by supplementing high-resolution, manually verified, annual disturbance data from Landsat satellite imagery (Healey et al. 2018). Landsat imagery was used to detect land cover changes due to disturbances including fires, harvests, and insects. The resulting disturbance maps indicate that fire has been the dominant disturbance type from 1990 to 2011 in terms of the total percentage of forested area disturbed over the period. However, according to satellite imagery fire affected a relatively small area of the forest during this time. In most years fire affected less than one percent of the total forested area. The percentage of Southwest forests forest burned annually has increased over the same time and, although wildfires varied in frequency and severity, they generally removed less than 50 percent of the canopy cover (magnitude).

The Forest Carbon Management Framework (ForCaMF) incorporates Landsat disturbance maps along with FIA data in Forest Vegetation Simulator (FVS) modeling (Crookston and Dixon 2005). The FVS is used to develop regionally representative carbon accumulation functions for each combination of forest type, initial carbon density, and disturbance type and severity (including undisturbed) (Raymond et al. 2015). The ForCaMF model then compares the undisturbed scenario with the carbon dynamics associated with the historical disturbances to estimate how much more carbon would be on each National Forest if the disturbances and harvests during 1990-2011 had not occurred. ForCaMF simulates the effects of disturbance and management only on non-soil carbon stocks (i.e., vegetation, dead wood, forest floor). Across all National Forests, fire has been the most significant disturbance affecting carbon storage since 1990, causing non-soil ecosystem carbon stocks to be two percent lower by 2011. Timber harvest accounted for only a loss of 0.2 percent of non-soil carbon stocks in the region.

After a forested area is harvested it will likely regrow and recover the carbon removed from the ecosystem in the harvest in most instances. However, several decades may be needed to recover the carbon removed depending on the type of the harvest (e.g., clear-cut versus partial cut) as well as the conditions prior the harvest (e.g., forest type and amount of carbon) (Raymond et al., 2015) not to mention climate warming and decreases in overall forest extent. The ForCaMF model does not track carbon stored in harvested wood after it leaves the forest ecosystem. In some cases, removing carbon from forests for human use can result in lower net contributions of GHGs to the atmosphere than if the forest was not managed when accounting for the carbon stored in wood products, substitution effects, and forest regrowth (Lippke et al. 2011, McKinley et al. 2011, Skog et al. 2014, Dugan et al. 2018). Therefore, the IPCC recognizes wood as a renewable resource that can provide a mitigation benefit to climate change (IPCC 2000). ForCaMF helps to identify the greatest impacts to carbon storage and puts those effects into perspective. Factors such as stand age, drought, and climate may affect overall carbon change in ways that are independent of disturbance impacts. The purpose of the InTEC model is to reconcile recent disturbance impacts with those of other factors.

Impacts of Forest Aging

InTEC models the collective effects of forest disturbances and management, aging, mortality, and subsequent regrowth on carbon stocks and uses inventory-derived maps of stand age, Landsat-derived disturbance maps and equations describing the relationship between net primary productivity (NPP) and stand age. Stand age serves as a proxy for past disturbances and management activities (Pan et al. 2011b). In the model, when a forested stand is disturbed by a severe, stand-replacing event, the age of the stand resets to zero and the forest begins to regrow. Thus, peaks of stand establishment can indicate stand-replacing disturbance events that subsequently promoted regeneration. Example outputs are shown in Figure 11 with carbon estimates for the Cibola NF 1950 to 2011 and the relative impacts of fire and harvest.

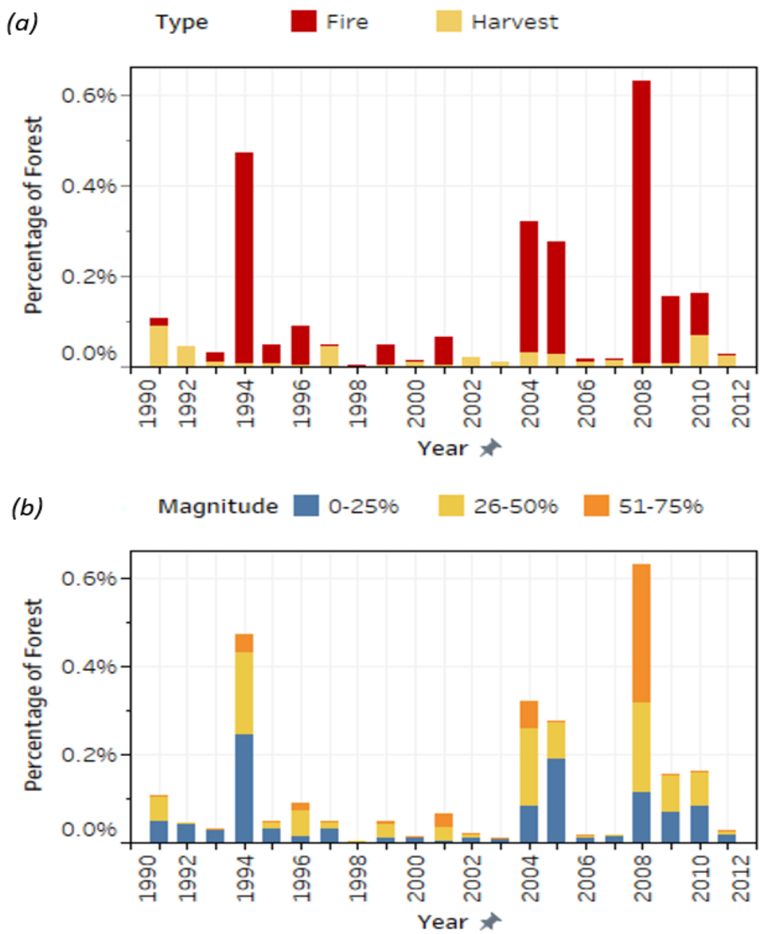


Figure 11. Percentage of forested areas disturbed from 1990 to 2011 on the Cibola NF (a) by fire and harvest and (b) the magnitude of disturbance according to change in canopy cover estimated using annual disturbance maps derived from Landsat satellite imagery.

Forest and woodland stands regrow and recover at different rates depending on forest type and site conditions. Forests are generally most productive when they are young to middle age, then productivity peaks and declines or stabilizes as the forest canopy closes and as the stand experiences increased respiration and mortality of older trees (Pregitzer and Euskirchen 2004, He et al. 2012). Stand establishment for woodlands of the region was relatively stable in the 20th century and represents a primary source of fuelwood. Ponderosa pine, the most common timber species, has had elevated establishment coinciding with the onset of fire suppression and historical timber harvest. In this time InTEC modeling and other sources indicate a steady accumulation of carbon through the mid-1960s because of regrowth following disturbances and heightened productivity of the young to middle-aged forests. As stand establishment has since declined and more stands reached slower growth stages around the 1970s the rate of carbon accumulation has declined overall.

Rangeland Carbon

Rangeland ERUs (shrubland, grassland, Great Plains types) make up about 70% of Arizona and New Mexico and about 25% of Forest Service lands. The majority of these lands, in addition to the majority of forested ERUs, are grazed by livestock producers. Most of the carbon in non-forest systems is found belowground in soils and roots (Derner and Schuman 2007, McKinley and Blair 2008, Janowiak et al. 2017). By contrast, forests typically store just about one-half of the total carbon belowground (Domke et al. 2017). Soils generally provide a stable ecosystem carbon pool relative to other ecosystem carbon pools.

There are several drivers that can cause rangelands to gain or lose carbon. Many rangelands are highly influenced by fire and grazing, which temporarily remove above ground vegetation (Knapp et al. 1998, Van Auken 2009). For example, altered wildfire regimes caused by fire suppression, overgrazing, and other factors is implicated in allowing many mesic and semi-arid grasslands in the US to convert to shrublands (Van Auken 2009). Replacement of grassland with woody plants generally tends to increase total ecosystem carbon storage (McKinley and Blair 2008, Li et al. 2016, Abdallah et al. 2020). Conversely, some invasive species, such as *Bromus tectorum*, can reduce carbon in shrublands by propagating more intense fire that cause mortality of co-occurring woody species (Bradley et al. 2006, Koteen et al. 2011). The extent to which these opposing factors influence carbon dynamics in rangelands is not well understood.

The greatest lasting influence in rangeland ecosystem carbon stocks is land use and landcover change. For example, it is generally assumed that federal grassland areas have negligible changes in carbon due to limited land use and management change (EPA 2019). Because soil carbon in rangelands is generally stable, substantial changes are typically a result of dramatic changes in land use or vegetation cover that persist indefinitely. For example, there can be substantial losses of soil carbon where rangelands have been converted to agricultural use (Derner and Schuman 2007). Like forests, managing the health of rangelands and avoiding land use and land cover change are key concerns for maintaining carbon stocks. Today, land-use change is less likely on public lands where there is managed grazing so that land use-based conversion of rangelands is concentrated on private lands and driven mostly by development.

Grazing has long played an important role in plant composition and nutrient cycling in many rangeland ecosystems (Galbraith and Anderson 1971, Knapp et al. 1999). Large grazing ungulates, including domesticated livestock and bison, produce a variety of greenhouse gas (GHG) emissions. Livestock and wild ruminates produce methane from enteric fermentation, resulting from their digestive process. Nitrous oxide can be produced as a byproduct from soil microbial processes that chemically transform nitrogen in animal waste. The Environmental Protection Agency (2019) estimates that about 47 percent of the total GHG emissions in the agricultural sector are attributed to livestock. In turn, the agricultural sector contributes to about nine percent of total GHG emissions in the US. The USDA's National Agricultural Statistics Service estimated in January 2019 that the United States had about 94.8 million cattle (NASS 2019).

Future Carbon Conditions and Impacts

Carbon assessment provides an understanding of how various factors may impact carbon storage now and into the future. Most forests on federal lands of the Southwest are middle-aged and older (80-400 years) with a minority of young stands that are often concentrated in wildfire areas. If forests continue this aging trajectory, more stands will reach a slower growth stage in coming years and decades, so that the *rate* of carbon accumulation declines though the standing carbon pool remains substantial. Figure 12 shows example yield curves for different forest types and how they can indicate when biomass carbon stocks approach maximum levels. Note that when the annual flux is still positive, that total ecosystem carbon can continue to increase as dead organic matter and soil carbon stocks accumulate (Luyssaert et al. 2008). Furthermore, while past and present forest aging trends can inform future conditions, the applicability may be limited, because potential changes in management activities or disturbances could affect future stand age and forest growth rates.

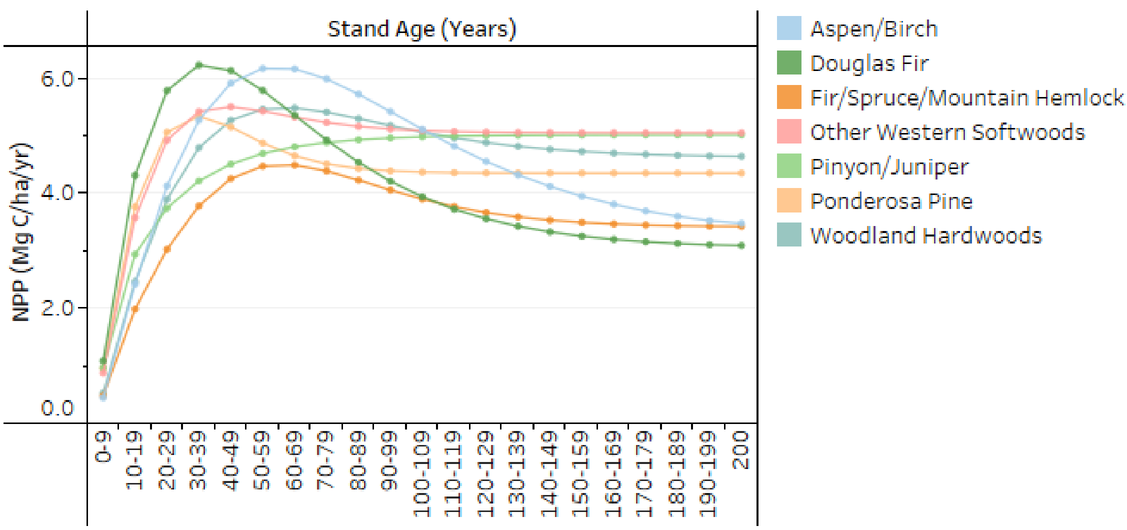


Figure 12. Curves of net primary productivity (y-axis) by stand age (x-axis) for forest types on the Cibola NF, derived from FIA data and He et al. 2012.

The RPA assessments provide regional projections of forest carbon trends based on a new modeling approach that uses FIA to base carbon stock estimates retrospectively to 1990 and forward to 2060 (Woodall et al. 2015, USDA Forest Service 2016). The RPA reference scenario assumes forested area will continue to expand at current rates until 2022, when it will begin to decline due to land use change. The approach may not fully account for carbon densities that are higher on National Forest lands than on private lands where land management objectives and practices differ.

For Rocky Mountain regions of the Forest Service, RPA projections indicate that the rate of carbon sequestration may decline starting in the 2020s mostly due to the loss of forested lands (land-use transfer) causing many forested areas to shift to a carbon source. The net sequestration rate, which shows the effects of aging, disturbance, and mortality, also indicates a small projected decline, further resulting in a shift to a carbon source. At global and national scales, changes in land use – especially the conversion of forests to non-forest land (deforestation) – have a substantial effect on carbon stocks (Pan et al. 2011a, Houghton et al. 2012). Converting forested lands to a non-forest use removes a large amount of carbon and inhibits future carbon sequestration. National Forests tend to experience low rates of land-use change so that forested land area is not expected to change substantially in the future by this driver. Assuming minimal influence from warming trends and catastrophic fire, small declines in the rate of net carbon sequestration are expected on National Forests through 2045 and then to remain relatively stable through 2060.

Aquatic, Riparian, and Watershed Resources

Introduction

Land managers are considering ongoing and potential effects of climate and drought on watersheds to coordinate responses for the protection of their water supply, aquatic and riparian biodiversity, and their other ecosystem services (Smith and Friggens 2017). Though climate vulnerability of these systems remains understudied (Mott Lacroix et al. 2017) the USDA Climate Hub, Forest Service, Rocky Mountain Research Station (RMRS) of the USDA Southwest Climate, the Forest Service, USGS, The Nature Conservancy (TNC), and other organizations have developed assessments, tools, and methods for evaluating the vulnerability of Southwest watersheds and their key components.

In general, increased minimum and maximum temperatures and a longer growing season translate to greater evaporative demand (Serrat-Capdevila et al. 2011). Climatic water deficit on exposed south aspects and steep canyon sidewalls are the most vulnerable to shift in evaporative demand. Earlier onset of snowmelt will reduce fuel moisture during fire season making a larger portion of the landscape flammable for longer periods of time (McKenzie et al. 2004). A longer burning window combined with regionally dry fuels will promote larger fires and increased annual area burned relative to modern recorded fire activity. This shift may be especially pronounced in mid- to high-elevation forested systems where fuels are abundant.

Mean monthly precipitation is projected to increase slightly by 2100 although projections for precipitation have high uncertainty compared to temperature projections and any increase in precipitation is expected to offset by warmer temperatures (Jones and Gutzler 2016, Williams et al. 2013). Future precipitation is anticipated to be more variable both spatially and temporally. Due to warming 20-30% loss of mean snow residence time though increases in precipitation could counter the effects on snowpack loss (Cayan et al. 2010). Shorter snowpack residence times and more variable timing and intensity of rainfall may translate to longer dry periods.

There is conjecture on the future susceptibility of flooding and hydrograph flashiness but, in general, increased probability of high intensity precipitation is likely to translate to more frequent high flows, with flood susceptibility more likely in mid to upper tributaries than in mainstems since larger drainages attenuate flood flows (Hurd et al. 1999, 2006). Given the likely monsoonal timing of these high intensity events it is unclear whether available channel capacity may limit the potential for flooding. Future streamflow estimates from Wenger et al. (2010) suggest a limited reduction in mean August flows by 2040 and a similar incremental reduction in August flows by late century. Stream temperatures overall are expected to increase modestly depending on location posing a problem for coldwater aquatic species in many watersheds (Hurd and Coonrod 2008).

Aquatic-Riparian Climate Change Vulnerability Assessment (ARCCVA)

The ARCCVA was a watershed-based approach to rate vulnerability according to inherent threats such as fire risk and according to factors directly related to 21st century climate forecasts such as stream flows and temperatures (Isaak et al. 2017, Wahlberg et al. 2022). This quantitative assessment is stratified on all 6th-level (HUC12) watersheds of Arizona, New Mexico, and the panhandles of Oklahoma and Texas that intersect Forest Service lands (Figure 13) and is of sufficient thematic detail to support natural resource policy and local prioritization, watershed assessment, monitoring systems, and effects analyses of landscape-scale projects. **The assessment was supported by existing data sources on over two dozen intrinsic and climate-related indicators of watershed condition, riparian and aquatic habitat, and the habitat of warm and coldwater fish. Ratings are provided for overall vulnerability (intrinsic plus climate-related risks) and for climate related risks alone (climate exposure)**. This work builds on methods established by Smith and Friggens (2017) for the Four Corners region of the US, with a modified spatial extent and additional indicators brought into account for other risk factors. The ARCCVA is available for download (www.fs.usda.gov/detailfull/r3/landmanagement/gis).

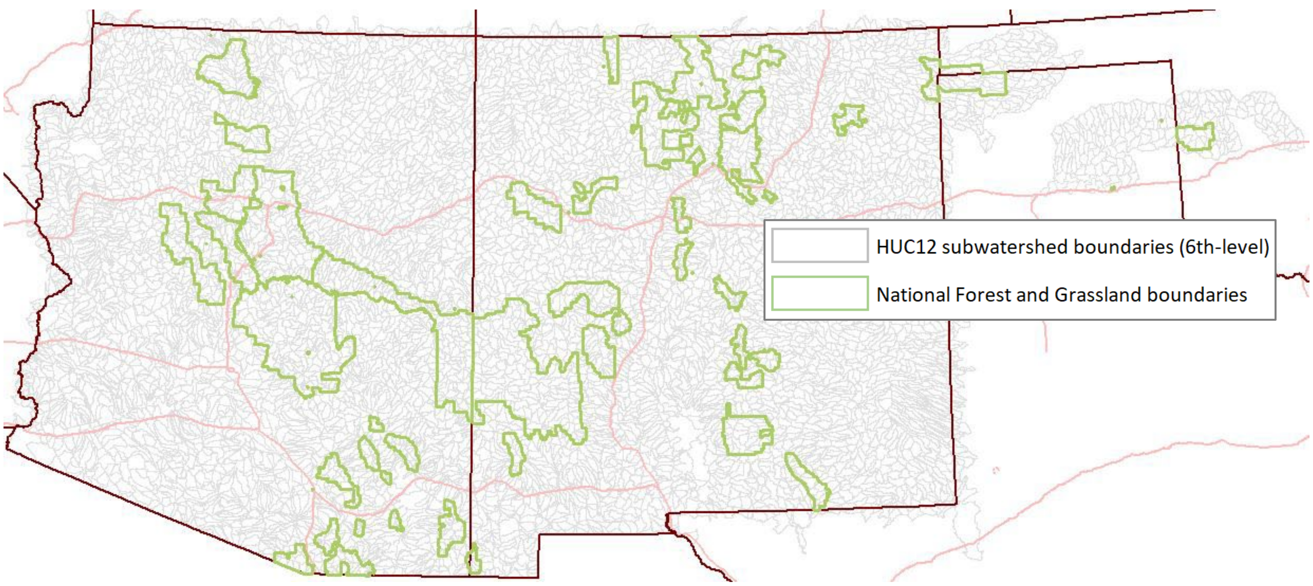


Figure 13. The distribution of watersheds included in the ARCCVA for Arizona, New Mexico, Oklahoma, and Texas in relation to National Forests and Grasslands of the Southwestern Region (green boundaries).

Summary of ARCCVA Results

The vulnerability assessment is stratified by coldwater, intermediate (i.e., coldwater, non-perennial) and warmwater subwatersheds with and without perennial segments. Much of the stratification hinged on coldwater habitat criteria including temperature (≤ 17 °C) (Zeigler et al. 2013, Isaak 2016, US Fish and Wildlife Service 2021) and the presence of perennial stream segments as designated in the USGS National Hydrography Dataset (NHD) or correspondence with the current distribution of coldwater fish populations. Only about 6% of watersheds in the region contain coldwater habitat (Table 5), likely a decline from characteristic pre-European levels. Another 15% are considered intermediate, those subwatersheds that may meet the coldwater threshold but are associated with intermittent or ephemeral stream flows. The remaining watersheds were categorized as either warmwater – perennial (2078%) or warmwater – non-perennial (59%) and then subclassified as perennial or non-perennial. The ARCCVA suggests that the majority (59%) of watersheds are moderately vulnerable to ongoing threats and contemporary climate trends (overall vulnerability) and that vulnerability is disproportionately higher in coldwater and intermediate watersheds. Not surprisingly, vulnerability averages much higher when looking only at future trends in climate (exposure) with over 70% of watersheds as high vulnerability and where exposure is disproportionately higher in warmwater watersheds.

Developers of the ARCCVA acknowledge that perennial springs, seeps, and smaller flowing stream segments may be present in some watersheds deemed non-perennial (Wahlberg et al. 2022). Where these features occur, they can be especially important ecologically (Chambers et al. 2013). The information regionally available at the time limited the consideration of some metrics that represent springs, seeps, and intermittent stream segments. Inventory data for some of these features is available on some extents from the online database of the Springs Stewardship Institute (Springs Stewardship Institute; springstewardshipinstitute.org). Protection and restoration needs can be identified using this information in combination with landscape-scale vulnerability assessments (Grand Canyon Trust 2016).

Table 5. The number and percentage of subwatersheds (HUC12) for ARCCVA ratings for (a & b) overall vulnerability and for (c & d) vulnerability specific to climate change (exposure only).

(a) Overall Vulnerability - Number of watersheds

Vulnerability Rating	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater – Perennial	Warmwater – Non-Perennial	Total
Low	75	107	236	1,511	1,929
Moderate	257	840	633	2,248	3,978
High	77	89	496	137	799
Total	409 (6%)	1,036 (15%)	1,365 (20%)	3,896 (59%)	6,706

(b) Overall Vulnerability - Percent of watersheds

Vulnerability Rating	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater – Perennial	Warmwater – Non-Perennial	Total
Low	18%	10%	17%	39%	29%
Moderate	63%	81%	47%	58%	59%
High	19%	9%	36%	3%	12%

(c) Climate Change Vulnerability - Number of watersheds

Vulnerability (exposure)	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater – Perennial	Warmwater – Non-Perennial	Total
Low	79	33	188	30	330
Moderate	112	464	344	482	1,402
High	218	539	832	3,383	4,972
Not Analyzed	0	0	1	1	2
Total	409 (6%)	1,036 (15%)	1,365 (20%)	3,896 (59%)	6,706

(d) Climate Change Vulnerability - Percent of watersheds

Vulnerability (exposure)	Coldwater (perennial)	Intermediate (non-perennial)	Warmwater – Perennial	Warmwater – Non-Perennial	Total
Low	19%	3%	14%	1%	5%
Moderate	27%	45%	25%	12%	21%
High	53%	52%	61%	87%	74%
Not Analyzed	0%	0%	<1%	<1%	<1%

Applying ARCCVA in the Climate Adaptation Strategy

Ongoing and projected climate trends in the Southwest indicate greater aridity with increasingly dry surface conditions and diminished stream flow (Gutzler 2013). With the majority of watersheds subject to decline in function and with limited management capacity it is important to consider the location and magnitude of vulnerability as an additional line of evidence in setting priorities and selecting adaptation options and tactics. Assessment information from ARCCVA and other resources such as Smith and Friggens (2017) are needed to inform management objectives in Step 3 and to select adaptation options in Step 4.

Active management may be **more successful in watersheds of low or moderate vulnerability**. Declining stream flows and warmer water temperatures in many watersheds suggest that limited restoration dollars may be better spent where vulnerability is lower. **Areas of high vulnerability may nevertheless warrant Resistance measures where there are regulatory requirements or high-value elements such as habitat for Federally listed species, tribal interests, particular recreation areas, neighboring environmental justice communities, or other values of immediate need of preservation.** As always, other lines of evidence are encouraged to corroborate ARCCVA findings or other assessments when evaluating the vulnerability of a watershed or its features and include local knowledge, independent observational data, or other scientific information sources.

Impacts to Aquatic, Riparian, and Watershed Resources and Considerations for Climate Adaptation

Below are descriptions of specific impacts expected for aquatic, riparian, and watershed resources of the Southwest. This information was drawn from ARCCVA, research, and other science references that have information on intrinsic vulnerability along with forecast effects of 21st-century climate. This information can be combined with additional evidence including local knowledge to minimize uncertainty for managers faced with the difficult task of balancing objectives and limited time and resources when determining an optimal mix of adaptation options and tactics for the sustenance of ecosystem services.

Increased aridity; Climate forecasting for the region indicates pronounced trends in the surface water budget towards aridity from decreased precipitation and increased evaporation associated with warmer temperatures (Gutzler 2013). Even in the eventuality of increased precipitation, warmer temperatures are expected to offset additional water inputs for a net increase in arid conditions (Hurd and Coonrod 2008). In mountainous areas snowpack is expected to decline with the higher winter temperatures and less winter precipitation (Brown and Mote 2009). **Consideration: The ARCCVA and other science information (e.g., Streamflow Metrics; Wenger et al. 2010; Streamflow in a Changing Climate StoryMap) provide a sense of location and magnitude of change anticipated with 21st-century climate trends to inform the selection of RRT and specific tactics.** In many valley bottom zones, **beaver dam analogs and introductions may provide a strong countervailing influence upon regional aridity for local moisture retention** and the sustenance of services (Bainbridge 2018 Goldfarb 2018).

Snowpack; Snowpack in forested mountains of the Southwest is a critical resource for ecosystem productivity, stream flows, and other services (Broxton et al. 2015). Research on springs habitat in the Zuni Mountains of western New Mexico show that springs are primarily recharged from snowmelt (Frus et al. 2020). Climate trends and other stressors and disturbances are rapidly changing vegetation structure on the landscape. Changes in hydrology following wildfire depend on vegetation structure, climate, and topography (Goeking and Tarboton 2020). Several studies have shown the control that forest structure has over snow depth and subsequent snow-water availability (e.g., Moeser 2015, Hojatimalekshah et al. 2023). **Consideration: Observations and model results from Broxton et al. (2015) suggest that open**

canopy interspaces that are less than about 15m from nearby tree canopies average greater snow accumulation than open areas at greater distances. These intermediate zones represent an optimization for snow accumulation and the disappearance of snow mostly as a consequence of incoming solar radiation (Veatch et al. 2009). These zones have more snow accumulation and snow-water availability than open areas farther away, and considerably more snow-water availability than areas directly beneath tree canopies. The disparity in snowpack between tree interspaces and areas beneath canopies averages less in the case of deciduous tree components (Schneider et al. 2019).

Streamflow; Predictions for total annual streamflow suggest an 8-29% reduction by late 21st century in portions of the Southwest (Hurd and Coonrod 2008). Spring runoff will be particularly reduced relative to conditions under historical climate, impacting downstream irrigation and other services afforded by public lands. Projected spring flood pulses are expected to be earlier in the year and weaker because of the diminished snowpack in mountainous areas. In an unpublished analysis of long-term stream gauge records (Triepke *unpublished*) historical and contemporary stream flows were compared in three reference watersheds of the Southwest – Upper Verde, Upper Gila, and Upper Pecos rivers. While stream flow patterns for the Pecos in northern New Mexico are relatively static, stream data from the Upper Verde and Upper Gila show decreased overall flows along with pronounced variability as evidenced by increases in the number of high-flow and low-flow days. There is also some indication of non-linear evaporative losses expected with warmer temperatures to corroborate Hurd and Coonrod. The analysis of seasonality shows that winter-spring runoff has been occurring earlier in the year, while monsoon rains in the summer are arriving later than expected as predicted for North America (Cook and Seager 2013**). Consideration: The ARCCVA and other resources for the region (e.g., Streamflow Metrics; Wenger et al. 2010; Streamflow in a Changing Climate StoryMap) provide a sense of location and magnitude of ongoing and predicted changes in stream flows to inform the selection of RRT and adaptation tactics.** In many valley bottom areas, beaver dams and analogs may provide a strong countermeasure to regional trends in aridity for the sustenance of ecosystem services (Bainbridge 2018).

Stream temperatures and coldwater habitat; Climate patterns are a major factor in determining the distribution of many aquatic species. Ongoing and projected warming trends are expected to modify both seasonal and decadal variability in precipitation, decrease snowpacks, and increase evaporative losses in the Southwest (Gutzler 2013). Associated changes include relatively rapid increases in stream temperatures and diminished stream flows that especially impact coldwater aquatic biota including trout (Kennedy et al. 2009). Pronounced impacts are anticipated for such coldwater species due to their limited dispersal capability, small ranges, sensitivity to higher stream temperatures, and low adaptive capacity. Research by Kennedy et al. (2009) suggests that the majority of habitat for Gila trout will be lost in the coming decades as a consequence of climate trends and increased aridity. Effects of nearby wildfires and other factors are likely to exacerbate habitat trends and population declines. **Consideration: Management aimed at restoration in reaches of low vulnerability (refugia) may be the best use of limited resources and represent greater likelihood of success. Any upstream increase in habitat extent as species envelopes shift upward in elevation is likely to be muted by other factors including reduced stream flows.** While ARCCVA provides a general perspective on overall vulnerability patterns it is less suited for individual species or populations that warrant more precise assessment, research, and monitoring. The USDA Forest Service StoryMap, Streamflow in a Changing Climate, offers data and reporting on past and projected streamflow and temperature conditions as a more appropriate tool for assessing habitat trends and identifying potential refugia (https://storymaps.arcgis.com/stories/6a6be7d624db41638a24b659305af522).

Riparian overstory; In riparian forests and woodlands, invasive species that are tolerant of increased salinity and aridity are likely to be favored under current warming trends, regulated streams, and dewatering (Kerns et al. 2009). Invasive overstory constituents include salt cedar (Tamarix spp.) and Russian olive.

Socioeconomic Resources

Introduction

Socioeconomic resources in the arid Southwest are increasingly vulnerable to higher temperatures and greater climate variability linked to increased drought probability, decreased snowpack, and greater evapotranspiration (Gutzler 2013). These changes in turn lead to diminished drier surface conditions and decreased stream flows. Not all people and people and communities will be equally affected and those communities that are more sensitive to change and lack adaptive capacity will be at greater risk to a changing climate (Borchers et al. 2021). Ongoing and expected climate trends, hydrologic responses, and economic consequences demand thoughtful climate adaptation to optimize for long-term socioeconomic and ecological sustainability. Urban and industrial demands will shift water resources away from agriculture to the further detriment of ecosystems in upstream watersheds (Hurd and Coonrod 2008). While total annual economic losses are estimated at over $300 million, both economic and natural resource losses will be significantly higher and do not fully account for the spectrum of agriculture and ecosystem services. Socioeconomic vulnerability hinges on ecosystem services and changes related to climate, on community risk and resource dependence, and on the capacity to adapt.

Regional Socioeconomic Vulnerability Assessment (SEVA)

The Regional Socioeconomic Vulnerability Assessment (SEVA) was completed in two phases, first for all National Forests and Ranger Districts (Hand et al. 2018) and then for all-lands across Arizona and New Mexico (Borchers et al. 2021). Both phases were informed by socioeconomic data available for counties and census tracts with the first phase also being informed by additional resource-specific information and proximity such as distance between dependent ranch operations and public lands. While both assessments resulted in vulnerability ratings and tabular quantitative results, the all-lands SEVA of Borchers et al. (2021) also includes spatial datasets available for download (www.fs.usda.gov/detailfull/r3/landmanagement/gis). Both assessments are of sufficient thematic and spatial detail to support natural resource policy and management prioritization, watershed assessment, administrative unit monitoring systems, and effects analyses of landscape-scale projects. The assessments represent sectors of forest products, rangeland grazing, recreation, and other socioeconomic dependencies associated with natural resources. **While the all-lands assessment of the second SEVA phase represents all counties and census tracts, the assessment was not stratified by tribal lands or any other landowner category**.

The SEVA was conducted based on climate-related exposure, sensitivity, and adaptive capacity of individual communities. *Sensitivity* represents the economic dependence of communities as measured through contributions of local ecosystem services to employment and income from market transactions. The all-lands SEVA applied a ‘location quotient’ to gauge the relative importance of natural resources to local economies. *Exposure* is the risk to selected ecosystem services provisions due to projected climate change as inferred by the likelihood of late 21st-century vegetation change and disturbance risk. *Adaptive capacity* was represented by socioeconomic data that infer the ability of a human community to cope with climate-related change. The flow of ecosystem services derived from natural lands are changing in the

Southwest and communities are vulnerable under their particular circumstances of exposure or sensitivity and their capacity to adapt. The all-lands SEVA included a social vulnerability index (SVI) where higher values indicate greater vulnerability and lower adaptive capacity based on specific socioeconomic proportions within counties and census tracts:

- Unemployment
- Income category
- Below poverty
- No high school diploma
- Aged 65 or older
- Aged 17 or younger
- Civilian with a disability
- Single-parent households
- Minority
- Speak English "less than well"
- Multi-unit structures
- Mobile homes
- Crowding
- No vehicle
- Group quarters

Initial SEVA, Forest Service Lands Only

Reporting units of the initial SEVA were organized by National Forests and Grasslands of Arizona, New Mexico, and the panhandles of Oklahoma and Texas (Hand et al. 2018) and then by individual Ranger Districts within each Forest (Hand et al. 2018; www.fs.usda.gov/treesearch/pubs/56851). The vulnerability of these lands is uneven due to varying circumstances of exposure, sensitivity, and the adaptive capacity of people in and near the administrative units. Box 2 shows example reporting based on the Apache-Sitgreaves NFs.

Box 2

Summary of Socioeconomic Vulnerability: Apache-Sitgreaves National Forest

Summary

Overall vulnerability may be low to moderate for Apache-Sitgreaves National Forest due to relatively moderate exposure, low sensitivity, and greater adaptive capacity (Hand et al. 2018). But within-Forest vulnerability patterns suggest that some areas could experience greater socioeconomic pressures. These would likely be areas dependent on ecosystem services from the Black Mesa and Lakeside districts in the eastern portion of the Forest and those communities with limited economic connections to larger metropolitan areas including Maricopa County and therefore lower adaptive capacity. The Alpine and Springerville Districts tend to have relatively low exposure while the Black Mesa and Lakeside Districts both rank in the upper quartiles for exposure. Primary sources of high exposure for these Ranger Districts are forecast vegetation changes, intersecting stressors, and the exposure of timber resources (figures 14-19 and Table 6).

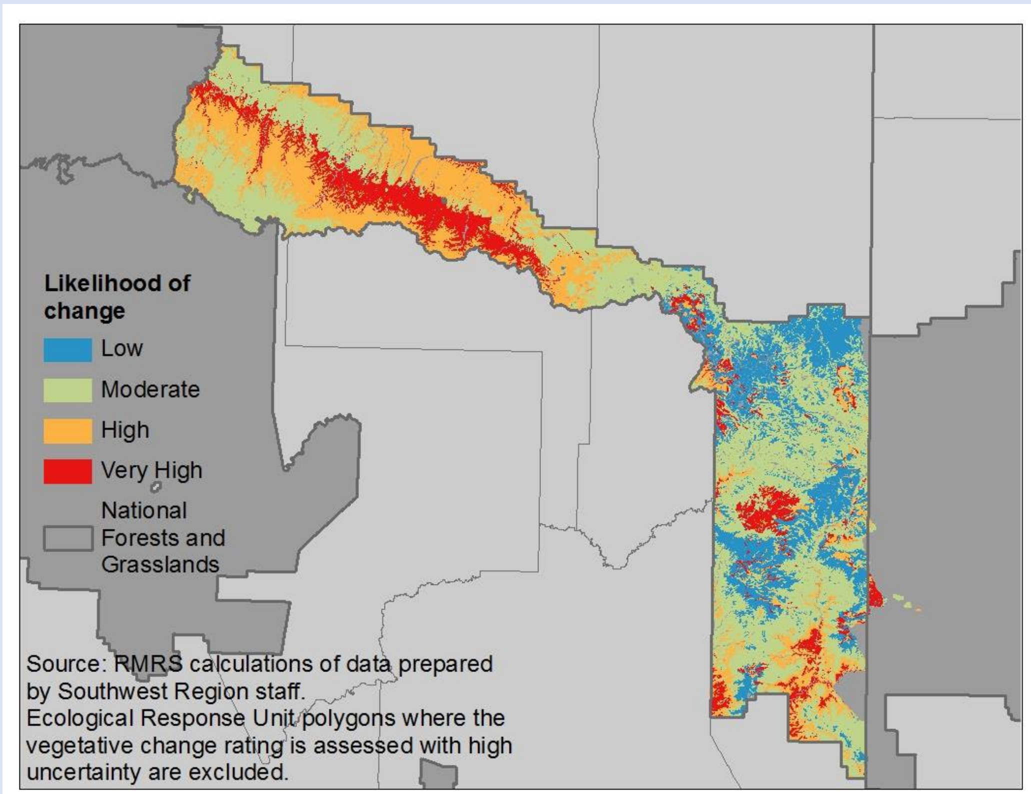


Figure 14. Ratings of likelihood of vegetation change due to climate exposure for the Apache-Sitgreaves NFs where orange and red areas indicate conditions likely to fall outside of characteristic climate and where green and blue areas are more likely to retain characteristic climate conditions.

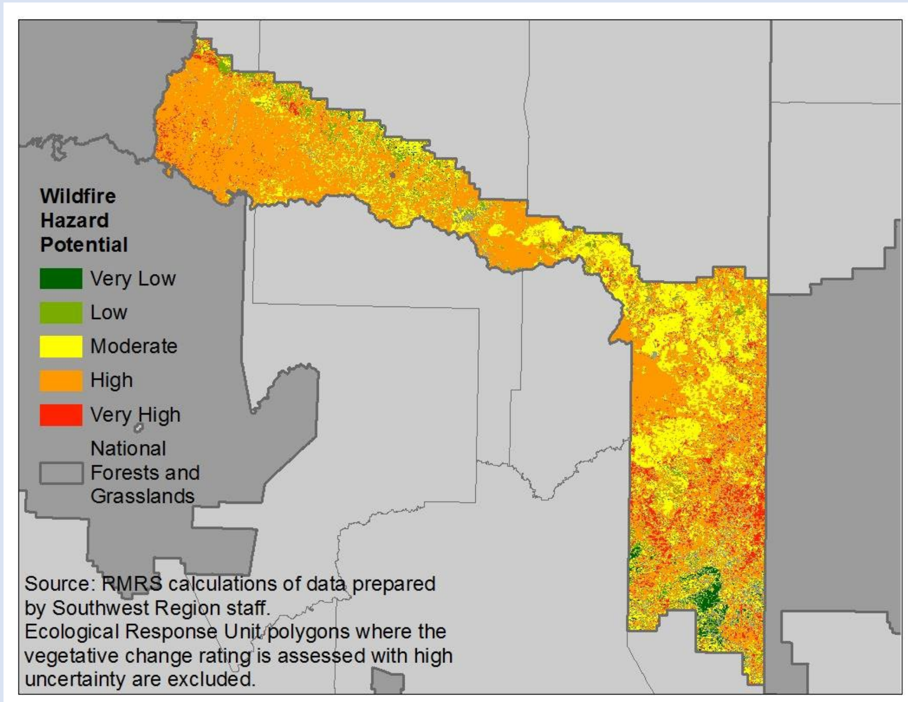


Figure 15. Current wildfire hazard potential for the Apache-Sitgreaves NFs on a scale of very low to very high where areas of higher ratings are more likely to experience extreme fire behavior including torching and crowning under average fire weather conditions.

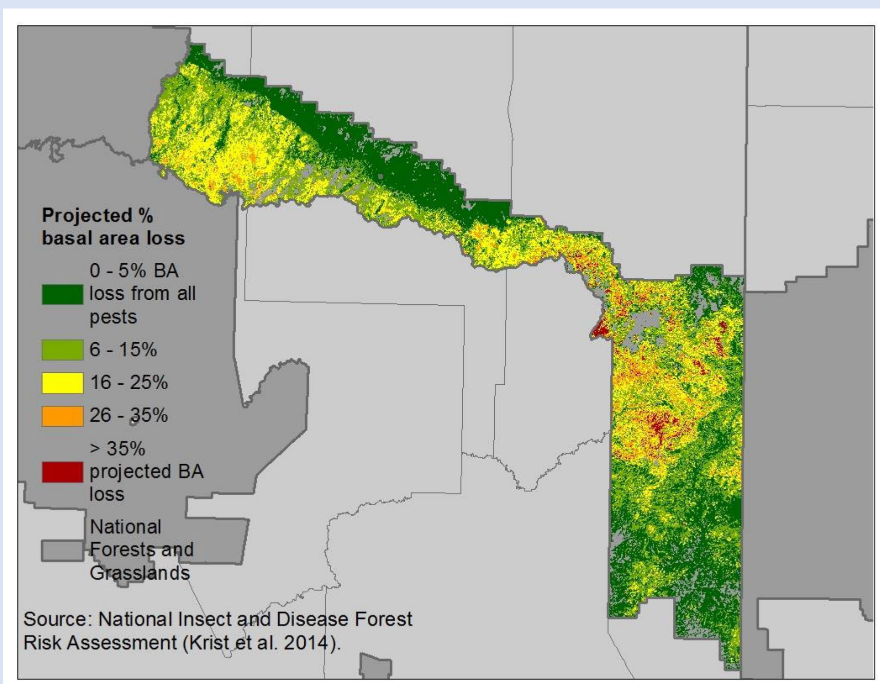


Figure 16. National insect and disease assessment in combination with likelihood of vegetation change showing projected percent basal area loss over the next 15 years, where each pixel represents 240m^2 and areas shaded orange or red are uncharacteristic tree mortality (Potter and Conkling 2015).

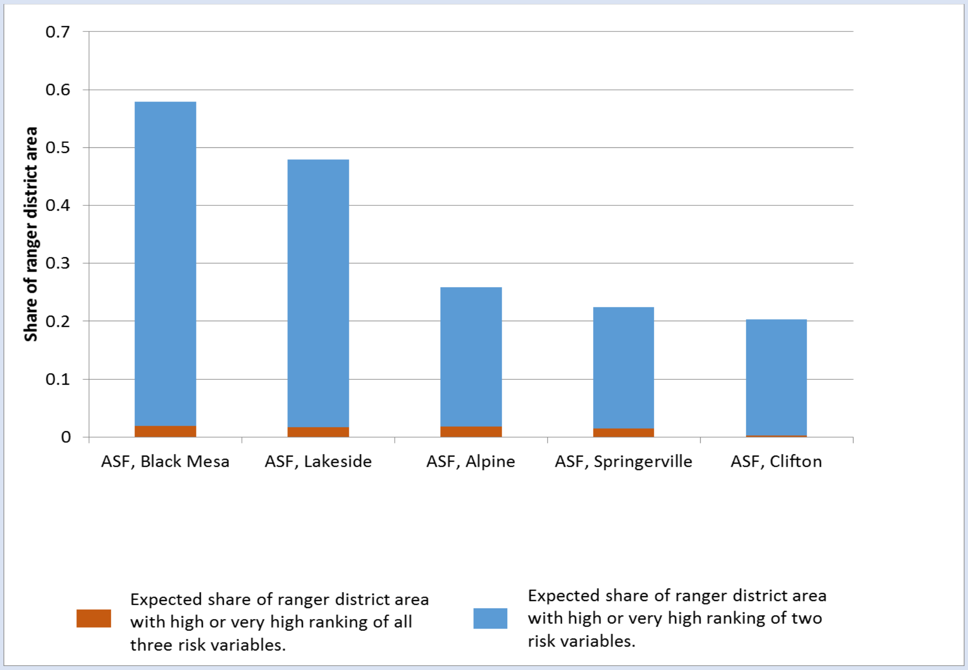


Figure 17. Expected proportion of each Ranger District exposed to likelihood of vegetation change in combination with wildfire hazard potential and insect and disease mortality calculated as all stressors (orange bars) or two of the three stressors (blue bars).

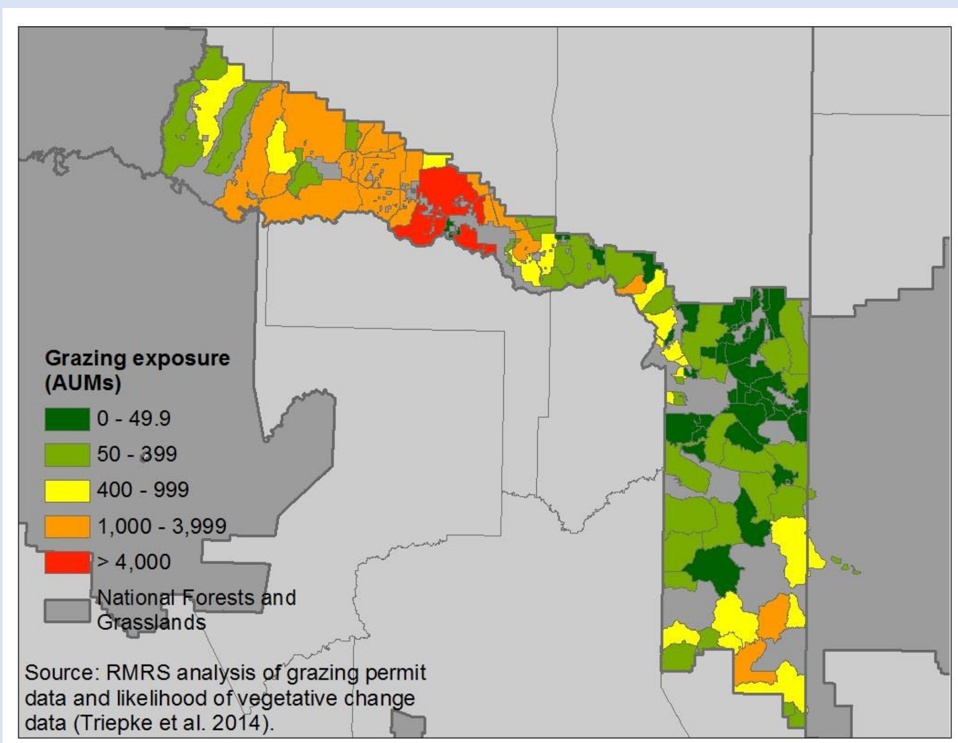


Figure 18. Exposure of grazing allotment use in *animal unit months* (AUMs) to the likelihood of vegetation change. Exposure values are calculated as the product of AUMs and the proportion of land at high or very-high likelihood of vegetation change, where larger values (in orange and red) indicate greater overall exposure.

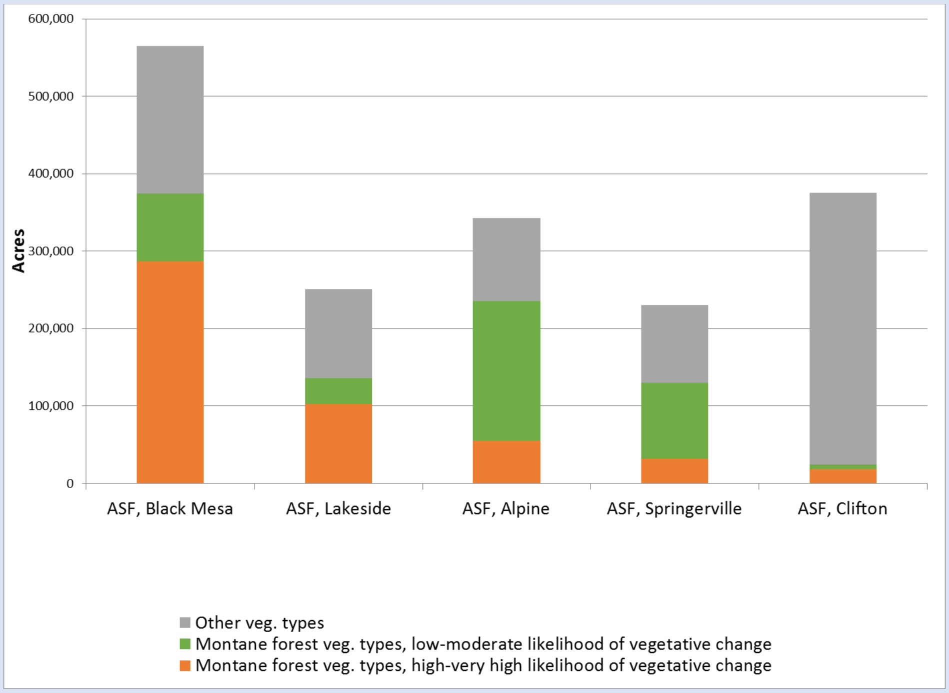


Figure 19. Exposure of timber vegetation types where the height of bars indicates total acres in montane forest that are at either high or very high risk of vegetation change (orange bars) or at low or moderate risk of vegetation change (green bars) and the grey bars indicate the area likely in non-timber production.

Table 6: Annual recreation visits to the Apache-Sitgreaves NFs by climate-sensitive recreation activity and origin where warm-weather recreation predominates followed by wildlife-related recreation by local visitors.

Non-Local Origin Visits

Activity Category	Days	Overnight FS Site	Overnight Non-FS Site
Warm weather	49,661	167,607	74,492
Winter (not incl. downhill skiing)*	0	0	0
Wildlife	29,943	101,057	44,914
Gathering forest products	609	2,054	913
Water (not incl. fishing)	2,069	6,984	3,104

Local Origin Visits

Activity Category	Days	Overnight FS Site	Overnight Non-FS Site
Warm weather	310,383	12,415	6,208
Winter (not incl. downhill skiing)*	0	0	0
Wildlife	187,142	7,486	3,743
Gathering forest products	3,804	152	76
Water (not incl. fishing)	12,933	517	259

All-Lands SEVA

Reporting units of the all-lands SEVA are counties and census tracts of Arizona and New Mexico (Borchers et al. 2021; www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd620538.pdf). Though reporting is not specific to tribal lands or other ownerships, SEVA can be summarized to any ownership pattern where the scale of counties or census tracts applies. The vulnerability of these lands is uneven due to varying circumstances of exposure, sensitivity, and the adaptive capacity of people in and near public and tribal lands (Figure 20).

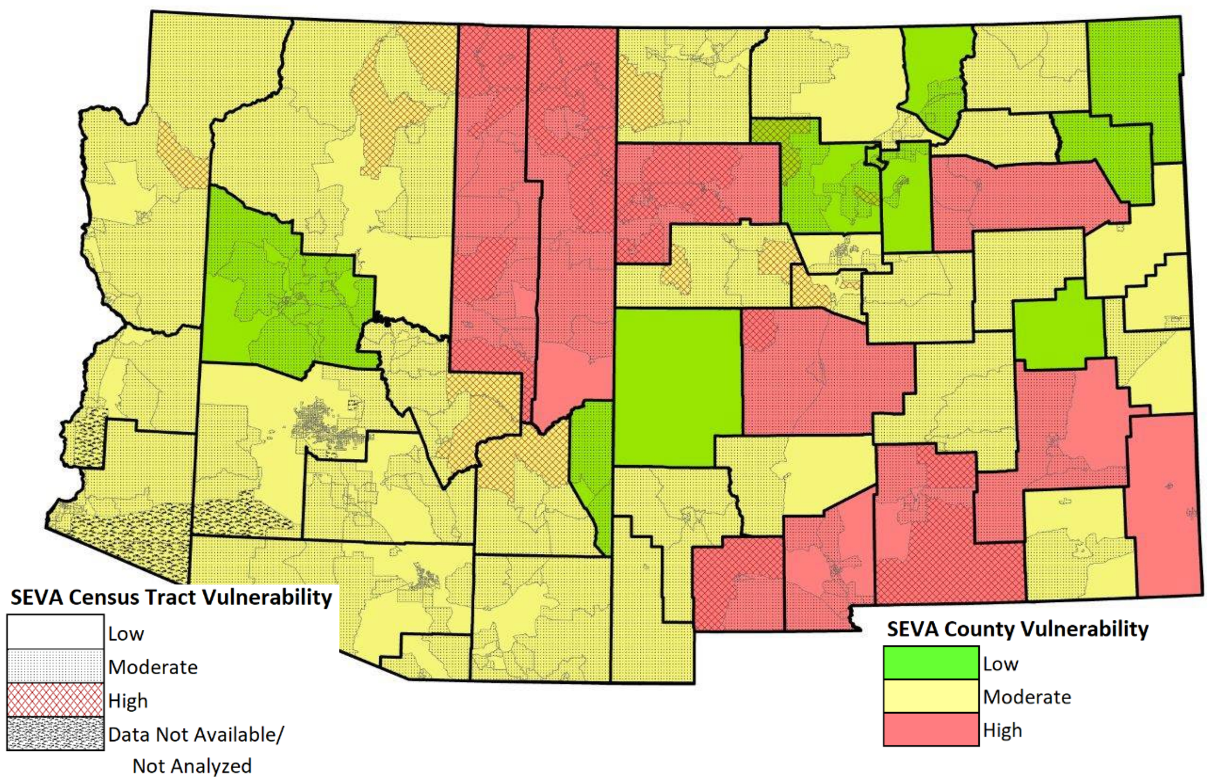


Figure 20. Overall county and census tract-level SEVA vulnerability ratings for Arizona and New Mexico.

Impacts to Socioeconomic Resources and Considerations for Climate Adaptation

Socioeconomic vulnerability is based on the interplay of community sensitivity and market dependence, climate exposure, and adaptive capacity expressed in vulnerability assessments. For now, guidance here is centered on principal socioeconomic sectors of forest goods and services, rangeland grazing, nature-based recreation, air quality, tribal values, and water supply (Table 7). The following chapter on identifying adaptation options (Workbook Step 4) includes adaption approaches and tactics specific to the needs and desires of Southwest tribes and includes an initial version of a Tribal Climate Adaptation Menu.

In many ways any climate adaptation focused on ecological integrity, watershed health, long-term carbon storage, and lowering fire risk will provide double service by benefitting local communities. For example, climate adaption for grassland ecosystems is likely to indirectly benefit the rangeland grazing sector and local producers. More **precise climate adaptation measures for socioeconomic resources or environmental justice are likely to be reflected in policy, land management planning prioritization,**

decision making, and through specific collaboratives that understand and respond to communities with heightened levels of sensitivity or climate exposure or with impaired adaptive capacity. Environmental justice involves special cases where policy and management activities have favored against nearby communities. And while those instances appear to be uncommon (Adams and Charnley 2020) when they do occur exceptional risk may be posed to environmental justice communities that also face issues of exposure, sensitivity, or adaptive capacity.

An understanding of impacts linked to ecosystem change can be helpful in identifying objectives and selecting adaptation options and tactics. Table 7 has a small but representative subset of impacts to consider when determining adaptation options and tactics for socioeconomic resources. Adaptation options are ideally aimed at Transition (preemptive or responsive) or at least at Resilience and continued delivery of provisioning services and protection of communities in the near term. The Resistance option is probably not relevant here unless asked for by the community. And unlike adaptation for natural resources, the assumption that success is more likely where there is low-moderate vulnerability does not hold: instead, adaptation measures and landscape prioritization may be far more warranted in communities of high socioeconomic vulnerability, especially where adaptive capacity can be leveraged. Oftentimes adaptation options do not align *categorically* between natural resources and human communities, as when Resistance measures for the protection of high-value elements such as cultural sites (Clark et al. 2022) may nevertheless aid active Transition of a vulnerable community.

Table 7. Likely impacts to some common ecosystem goods and services of Southwest landscapes (adapted from Hand et al. (2018)).

Nature-Based Recreation

Description	Potential Impacts	Scope of Beneficiaries
Site access and availability for on-site recreation opportunities	- Reduced snowpack for skiing - Vegetation changes to suitable habitat for game mammals and fish - Degradation or enhancement of sites due to wildfire	Benefits derived on-site, but could accrue to local and non-local beneficiaries
Viewsheds and landscape characteristics that hold aesthetic value that can be enjoyed off-site	- Changes in vegetation composition of land adjacent to private properties - Effects of wildfire on desirable viewsheds	Communities adjacent or within close proximate to natural landscapes

Tribal and Heritage Values

Description	Potential Impacts	Scope of Beneficiaries
Sites, species, and landscape characteristics that hold spiritual, cultural, or historical value	- Changes in the amount and extent of plant or animal habitat for cultural and spiritual uses - Damage to cultural sites from wildfire	Regional spiritual site users; residents within and outside the region with cultural and historical ties to landscapes within the region

Rangeland Grazing

Description	Potential Impacts	Scope of Beneficiaries
Forage availability and quality on landscapes suitable for grazing	- Changes in the amount or distribution of suitable forage - Incidence and severity of invasive plants	On-site use by local livestock operations

Forest Goods and Services

Description	Potential Impacts	Scope of Beneficiaries
Commercial timber and biomass, wood for personal use, food and forage for personal use	- Changes in range and extent of certain plant species - Increased bark beetle mortality; increased incidence and severity of wildfire	Wood product market participants and forest users, ranging from local to global
Fuel wood, food, and forage	- Changes in the amount and distribution of key plant species - Increased bark beetle mortality; increased incidence and severity of wildfire	Mostly residents within the region, particularly those in close proximity to forested landscapes
Forests as a carbon sink and carbon sequestration option	- Reduced biomass/carbon sequestration - Increased emissions from wildfire; loss of biomass due to bark beetle mortality	Global

Air Quality

Description	Potential Impacts	Scope of Beneficiaries
Forests as a source or sink for particulate emissions	Net increase in smoke from wildfires	Local and regional residents within regional airshed

Water Supply

Description	Potential Impacts	Scope of Beneficiaries
Municipal, agricultural, commercial, and in-stream uses	- Decreases in supply from reduced precipitation and increased temperatures - Decreases in water quantity or quality from increased incidence and severity of wildfires and erosion events	Within region; on-site; downstream users including across regions (e.g., Texas and Mexico)

Applying Vulnerability Assessments and Understanding Impacts

With much of the region subject to declines in the types and amounts of ecosystem services, it is important that the climate adaptation strategy consider vulnerability of affected communities relative to their exposure to change, sensitivity to changes in the flow of services, and in their inherent adaptive capacity to absorb change. Socioeconomic vulnerability assessments have become more consequential as a result of insufficient responses to global emissions (IPCC 2014), with the abundance of public lands in the Southwest, and with the strong dependence of many rural and tribal communities on natural resources. Although the SEVA does not include benefits and costs of specific planning and activities, the results are useful for prioritizing landscapes for management by the proximity of natural resources to affected communities for helping to identify adaption option and tactics, and as an objective means of integrating environmental justice with land management. Land management organizations have unique opportunities to consider socioeconomic vulnerability and advance climate adaptation for environmental justice and the continued provision of services.

With much of the landscape subject to stress and functional degradation, and with limited management capacity, it is important that climate adaptation strategy consider the magnitude of vulnerability as an additional line of evidence in setting priorities and selecting adaptation options and tactics. Climate vulnerability forecasts have become more consequential as potential strategy scenarios have narrowed due to insufficient responses to global emissions in recent decades (IPCC 2014). As a result, the vast majority of the Southwest is projected to be at least moderately vulnerable to climate change (Gutzler and Robbins 2010, Seager et al. 2007). Vulnerability assessment information is essential to informing management objectives in Step 3 and to selecting adaptation options in Step 4.

Active management and restoration may be more successful in areas of low to moderate vulnerability. But areas of high vulnerability may nevertheless warrant resistance measures where there are high-value elements such as habitat for Federally listed species, cultural legacies, popular recreation areas, and other features of immediate need for preservation to meet regulatory requirements or the needs of tribes and local communities.

Updating Vulnerability Assessments

Continual synthesis of available research and data on climate impacts is needed to capture additional scientific information, further corroborate impacts summarized in this section of the strategy and identify additional working hypotheses. **The science-manager partnership is critical for updating this guidance** through inquiry, experience, best available science, and late-breaking observations within a forum of adaptive management. The eventual outcomes of this process will represent a mixture of management intention, ecological processes, and climate trends (Figure 21).

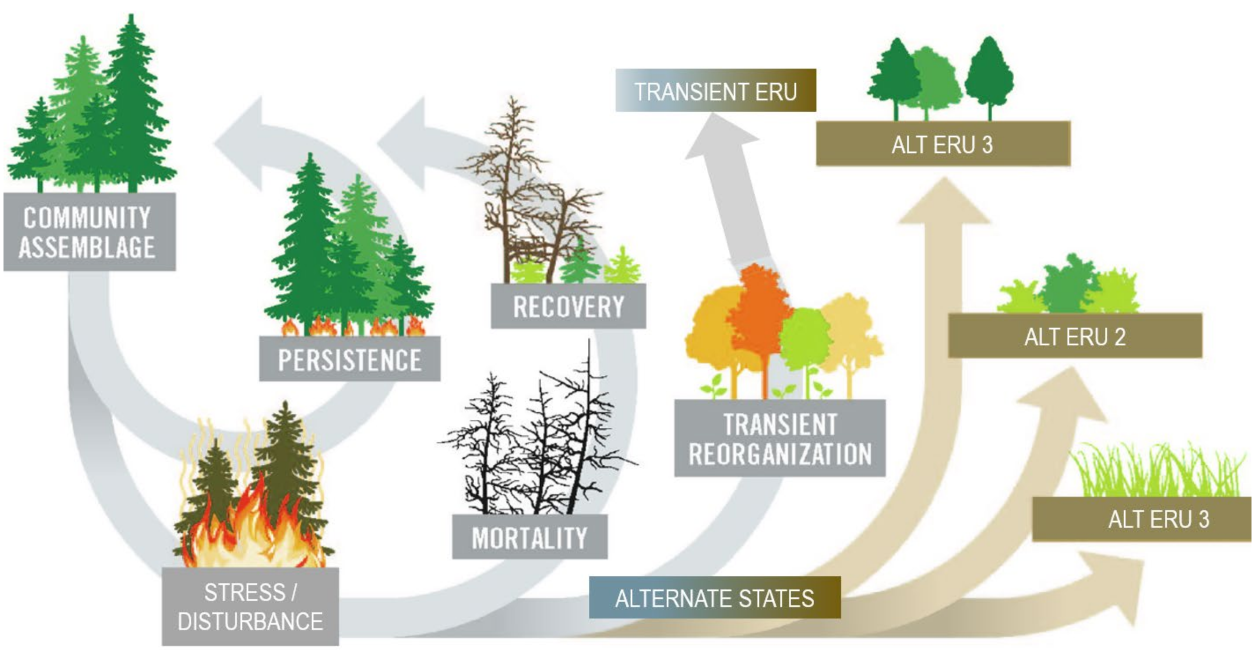


Figure 21. Adaptation of Falk et al. (2022) of the theorized continuum among potential outcomes of *persistence*, *recovery*, and *reorganization* resulting from ecological processes, individualistic plant responses, stochasticity, and management intentions.

Refining climate vulnerability forecasts have become more consequential as potential strategy scenarios have narrowed due to insufficient responses to global emissions in recent decades (IPCC 2014). As a result, the vast majority of the Southwest is projected to be at least moderately vulnerable to climate change (Gutzler and Robbins 2010, Seager et al. 2007). Having vulnerability assessment information that is useful at the local level is essential to informing management objectives in Step 3 and to selecting adaptation options in Step 4.

EVALUATE Management Objectives (Workbook Step 3)

Step 3 is to determine management objectives given the goals from Step 1 and the projected vulnerabilities and impacts from Step 2. Objectives reflect this information and the management challenges and opportunities associated with climate change. Step 3 is the middle step between identifying the broader management goals and then exploring adaptation options. Objectives are evaluated for their feasibility under current management and then refined to account for anticipated climate impacts (Step 2). This step provides the required backdrop for Step 4 and will likely include initial discussions on adaptation options and desired conditions under a changing climate.

Description of Workbook Items

Management objectives; List the management objectives. These will explain how management goals will be achieved. There may be multiple objectives for a single management goal. To develop objectives consider:

- The goals and sideboards identified in Step 1
- Climate vulnerabilities and impacts determined in Step 2
- Fine-filter questions about local priorities, resources, and feasibility
- The SEVA and specific vulnerabilities of nearby communities that could apply for environmental justice

Other considerations; Note any remaining social, financial, administrative, or other factors that may form objectives or the eventual comparison of management alternatives. Note reasons to pursue management objectives with low feasibility, such as regulatory requirements, high social values, or if an objective with low feasibility has the higher likelihood of success when compared to other objectives with low feasibility.

Purpose and need; Write a purpose and need statement that articulates the reasons for the project or management plan and other factors relevant to bounding and selecting among management alternatives. Central to the climate adaptation strategy is building on existing climate science and vulnerability assessment to inform purpose and need. Interim 2023 CEQ guidance includes a recommendation for agencies to leverage early planning processes to integrate greenhouse gas (GHG) emissions and climate change considerations into the identification of management alternatives and proposed actions and potential mitigation measures (88 FR 1196).

Opportunities for meeting management objective with climate change; List ways in which climate change vulnerabilities and associated impacts may make it easier to achieve each management objective or create new management opportunities. For example, increases in small- and medium-scale disturbance may help increase structural heterogeneity within a stand or landscape. Focus on concerns related to ecological or environmental challenges; other considerations (e.g., financial, social, traditional ecological knowledge) will be included later in this step.

Feasibility of meeting management objectives without climate-smart management; Consider how 21st-century climate trends, vulnerability, and likely impacts (Step 2) may affect the ability to achieve management objectives with and without climate adaption. Feasibility can be determined for individual or multiple time frames (e.g., short-term versus long-term).

Climate change may leave some management goals and objectives more difficult to achieve in the future (Joyce et al. 2009, Millar et al. 2007) so that they need to be refined to better account for anticipated climate change impacts. If feasibility is unlikely under the projected climate change impacts (e.g., managing for an ERU or species likely to experience severe decline), then it is reasonable to reconsider management objectives or the broader management goals. Record any potential issues or changes in the "Other considerations" section of Step 3 or return to Step 1 to alter management goals. Otherwise, proceed to Step 4 to explore adaptation options and desired conditions.

IDENTIFY Adaptation Options and Desired Conditions (Workbook Step 4)

This step is at the core of the workbook and is about identifying adaptation options and desired conditions for resolving ecosystem characteristics to climate change. Steps 1-3 have provided the necessary background to evaluate adaptation options and desired conditions under specific management objectives for a program or project area. Step 4 has five workbook items:

1. Understand the range of adaptation options (RRT) and subcategories along an intervention continuum (Chazdon et al. 2021);
2. Explore important questions about vulnerability patterns at the context scale to inform management objectives, adaptation options, and desired conditions at the local scale;
3. Identify adaptation options through the filters of management objectives and climate vulnerability and impacts;
4. Describe desired conditions from the perspective of adaptation options for specific ecosystem characteristics; and
5. Consider climate vulnerability and climate adaptation in project-level NEPA (VAN Framework).

As mentioned, separate tactical guidance will be developed so that this strategy focuses mostly on adaptation options and desired conditions for chosen ecosystem characteristics (indicators).

1. Understanding Climate Adaptation Options

This strategy uses an Adaptation Option typology of *Resilience*, *Resistance*, and *Transition* (Millar et al.2007). Efforts to communicate adaptation perspectives have been greatly complicated by the varied definitions and applications of common terms such as 'resilience' which has become increasingly vague (Myers-Smith et al. 2012, St-Laurent et al. 2021). For manager guidance, precise definitions are critical to describing and applying adaptation options. Accordingly, Peterson et al. (2011) added a fourth category to bring more precision to the range of adaptation options along with additional description. Nevertheless, this strategy utilizes the three-category RRT typology as the Forest Service convention and then brings needed precision using subcategories and additional description (Box 3). There is also an acknowledgement that a given management alternative is more likely to reflect an intervention *continuum* rather than a particular category of adaptation (Chazdon et al. 2021) and that actual outcomes of an invention will represent a mixture of persistence, recovery, and reorganization among ecosystem elements and processes (Falk et al. 2022) depending on the success and intent of interventions.

In each case here, **the option *category* is focused on intent and not outcome** since outcomes will more often overlap. For instance, an option of Resistance successfully applied may provide benefits of both resistance and resilience in the literal sense. Fire used to promote forest resilience (Waltz et al. 2014) may be suited to either Resilience, Resistance, or Transition options. **Management options in this guide are capitalized to maintain the distinction between intent (i.e., a selected option) and literal meanings and potential outcomes** (Figure 21; Falk et al. 2022).

The authors recognize that conventional management is sometimes warranted, particularly in case of wildland-urban interface (WUI) treatments where a substantial portion of agency resources are currently focused. Likewise, *Restoration* may sometimes be appropriate as with climate refugia. But most circumstances of vulnerability, scale, and the optimization of ecosystem services will warrant climate-smart management in the form of Resilience or Transition. The authors also recognize that National Forests of the Southwestern Region are under the policy of newly revised Forest Plans and a paradigm of restoration (Mast et al. 1999). Many Plan components have been written with sufficient flexibility to implement climate adaptation without Plan amendments. An excerpt from the regional desired conditions for the forests and woodlands (USDA Forest Service 2019):

> *In areas of high vulnerability to climate change, based on 100-year climate projections (Triepke et al.2019), tree basal area is restored or maintained at the low end of the desired range to mitigate water stress. In these areas, early-mid seral species dominate over late-seral species, given the adaptations of many early-mid species for warmer and drier conditions. Encroaching species characteristic of lower life zones are maintained.*
>
> *While future effects of changing climate remain speculative, there is growing consensus among forest scientists, in the vein of Bradford and Bell (2017), that management aimed at reducing tree densities, especially but not only in frequent fire-adapted types, can serve proactively as resistance or realignment (Transition) responses in areas vulnerable to drought and warmer temperatures. Untreated areas that have stem densities predisposed to high severity fire and subsequent type conversions may possess inevitable outcomes; but ignoring high stem densities based on uncertainty precludes treatments that are aimed at conserving habitat and carbon by delaying type conversions (resistance), treatments that facilitate gradual transition and ecological acclimatization (realignment), or treatments that consider HRV (restoration) (Millar et al. 2007). In general, lowering tree densities can be an effective safeguard for resource conservation and for optimizing ecological function and management options across planning cycles.*

Though Plan amendments may someday be necessary, there is climate adaptation language is written into every revised Plan and there is often enough flexibility in Plan components to implement RRT (Box 3).

Box 3

Adaptation Options

Resistance

The Resistance option is aimed at improving the defenses of a system against anticipated changes, or directly resisting, delaying, or buffering the system against disturbance that is likely to trigger change so that the system remains relatively unchanged in structure and composition. The resistance option broadly tries to put resources into maintaining what is currently on the landscape (Figure 22). As the climate trajectory diverges, this approach will become more costly and uncertain so is best thought of as a short-term option for things of high cultural, economic, or ecological value (Swanston et al. 2019). This option has subcategorization for buffer zones, treated to protect neighboring elements, or matrix resistance, to treat and provide defenses for the area itself.

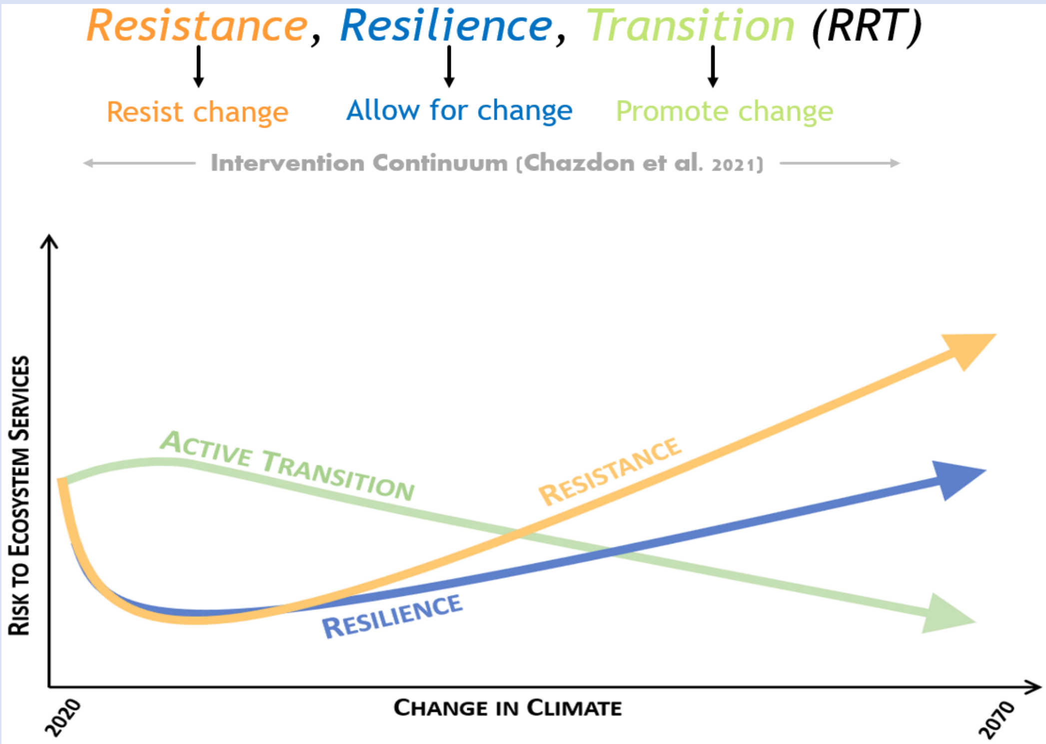


Figure 22. Adaptation of RRT concepts from Swanston et al. (2016) showing overall tradeoffs among adaptation options for ecosystem services in the near to long term.

This option could be most useful for high-value elements that may not be able to cope with disturbances and pressures from a changing climate, such as such as Protected Activity Centers for the threatened Mexican spotted owl (MSO). These resources may be economically, socially, or culturally valuable, or protected for specific values or characteristics. In practice, Resistance would only be selected in specific instances knowing that risk of failure and loss of ecological integrity likely increases with time, and the investment and resources to maintain the bubble are likely to increase.

The tactics used for Resistance and conventional Restoration will be similar but apply to different circumstances of vulnerability and risk, with Restoration viable primarily in low-vulnerability areas. Over time, Resistance (moderate-high vulnerability areas) may become less and less viable if plant species fail to regenerate, the system becomes simpler, ruderal vegetation takes on plurality, or risk to the protected elements themselves increases (Coop 2022). One disturbance of substantial severity can foil the intent of Resistance.

Resilience

The Resilience option intends to enhance the ability of a system to return to prior conditions after a disturbance while accommodating some degree of change based on climate trajectory (Stephens et al. 2010, Elias et al. 2015, Peterson et al. 2011, Swanston et al. 2016). Although some change may occur, the intent is for the system to return to a state like what it was before the disturbance yet allow for subtle change and some new elements in the system (composition, structure, process). Resilience may be chosen as the adaptation option to increase the capacity of the system to absorb changes and recover from any disturbance. The system may undergo relatively minor changes as climate pressures increase, but Resilience intends to support maintaining structure, composition, and process into the future even though the system may gradually take on changes driven by climate. Resilience carries less risk than Resistance because the system is managed to cope effectively with a changing climate (Hansen et al. 2003). But risk still increases over time because the system may not be able to maintain the same character in a different climate and shifting site potential.

The tactics used for Resistance and Resilience may overlap, but Resilience is 1) tolerant of novel components such as encroaching plant species of lower life zones and 2) tolerant of or even utilizing disturbance such as prescribed and cultural burning to promote resilience and reduce stress (see Table 8). Like Resistance, Resilience is always proactive but where Resistance is designed to forestall climate effects, Resilience allows for gradual change. Resilience differs from Transition in that it allows for but does not promote realignment of the system. Resilience represents a middle ground between Resistance and Transition and carries less long-term risk than Resistance. As an example, reducing tree basal area and implementing prescribed or cultural burning in fire-adapted forests, to restore forest structure and disturbance processes, can be an effective resilience tactic if new elements are allowed into the system. If applied carefully Resilience can be effective in facilitating change and may be less costly than Preemptive Transition that requires additional actions meant to speed realignment.

Table 8. Examples and comparison among RRT in application and risk.

All Vegetation Types

Example	Resistance	Resilience	Transition
Shifts in structure and composition	Limit	Allow	Encourage
Risk*	High	Moderate	Low

Fire-Dependent Forests and Woodlands

Example	Resistance	Resilience	Transition
Rx burning	Encourage	Encourage	Encourage
Risk*	Low	Low	Low

Semi-Desert Grassland

Example	Resistance	Resilience	Transition
Rx burning	Allow	Allow	Limit
Risk*	High	Moderate	Low

Mixed Conifer w/ Aspen (with shifts to dry forest)

Example	Resistance	Resilience	Transition
Rx burning	Limit	Allow	Allow
Risk*	Moderate	Moderate	Low/Moderate

Transition

Transition actions intentionally accommodate or speed change, enabling a system to adaptively respond in a deliberate way. By encouraging a gradual and intentional transition, it may be easier to maintain important functions and values over time, even as the character of a system changes. Transition is the adaptation option chosen to facilitate change so that the system is better suited to expected conditions of the future. And by anticipating likely effects on the system, Transition can be shaped to maintain desired functions and values even as the system is altered. Transition actions can take place in advance of climate change effects or in response to them. In the long term, Transition may carry less risk than Resistance or Resilience since changes in the systems are being actively considered to assist change (see comparison Table 8).

Transition is the only option focused on purposeful transformation driven by climate change. Assisted migration is one example of Preemptive Transition. Transition acknowledges that not all ecosystems will be able to maintain their current locations on the landscape and management tactics can be used to support realignment from one system to another at a given location. Unlike Resistance and Resilience, Transition can be passive. This strategy recognizes three subcategories of Transition – Preemptive, Responsive, and Passive:

Preemptive Transition

Preemptive Transition includes active and immediate actions to transition a system consistent with ongoing and future climate trends. Preemptive Transition is focused on proactive management and actions taken prior to severe disturbance. For example, the active harvest of vulnerable forests coincident with planting of more heat or drought tolerant species would constitute Preemptive Transition and includes both forced and assisted migration. The defining factor in Proactive Transition is that the action occurs before or in anticipation of climate influenced stress and disturbance.

Responsive Transition

Responsive Transition actions are taken following a major disturbance to better facilitate realignment of the ecosystem or element to changing conditions. These actions are akin to jumpstarting disturbed systems and providing more climate-suitable properties instead of attempting to reestablish prior components that are unlikely to thrive. An example of Response Transition is the replanting of forested areas with different tree species or progeny suited to shifting climate and site potential.

Passive Transition

Passive Transition, sometimes referred to as “acceptance” (Schuurman et al. 2020), in an option with the intent to allow natural transitions to occur without active manipulation. Passive Transition may be best suited to areas where results may be predisposed or where there is less risk. It also applies to areas where other Transition options may not be allowed (regulatory or policy) or warrant prioritization. Passive Transitions should be viewed as an affirmative choice and it’s likely that most lands will default to Passive Transition (Lynch et al. 2021) given that there are limited resources for active management.

Conventional Management

Definitions of conventional management options are included here as a means of clearly delineating them from climate adaptations. Though the preference and the emerging paradigm is one of climate-smart management, there will be some instances when conventional management is desired and appropriate. Conventional management such as Restoration may be similar to RRT but the distinction is in *intent* and involves the level of climate vulnerability for a given area.

Restoration

Classic restoration towards historical conditions of structure, composition, and process is only viable over the long term in low vulnerability areas. Restoration applied in moderate- or high-vulnerability areas is actually Resistance, given climate pressure and likely change in site potential and ecosystem conditions. Restoration is often followed by maintenance actions such as prescribed or cultural burning to keep desired conditions, typically tied to the historical range of variation (Covington and Moore 1994, Mariani et al. 2022). Restoration will be viable in relatively few instances, so that Resilience or Transition are typically the options of choice for a given landscape project. Restoration of some areas might be prioritized for climate refugia in response to rarity of an ERU in a given Ecoregion.

Preservation (high-value elements)

Preservation is referenced broadly here to describe management emphasizing climate refugia and high-value elements in low-vulnerability areas that may be in decline or difficult to produce on the landscape under a warmer climate. Examples include old forest conditions that are often deficit on a given landscape and take significant investment to protect or develop. In fact, managers may consider disproportionately favoring old forest states given the likelihood of continual loss of their services in the long term.

Wildland Urban Interface (WUI)

The wildland-urban interface is a zone of transition between natural, unoccupied lands and lands with human development – an area where built environment meets or intermingles with natural and semi-natural lands (Stein et al. 2018). The Forest Service defines the wildland-urban interface generically as a place where "humans and their development meet or intermix with wildland fuel." Communities that are within half-mile of this zone are included. A substantial number of resources available for land management in the Southwest is devoted to the WUI. The WUI spans the majority of ERUs and reflects all categories of vulnerability and uncertainty. It is expected that the WUI will continue to be managed neutral of climate adaptation and vulnerability.

2. Explore context-scale vulnerability to inform local-scale considerations

The following guiding questions are intended to help the manager integrate information about climate vulnerability patterns at the Ecoregion context to help identify adaptation options, desired conditions, and tactics at the local scale.

Guiding Question: What proportion of the overall ecosystem or element in question is moderately or highly vulnerable?

What is the context vulnerability of the ERU or element? Understanding the context vulnerability helps better understand the weight and meaning of the local vulnerability of an ecosystem or element. For instance, there may be added rationale for aggressive climate adaptation measures for an ERU that is highly vulnerable across the context.

Guiding Question: Does the area serve as important or critical habitat?

Are there important habitat considerations for the ERU or area in question? Ecoregions that serve as important or critical habitat for at-risk species may warrant special consideration for preservation.

Guiding Question: Does the area include seral and / or structural elements that are underrepresented?

Are there specific seral or structural elements that are underrepresented across the broader landscape? If so, a given project could be a limited opportunity to preserve key functional elements of the system. An example is old and complex forest systems which may be under-represented and vulnerable across the context, and that are also hard to establish, may indicate a need for preservation where those features do occur.

Guiding Question: Is the area culturally or socially Important (and limited)?

Are features of elevated cultural or social importance highly vulnerable or limited across the broader landscape? If so, this might be additional rationale for managing these systems with added caution or to deliberately preserve areas where those features occur (Clark et al. 2022). Areas with cultural or social importance are not limited to designated cultural sites. An example of socially important feature could be aspen clones along a designated scenic byway.

Guiding Question: Is the system limited geographically?

Is this system or element limited in geographic extent or range across the region? ERUs or elements that are rare across the region have limited redundancy and therefore higher conservation burden to the broader context.

3. Selecting Adaptation Options

This step guides local project teams and practitioners in the assessment of adaptation options. Adaptation options are identified through the filters of management objectives and climate vulnerability and impacts. Evaluation tools such as FireCLIME, SyncroSim, or FireBGC (Keane et al. 1996, Ford et al. 2019, Friggens et al. 2019), the *Adaptation Menu for Fire Management* (Sample et al. 2022; Box 4), and Indigenous knowledge reflected in *A Tribal Climate* Adaptation Menu (TAMT 2019) and other tribal resources can assist in identifying adaptation options, desired conditions, and tactics (Petzold et al. 2020). *Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options* (Peterson et al. 2011) and *Forest Adaptation Resources: Climate Change Tools and Approaches for Land managers* (Swanston et al. 2016) has additional menu information on adaptation for individual species and genetic diversity, soils, planning, infrastructure, policy, and other resources and sectors.

For Forest Service lands, this strategy comes with a first approximation for the general location and selection of RRT that is later validated or modified:

> *A first approximation of RRT was formed based on variables of 1) ERU, 2) climate vulnerability, 3) uncertainty, 4) ecoregion context, 5) integrated landscape prioritization (e.g., Shared Stewardship, Fireshed Registry), and 6) environmental justice (SEVA) to form default adaptation options.*
>
> *For a second approximation, additional variables are considered including 6) management objectives from Step 3, 7) current ecosystem conditions and trends, 8) the presence of high-value elements such as MSO habitat or cultural sites, and 9) logistical and management constraints. Finally, 10) adaptation options are validated based on conditions on the ground and other lines of evidence and then modified as appropriate.*

Climate trends in the 21st century will compromise ecological integrity of most ecosystems sooner or later and sound strategy calls for thoughtful blending and application of adaptation options to best facilitate migration of systems and species to better suited locals and allowing for some ecological surprises (Williams and Jackson 2007). Table 9 shows the general relationships among variables of uncertainty, vulnerability, adaptation/management options, and risk. Information in Table 9 is assuming a level of scarcity in management resources so that active management on most high-vulnerability extents would be deferred to passive Transition, and limited manager capacity would be focused on moderate vulnerability extents areas where Resistance and Resilience are more likely to succeed. Comer et al. (2019) offers an alternative strategy to consider that links low vulnerability with Resistance and high vulnerability with Transition.

Table 9. Management option matrix showing the approximate relationship among climate vulnerability and uncertainty projections, adaptation/management options, and risk to ecosystem services.

Uncertainty in Forecast	Vulnerability Forecast	Management Options	Short Term Risk to Ecosystem Services	Long Term Risk to Ecosystem Services
Low-Mod	Mod	Resistance	maybe	yes
Low-Mod	Mod	Resilience	no	maybe
Low-Mod	Mod	Transition - Preemptive	no/maybe	no
Low-Mod	Mod	Transition - Responsive	maybe	no
Low-Mod	High	Transition - Passive	maybe	maybe/yes
Low-Mod	Low	Restoration	no	no
Low-Mod	Low	Climate refugia	no	no
Low-Mod	All	WUI	no/maybe	maybe
High	All	Transition - Passive	unknown	unknown

Adaptation Menu for Fire Management

Wildfire is likely to hasten the decline of ecological integrity on many landscapes due to the rapid change in ecosystem structure and function that is often triggered by severe wildfire and the lags in an ecosystem's ability to realign following disturbance. The importance of overstory structure in buffering microclimates to overarching warming trends in large part depends on the absence of stand replacement disturbance (Elias et al. 2015, Hill and Field 2021). The effects of a warmer and dryer climate will increase severe wildfire and heighten the urgency for managers to integrate information on climate impacts and implement climate adaptation. Sample et al. (2022) have developed an *Adaptation Menu for Fire Management* to help managers to narrow adaptation options and tactics, and the menu has been integrated with the A Tribal Adaptation Menu in Box 4. This guidance is specific to fire and climate and was developed from a science-management partnership as a flexible menu for planners, practitioners, and specialists who face the difficult task of simultaneously considering uncertainty, vulnerability, adaptation options/tactics, and both short- and long-term risk. **When using the menu, the reader is referred to Sample et al. (2022), 'Strategies and Approaches for Managing Fire in a Changing Climate', for necessary details.**

Though fire-oriented, the Fire Menu represents a diversity of conservation values and climate adaptation responses. It offers land managers a wide variety of approaches that are robust to uncertainty in vulnerability forecasts. There are 27 approaches among ten categories of the menu below reflecting management activities that are both conventional and some that are less common given the new paradigm of climate adaptation. Some of the approaches reflect specific tactics while others leave it to project teams to identify appropriate tactics for their circumstances. Each category of the menu is designed to respond to one or more of the adaptation options of Resistance, Resilience, or Transition. The menu lends itself to the tiered system of adaptation option, desired conditions, and tactics and can help managers identify intent of RRT and help them to identify approaches to fulfill intent.

Indigenous Knowledge and Tribal Approaches

Climate-related impacts to Indigenous people of the Southwest are recognized by tribal natural resource organizations who understand the need to adapt to ongoing and future change and are spreading awareness to their people, community leaders, resource practitioners, and partners. Tribal members practice traditional gathering and hunting and rituals that depend on particular ecosystem services and the long-term sustainability of tribal lands and nearby landscapes. Members have expressed concerns about the loss of traditional practices due to climate stress. In response to these concerns, tribal nations of the region have conducted numerous workshops and climate assessments in the last two decades (e.g., Mawdsley and Lamb 2013) and are formulating climate adaptation strategy such as the Climate Adaptation Plan for the Navajo Nation (NNDFW 2018). **Tribal resources referenced below and A Tribal Climate Adaptation Menu in Box 4 represent a small subset of the diversity of Indigenous knowledge of the region but have broad application to landowners and natural resource agencies considering climate vulnerability, important ecosystem services, and land management approaches (Petzold et al. 2020)**. This section of the Climate Adaptation Strategy will be updated with more comprehensive and Southwest-specific information.

National Congress of American Indians climate action resources (NCAI 2022) – This website contains a listing of adaption plans and approaches and climate assessments developed by intertribal organizations along with individual tribal nations (www.ncai.org/ptg/climate-action-tribal-approaches). The NCAI listing is occasionally updated with new information.

Climate Adaptation Plan for the Navajo Nation (NNDFW 2018) – The Navajo Nation spans the Four Corners region and over 26,600 square miles (69,000km^2) of Arizona, New Mexico, and Utah, largely within the area of the sacred mountains of Mount Hesperus to the north, Mount Taylor to the south, Mount Blanca to the east, and San Francisco Peak to the west. There are currently over 330,000 enrolled tribal members in the US including 157,000 members living on the reservation itself and over 119,000 living in nearby border towns (e.g., Gallup, Holbrook, Winslow) and metropolitan areas (e.g., Albuquerque, Phoenix) (Donovan 2011, Center 2013). A majority of tribal members still practice traditional ceremonies, dances, and other culturally sensitive events and practices reliant on ecosystem services (NNDFW 2018). During workshops and other community gatherings in the last two decades community members have articulated concerns about risks that climate stress poses to traditional practices.

In response to climate-related risks the Navajo Nation has identified six priorities to focus climate adaptation with an emphasis on community and continual sustainability of the land:

1. Water
2. Feral Horses
3. Communication
4. Enforcement/compliance
5. Pollution, air quality, illegal dumping
6. Grazing management

For each of the six priority points the Climate Adaptation Plan for the Navajo Nation summarizes vulnerabilities and risks, adaptation approaches, and an implementation plan. Though focused on the Navajo Nation the plan contains science, management guidance, and Indigenous knowledge with broad applicability to fellow land managers of the region.
www.nndfw.org/docs/Climate%20Change%20Adaptation%20Plan.pdf

A Tribal Climate Adaptation Menu – Climate stress is impacting the ecosystems of Indigenous people and their culture and lifeways. Other climate adaptation guidance does not address the unique needs and interests of Indigenous communities. A Tribal Climate Adaptation Menu was developed by a diversity of tribal, academic, and government organizations in the midwestern US and Indigenous people of the Southwest were not represented; rather, the menu was intentionally designed to be adaptable to other Indigenous communities and provides a placeholder for more specific knowledge, culture, and practices of Southwest tribes to inform climate adaptation. The menu is tiered by general and more specific concepts and approaches and should be considered with its parent document (TAMT 2019) for full perspectives and details. A Tribal Climate Adaptation Menu provides insights to essential ecosystem services and traditional and contemporary adaptation responses. The menu also offers important information for interacting with tribal partners and for servicing tribal needs and interests. There are 57 approaches among 14 categories of the menu below reflecting Indigenous practices, engagement, and tribal management activities including some less familiar given the new paradigm of climate adaptation. Some of the approaches reflect specific tactics while others leave it to project teams to identify appropriate tactics for their circumstances. Each category of the menu can respond to one or more of the adaptation options of Resistance, Resilience, or Transition. As with the Fire Menu, A Tribal Adaptation Menu lends itself to the tiered system of adaptation options, desired conditions, and tactics and can help managers identify appropriate approaches or help them to identify approaches and tactics to fulfill intent.

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Box 4

Adaptation Menu for Fire Management (Fire Menu)

and

A Tribal Adaptation Menu

Guidance here combines the Fire Menu with A Tribal Adaptation Menu as a functional integration of these important resources in a common reference. The two menus have some thematic overlap and, in combination, are a more comprehensive suite of approaches to climate adaptation in response to RRT. The Fire Menu has strong overlap with the adaptation and mitigation framework of Ontl et al. (2020) and others, and both menus were strengthened by participatory efforts and workshops within an ongoing science-management partnership (Friggens et al. 2019, Sample et al. 2022). Both menus place emphasis on fire and restoration but also contain measures specific to climate adaptation and are broadly applicable to resource program and projects including CFLRP work, watershed improvement, wildlife habitat conservation, and other land management. The source menus can be discerned by font shading with the Fire Menu in black and A Tribal Adaptation Menu in gray.

1: Sustain fire as a fundamental ecological process – Resistance, Resilience, Transition

- 1.1: Restore or maintain fire in fire-adapted ecosystems
- 1.2: Develop fire use approaches in altered or novel ecosystems where fire can play a beneficial role

2: Learn through careful and respectful observation while considering cultural practices and seeking spiritual guidance – Resistance, Resilience, Transition

- 2.1. Learn from beings and natural communities as they respond to changing conditions over time
- 2.2: Consult cultural leaders, key community members, and elders
- 2.3: Consider mindful practices of reciprocity
- 2.4: Understand the human and landscape history of the community
- 2.5: Hold respect for all our relations, both tangible and intangible
- 2.6: Maintain dynamic relationships in a changing landscape

3: Support tribal engagement in the environment – Resistance, Resilience, Transition

- 3.1: Maintain and revitalize traditional relationships and uses
- 3.2: Establish and support language revitalization programs
- 3.3: Establish, maintain, and identify existing inventory and monitoring programs
- 3.4: Establish and maintain cultural, environmental education, and youth programs
- 3.5: Communicate opportunities for use of tribal and public lands
- 3.6: Participate in local- and landscape-level management decisions with partner agencies

4: Reduce impact of biological and anthropogenic stressors– Resistance, Resilience

- 4.1: Remove and prevent establishment of non-native invasive species
- 4.2: Maintain or improve the ability of forests to resist pests and pathogens that may alter fuel regimes
- 4.3: Limit, selectively apply, and monitor land uses that increase fire risk or threaten fire resilience
- 4.4: Maintain or improve the ability of communities to balance the effects of little spirits (and non-local beings)
- 4.6: Manage herbivory to promote regeneration of impacted beings
- 4.7: Reduce negative impacts from anthropogenic disturbances
- 4.8: Monitor and reduce ambient air pollution

5: Reduce the risk of unacceptable fire – Resistance, Resilience

- 5.1: Protect fire-sensitive and vulnerable ecosystems from fire
- 5.2: Alter forest structure and composition to reduce the risk and spread of unacceptable severe fire
- 5.3: Establish or maintain fuel breaks to stop the spread of unacceptable fire
- 5.4: Engage and incorporate values of Indigenous communities in fire management decisions

6: Limit the effects of unacceptable fire and promote post-fire recovery and other long-term impacts of disturbances – Resistance, Resilience

- 6.1: Promote habitat connectivity and increase ecosystem redundancy
- 6.2: Maintain or create fire refugia
- 6.3: Stabilize and enhance the physical fire footprint
- 6.4: Promote recovery of native vegetation and habitat (promptly revegetate sites after natural disturbance)
- 6.5: Alter community structure or composition to reduce risk or severity of major disturbances
- 6.6: Care for cultural sites after a severe disturbance
- 6.7: Plan harvesting, gathering, and collecting opportunities to reduce the risk and impacts of disturbances

7: Maintain and enhance structural, community, and species diversity – Resistance, Resilience

- 7.1: Maintain or increase structural diversity from stand to landscape scale
- 7.2: Promote diversity within and among communities to enhance fire resilience (promote diverse generations, both elder and younger beings)
- 7.3: Maintain and restore diversity of native beings
- 7.4: Retain biological and cultural legacies
- 7.5: Establish protected areas to maintain ecosystem and cultural diversity

8: Identify, promote, and conserve fire- and climate change-adapted species and genotypes – Resilience, Transition

- 8.1: Promote native species and genotypes that are better adapted to future climate and fire regimes, disfavor species that are distinctly maladapted
- 8.2: Use plant materials from regional areas that have current climate and fire regimes similar to anticipated future conditions
- 8.3: Use seeds and other biological material from relatives of beings from across a greater geographic range
- 8.4: Collect and preserve seeds from beings that are at-risk or of concern to the community
- 8.5: Engage and incorporate values of Indigenous communities in climate adaptation decisions

9: Facilitate ecosystem adaptation to expected future climate and fire regimes – Resilience, Transition

- 9.1: Facilitate the movement of species that are expected to be adapted to future climate and fire regimes
- 9.2: Use fire as a tool to align existing vegetation communities with changing climate and fire regimes
- 9.3: Promptly prepare and revegetate sites after disturbance
- 9.4: Allow for areas of natural regeneration to observe which beings naturally appear on the site
- 9.5: Adapt significantly disrupted ecosystems to meet expected future conditions and needs
- 9.6: Relocate ecosystems, beings, or cultural sites

10: Use fire events as opportunities for ecosystem realignment – Transition

- 10.1: Revegetate burned areas using fire-tolerant and drought-adapted species and genotypes
- 10.2: Allow for areas of natural regeneration to test for future-adapted species
- 10.3: Maintain ecosystems that have undergone post-fire type conversion or realignment
- 10.4: Maintain or restore hydrology and soils
- 10.5: Maintain or restore riparian areas
- 10.6: Maintain or restore water quality
- 10.7: Support specific plants or plant communities with essential requirements
- 10.8: Revitalize and maintain cultural use of fire as a stewardship tool
- 10.9: Maintain and revitalize cultural approaches to harvesting and caretaking
- 10.10: Manage habitats and access opportunities over a range of sites and conditions
- 10.11: Reduce fragmentation to promote continuous natural ecosystems
- 10.12: Maintain and create habitat corridors through restoration

11: Promote organizational and operational flexibility Resilience – Transition

- 11.1: Develop adaptive staffing and budgeting approaches
- 11.2: Explicitly consider changing climate and fire regimes during the planning process and adaptive management cycle
- 11.3: Engage and incorporate values of Indigenous communities in fire management decisions
- 11.4: Favor or restore native beings that are expected to do well under future conditions and that can help meet future needs
- 11.5: Establish or encourage new mixes of local beings and/or non-local beings expected to do well under future conditions to meet future needs
- 11.6: Guide changes in composition of beings at early stages of development
- 11.7: Seek out and share traditional and cultural knowledge of potential new beings from tribal communities where these beings are native
- 11.8: Identify additional lands for acquisition to expand the tribal land base, maintain diversity, and improve connectivity

12: Promote fire-adapted human communities – Resilience, Transition

- 10.1: Increase fuel reduction treatments in the wildland–urban interface (WUI)
- 10.2: Actively promote broad social awareness and increase education about anticipated effects of climate change on fire regimes

13: Establish, support, and recognize opportunities for beings or sites of concern to the community to withstand climate change – Resistance

- 13.1: Identify, prioritize, and maintain cultural sites and/or culturally sensitive areas
- 13.2: Identify, prioritize, and maintain at-risk and/or culturally important beings or communities
- 13.3: Establish places for at-risk or displaced beings outside of their normal environments (biological nests/refugia)
- 13.4: Seek out or share traditional and/or cultural knowledge to inform management of sensitive or at-risk beings or communities
- 13.5: Create and/or maintain access routes to traditional gathering and harvesting sites
- 13.6: Work across treaty or tribal areas with partners and other tribes to manage at-risk beings

14: Design and modify infrastructure and access to match future conditions and community needs – Resilience, Transition

- 14.1: Reinforce infrastructure to meet expected conditions
- 14.2: Incorporate natural or low impact development into designs
- 14.3: Reroute, relocate, or remove infrastructure to increase access efficiency and minimize harmful impacts

15: Accommodate altered hydrologic processes – Resilience, Transition

- 15.1: Plan for decreased streamflow and limited water availability
- 15.2: Enhance the ability of ecosystems to retain water
- 15.3: Adjust systems to cope with increased water availability and high-water levels
- 15.4: Respond to or prepare for excessive overland flows (surface runoff)
- 15.5: Adjust the location and size of forested areas to new or changing water levels

Adaptation Option Selection, Summary

Finally, some general perspectives on adaptation options:

- Because of manager limitations, much of the landscape is likely to be relegated to an option of passive Transition; however, managers can affect the overall success of realignment by carefully considering how active and passive management are focused.

- Resistance will likely be used in limited and targeted circumstances to preserve high-value elements such as rare species habitat.
- For the most part, Resilience or Transition are the most viable options and an understanding of vulnerability and potential impacts can help determine a path forward. Resilience is useful as an intermediate option (tables 8 and 9) along an intervention continuum that purposely allows for features of existing and future site potential, while allowing for continual transition.
- For moderate and high vulnerability areas where there are not extenuating circumstances that warrant Resistance, Transition options are appropriate. Passive, Responsive, and Preemptive Transitions may exist on a continuum with Passive Transition likely to be the dominant option on many landscapes. However, there are compelling reasons for applying both responsive and preemptive options. Two contributing factors in determining which Transition option to select are uncertainty (regarding the vulnerability of the area) and adaptive capacity of the area in question. Because Preemptive Transition options represent the most drastic adaptation option in this strategy, it is important to apply Preemptive Transition in areas where there is less uncertainty regarding vulnerability and future outcomes of the system. In many cases, applying this Transition option represents actions that cannot be easily rolled back so that caution is warranted.
- The rapid rate of climate change, increasing wildfire activity, and inherent lags in the realignment of ecosystems to changing climate suggest that, without intervention, ecosystems will continue becoming simpler and less diverse and will have decreased services associated with the loss of viable plant propagules at the site level, net loss of animal and plant diversity, lower overall carbon retention, and compromised watershed conditions associated with soil loss, loss of productivity, and other factors. Figure 23 shows the relationship between CCVA vulnerability categories and trends in increasing amounts of bare ground in the Southwest since the 1980s (RAP 2022).

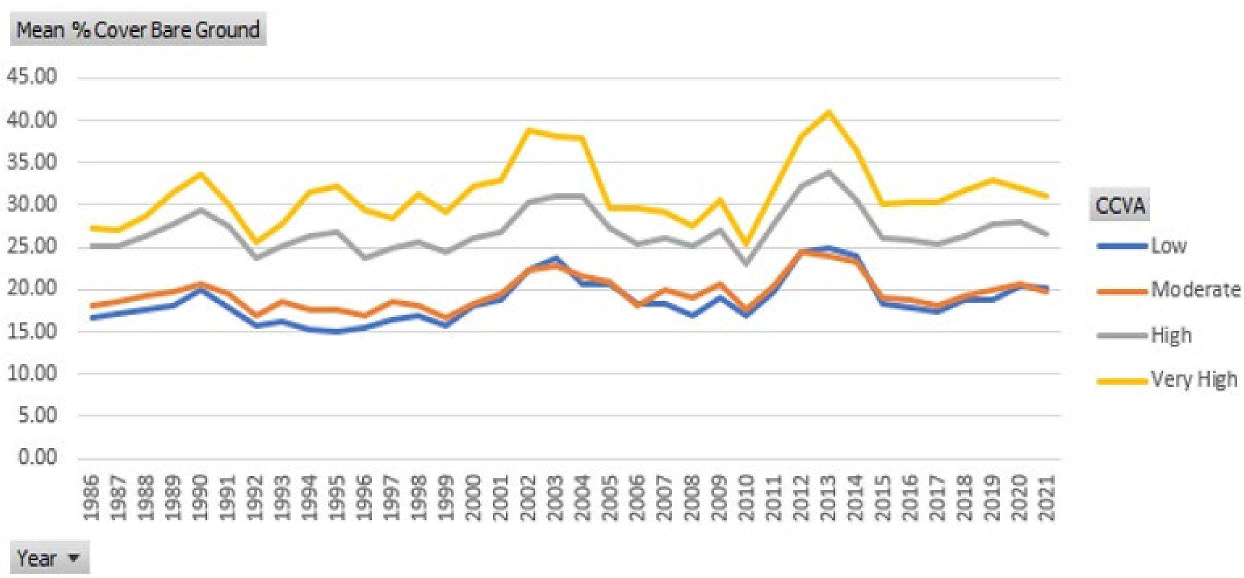


Figure 23. Trends in average percent bare ground among CCVA vulnerability categories across the Southwest.

The desired conditions worksheet (Box 6 and Appendix B) offers an ordered approach for considering adaptation options at the level of individual ecosystem characteristics while developing desired conditions through the lens of a given adaptation option.

4. Describe Desired Conditions

Desired conditions are tiered from the management objectives and adaptation options. Desired conditions and adaptation options can be more thoroughly evaluated using FireCLIME, SyncroSim, and FireBGC (Ford et al. 2019, Friggens et al. 2019, Keane et al. 1996) and other tools. The desired conditions worksheet provides a direct link between Forest Plans or other land management plans or strategy documents (Appendix E) and the climate adaptation strategy and adaptation options. For large landscape projects, desired conditions are best when they reflect all four pillars of structure, composition, process, and connectivity (FSH 1909.12, CHAP. 40, SEC. 43.12). This guide is applicable to any number of ecosystem characteristics (=indicators) representative of these pillars including terrestrial indicators of the Southwestern Region:

Process (disturbance)

- Fire regime (frequency and severity) (all ERUs)
- Insect and disease (forested ERUs)
- Flood regime (riparian ERUs)

Connectivity

- Patch size (all upland ERUs)
- Riparian corridor connectivity (riparian ERUs)

Composition

- Functional group diversity OR ecological status (all ERUs)
- Exotic woody species cover (riparian ERUs)

Structure

- Seral state diversity (all ERUs)
- Bare ground OR ground cover (all ERUs)
- Coarse woody debris (forested ERUs)
- Snag density (forested ERUs)
- Large trees (PPE, PPF, MCD)
- Riparian woody regeneration (riparian ERUs)

Process + structure

- Fire Regime Condition Class (FRCC) (all ERUs)

Mitigation/climate

- Carbon stocks/biomass (all upland ERUs)

These indicators are included in the desired condition descriptions for all forest and woodland types (USDA Forest Service 2019) as important characteristics of ecosystem function and condition that can be assessed through common monitoring, inventory, and map sources. The list of indicators is not exhaustive, and each individual or project team needs to select indicators for their needs. The **climate adaptation strategy was developed to promote the realignment of ecosystems, and key indicators can provide an outline and focus for optimizing the selection and location of adaptation options and tactics** for the best use of limited capacity for active management. Box 5 has information on policy for Forest Service users who are building or implementing desired conditions and applying ecosystem mapping and other conventional information sources in a way that endures beyond the immediate planning cycle for purposes of climate-smart management.

Box 5

Climate Adaptation and Forest Planning

The Planning Rule and Forest Service planning directives promote climate adaption across adaptation options of Resistance, Resilience, and Transition (RRT) (Millar et al. 2007, St-Laurent et al. 2021) in terms of management intent. While restoration is sometimes appropriate, as with climate refugia, most circumstances of climate vulnerability and optimizing ecosystem services warrant climate-smart management. There are no plans or apparent need to revise the Rule or planning directives in this regard. The WO *is* in the process of revising the silviculture handbook to make clear that assisted migration is an acceptable measure since current direction is unclear.

The Transition option (preemptive and responsive) represents the most assertive mode of climate adaptation with assisted migration being a subset of this option. Transition is the greater expression of long-term system adjustment and ecological integrity among adaption options. Passive transition is already underway in the Southwest with upward shifts in life zones at the rate of about 15m or more in elevation per decade (average 14-32m; Brusca et al. 2013, Guida et al. 2014, Kelly and Goulden 2008).[1] The Transition option can be serviced by Plan components and desired conditions for both existing and future conditions for a given area.

The Rule and directives are clear on these points and consistently support climate measures and Plan components that adapt to new information and conditions such as ERU map revisions and climate projections. The Rule and directives are explicit about 1) planning *for* climate change and 2) developing Plan components that adapt to change and are responsive to future conditions:

> The intent of this [planning] framework is to create a responsive planning process that informs integrated resource management and allows the Forest Service to adapt to changing conditions, including climate change, and improve management based on new information and monitoring (CFR 219.5)
>
> *Assessment*
> When assessing existing conditions of key ecosystem characteristics, and identifying trends, the Interdisciplinary Team should assume existing plan direction remains in place and the influence of climate change and other large-scale threats and stressors continues (FSH Ch 10, 1909.12.14c).
>
> Using the ecological reference model as the normal for ecological integrity the interdisciplinary team should consider whether the key ecosystem characteristics and associated physical, chemical, and biological processes are functioning and would likely continue to function in a way that contributes to long-term integrity of ecosystems and provide conditions for species adaption to a changing climate (FSH Ch 10, 1909.12.14c).
>
> System drivers, including dominant ecological processes, disturbance regimes, and stressors, and ecosystems processes such as natural succession, wildland fire, invasive species, and climate change affect the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change (36 CFR 219.6(b)(3)).
>
> The assessment of the status of ecosystem integrity should describe the projected future status of each key ecosystem characteristic assuming:

[1] For contrast, upward shifts in plant populations of western Europe have been averaging 29m per decade (Lenoir et al. 2008) while some bird populations in Scandinavia are averaging 10m decade (Couet et al. 2022).

- The influence of climate change and other large-scale threats and stressors will continue, based on best available scientific information regarding trends (sec. 12.3 of this Handbook) (FSH 1909.12, Ch 10,.14c)
- Determine whether existing ecological conditions sustain ecological integrity (or sustain fully functional ecosystems), and if not, the extent to which existing conditions vary from conditions that would do so, and what the projected future ecosystem conditions would be. See FSH 1909.12, chapter 20, section 23.11 for a discussion of functional ecosystems. Indicate if one of the following is true for each key ecosystem characteristics: The key ecosystem characteristic is functioning in a way that contributes to long-term integrity of ecosystems and species adaption to a changing climate and is expected to continue to do so under existing plan direction (FSH Ch 10, 1909.12.14c).

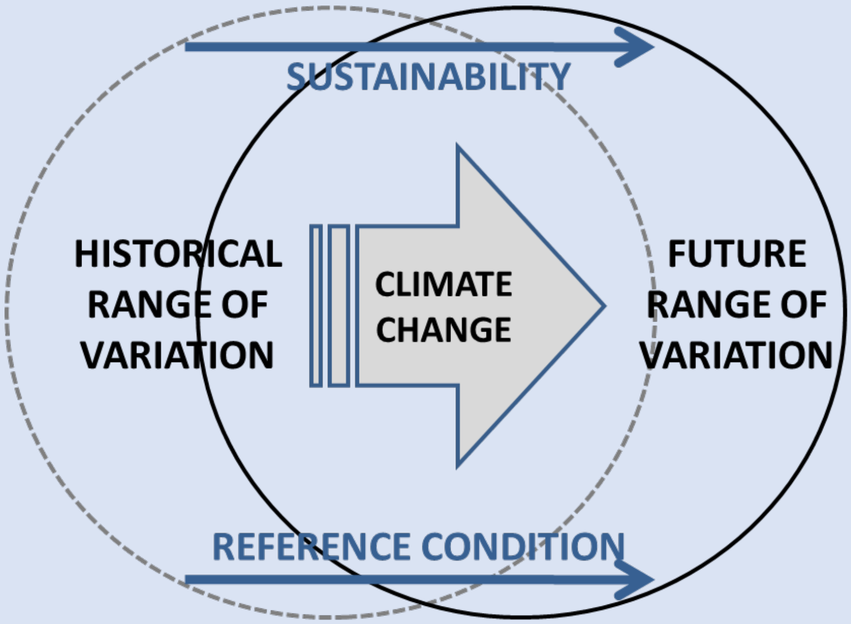
The planning regulation at 36 CFR 219.6(b) requires that the Responsible Official identify and evaluate available information relevant to the plan area for system drivers of key ecosystem characteristics of terrestrial, aquatic, and riparian ecosystems and watersheds including the influence of a changing climate (FSH Ch 10, 1909.12.3).

Developing Plan Components

- When developing integrated plan components, the Interdisciplinary Team should consider the following: Stressors, such as changes in human impacts within the plan area, disruptors of a key ecosystem characteristic by catastrophic fire, effects of a changing climate, invasive species, or water obstructions (FSH 1909.12, Ch 23.1).
- The Responsible Official should coordinate with Research and Development to develop plan components to adapt to the effects of climate change (FSH 1909.12, Ch 23.11).
- In light of possible changes in species composition under the effects of climate change and with a focus on restoration, the Agency designs plan components to provide ecological conditions to sustain functional ecosystems <u>based on a future viewpoint</u> (FSH 1909.12, Ch 23.11).

Linking desired conditions to one particular map version, data source, or science reference without regard to future conditions will create issues for Plan implementation and not just for climate adaptation. Over the life of the Plan physical features like soils may be relatively stable. Climate-related shifts in plant composition are likely to have already occurred but occur gradually and with individualistic species responses. Brusca et al.(2013) found that the majority of plant species populations have contracted at their lower elevation thresholds over the last 50 years, but the elevational ranges of other species are stable. Other studies in the region (Guida et al. 2014, Parks et al. 2019, Triepke et al. 2019) further corroborate upward life-zone shifts in recent decades. Understanding and communicating gradual shifts in site potential and ecosystem features helps to identify the adaption options best suited for meeting desired conditions which are not static to a particular area but remain applicable to the overall ecosystem, Forest, and life of the Plan.

The directives anticipated climate trends and shifting vegetation patterns in application of ecological reference models: “In some situations…the system is no longer capable of sustaining key ecosystem characteristics identified as common in the past based upon likely future environmental conditions. In these cases, the Interdisciplinary Team should establish an alternative ecological reference model for context for assessing for integrity by identifying the conditions that would sustain these key ecosystem characteristics” (FSH 1909.12, Ch10 12.13). “When natural range of variation information is lacking or the system is no longer capable of sustaining key ecosystem characteristics identified as common in the past based upon likely future environmental conditions, use an alternative ecological reference model to assess whether the existing condition of each characteristic would sustain ecosystem integrity.”



(Friggens et al. 2013)

There is increasing evidence that legacy ecosystem mapping is gradually becoming outdated and should not be viewed as static in a given planning cycle for the application of reference conditions. **Ongoing climate trends are challenging planners and vegetation specialists to adapt their roles in interpreting, communicating, and guiding clients and partners on the use of maps and other resource information in these unprecedented times**. These resources will not lose their value overnight; rather, there needs to be consideration for existing conditions, changes, and probable future conditions. Likewise for Species of Conservation Concern, managers need to recognize where habitat locally exists, where it is not likely to exist in the future, and where it may exist elsewhere as driven by climate and active management – an approach compliant with desired conditions, not to the exact acre, but to the Plan area overall.

While Plan amendments may be needed someday, the revised Plan should accommodate ongoing and future changes beyond a fixed planning cycle. For example, in areas where climate change is driving type conversion the Plan should provide direction for climate adaptation (Guiterman et al. 2022). It is not desirable or necessary to defer climate adaptation to a future policy regime, particularly given the rate of change in the Southwest and given the time it will take to educate clients and the public to gain more social license for unconventional management. Existing federal and agency policy, Plan components, and recent Department direction have all placed land managers in a good position to implement climate adaption. Plan components developed by most National Forests remain relevant and reflect a high level of ownership and expertise that are not constrained by any particular ecosystem map or data source.

Finally, it may be helpful to contrast the use of 'resistance' and 'resilience' in the conventional sense with the use of these terms for climate adaptation given that the same terms were used for RRT. 'Resistance' and 'resilience' in the conventional sense (i.e., resistance to disturbance, resilience/return of the system following disturbance) do not have the same meanings with climate adaptation (i.e., purposeful management to resist change from climate trends, and Resilience being tolerance/allowance for climate-related change with or without disturbance). The R3 Climate Adaptation Strategy makes the distinction between the two paradigms, capitalizing Resistance, Resilience, Transition in the context of climate adaptation and then limiting the use of these terms in the conventional sense particularly given how 'resilience' has lost its essence (Myers-Smith et al. 2012).

For administrative units without formalized desired conditions or with desired conditions that are no longer applicable/achievable, desired conditions should be developed or updated to represent the best inference of ecological integrity in the long term. Desired conditions are often based on the natural range of variation (NRV; FSM 1909.12.14.a), those ecosystem patterns of the prior climatic period that existed before European settlement and the significant interruption of disturbance processes; however, desired conditions need to reflect the current and foreseeable potential of the ecosystem and be derived from best available scientific information (aka BASI) to support long-term ecosystem function. While NRV likely provides a reasonable starting point in understanding conditions of ecological sustainability (Morgan et al. 1994), desired conditions are ideally adaptive to new information and conditions knowing that current climate trends are changing more rapidly than ecosystems have the capacity to respond (Millar et al. 2007). Desired conditions are used to define realistic management goals and to evaluate the success of adaptation efforts, with benchmarks identified for indicators such as those listed above.

The desired conditions worksheet in Box 6 provides a thought process for simultaneously considering adaptation options and desired conditions under likely climate impacts including the transition of ERUs and their elements. Project teams will be challenged to use the flexibility written into the desired conditions of a land management plan with the desired conditions of a likely future outcome – say, Ponderosa Pine-Evergreen Oak transitioning to Madrean Pinyon-Oak.

Box 6

Desired Conditions Worksheet – Example Ponderosa Pine-Evergreen Oak

The following worksheet example focuses on the Ponderosa Pine – Evergreen Oak ERU (Figure 24) and the relationships between climate vulnerability, adaptation options, and desired conditions. The example demonstrates how adaptation options could be integrated with the existing desired conditions from a land management plan without the need for policy amendment.

Figure 24. Ponderosa Pine - Evergreen Oak (PPE) on the Prescott NF in central Arizona.

The Ponderosa Pine-Evergreen Oak (PPE) is a fire-adapted montane forest system of warm-temperate zones that is characteristically dominated by ponderosa pine. It is distinguished from its cold-temperate counterpart, Ponderosa Pine Forest, by somewhat more even-aged dynamics and by one or more well-represented evergreen oak tree species. In the reference and desired conditions, stand dynamics support open and mostly uneven-aged conditions. Forest appearance is generally uneven-aged and open, with some areas of even-aged structure present. The ERU is dominated by ponderosa pine and evergreen oak trees are well-represented.

Desired conditions for forests and woodlands of the Southwestern Region already include some provisions for climate adaptation (USDA Forest Service 2019):

- "…tree basal area is restored or maintained at the low end of the desired range to mitigate water stress."
- "…early-mid seral species dominate over late-seral species…"
- "Encroaching species characteristic of lower life zones are maintained."

The CCVA indicates that the majority of PPE in the Southwest is of moderate to high vulnerability but that vulnerability varies considerably by location, with areas of higher vulnerability concentrated in the southern extremities of the region (Figure 25). At the context scale, PPE is less vulnerable than Ponderosa Pine Forest.

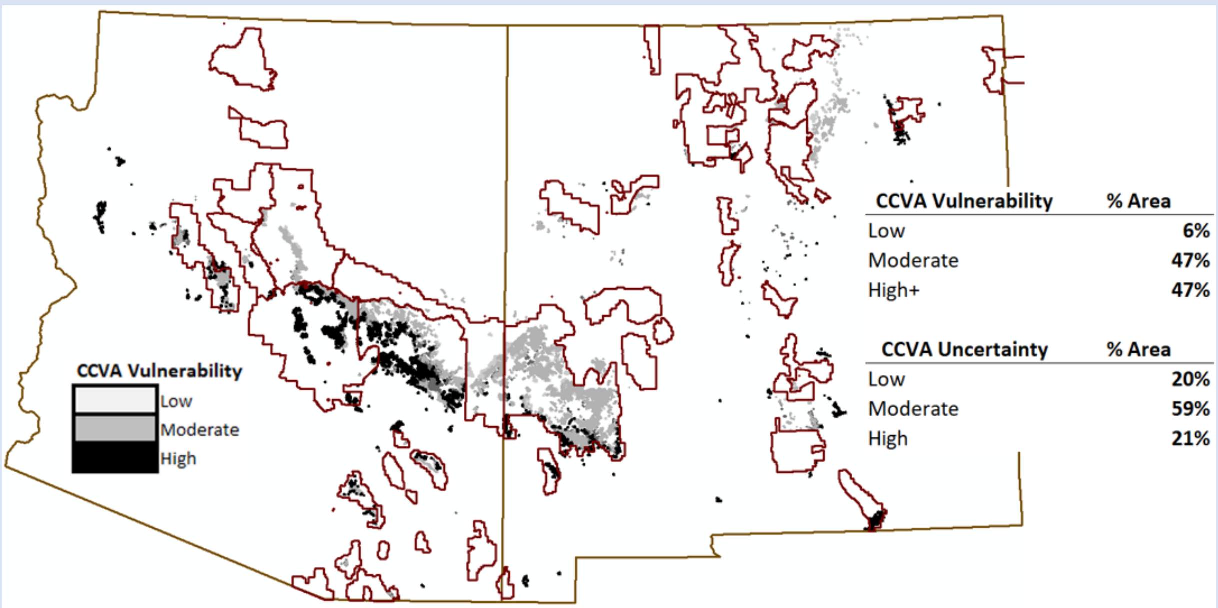


Figure 25. Spatial distribution of climate vulnerability for Ponderosa Pine - Evergreen Oak (PPE).

The previous Table 9 shows general relationships among categories of vulnerability, plausible adaptation options, and the potential risk to the long-term delivery of ecosystem services for a given option. The worksheet on the following page shows the relationship of adaptation options and desired conditions for PPE for a given extent.

Desired Conditions Worksheet

Ecological Response Unit: Ponderosa Pine – Evergreen Oak

Likely future ERUs: Madrean-Pinyon Oak, Juniper Grass

	Ecosystem Characteristic	*RESISTANCE* Ponderosa Pine – Evergreen Oak	*RESILIENCE - TRANSITION* Madrean-Pinyon Oak	Juniper Grass	Management Implications
STRUCTURE	Seral state diversity Early seral Mid seral, open Mid seral, closed Late seral, open Late seral, closed	Approx means 9% 24% 3% 60%[1] 4%	Approx means 9% 24% 3% 60%[1] 4%	Approx means 5% 25% 10% 50%[1] 10%	Low severity fires and fire surrogates remain valuable low-risk tactics for maintaining small patch sizes with all adaptation options (RRT). Mechanical treatments sometimes needed to restore open, uneven-aged structure.
COMPOSITION	Tree composition	Dominated by ponderosa pine, evergreen oaks well represented	Dominated by both evergreen oaks and pinyon, juniper can be co-dominant.	Dominated by juniper	Resistance option suggest favoring against pinyon and juniper. Resilience and Passive Transition options allowing for pinyon and juniper, while Preemptive and Responsive Transitions suggest promoting pinyon and juniper.
PROCESS	Fire regime	Primarily low severity fires with mixed-severity and stand replacement on minor extents	Primarily low severity fires with mixed-severity on minor extents	Primarily low severity fires	Likely future ERUs are also fire-dependent so that fire and fire surrogates remain valuable low-risk tactics for all adaptation options (RRT). Mechanical treatments sometimes needed to restore open, uneven-aged structure.
CONNECTIVITY	Patch size	Range from <1ac to 10s of acres, and occasional patches of even-aged structure are present	Range from <1ac to 10s of acres, and occasional patches of even-aged structure are present	Range from individual trees to about 1ac, with and occasional patches of even-aged structure	Low severity fires and fire surrogates remain valuable low-risk tactics for maintaining small patch sizes with all adaptation options (RRT). Mechanical treatments sometimes needed to restore open, uneven-aged structure.

1 – Uneven-aged tree structure

As shown in the worksheet example using the Ponderosa Pine-Evergreen Oak ERU, in some circumstance tactics such as fire, cultural burning, and fire surrogates may be consistent across adaptation options and service multiple possible outcomes in ecosystem transitions (Falk et al. 2022). In these cases, the use of such tactics can be robust to uncertainties in the trajectory of an ecosystem.

In the process of determining desired conditions under climate change, the team begins to identify likely tactics to bring into design features, prescriptions, and grazing plans. The PNW Climate Adaptation Library (http://adaptationpartners.org/library.php) is an excellent tool for exploring connections among climate impacts and adaptation approaches and tactics.

5. Considering Climate Vulnerability, Adaptation, and Greenhouse Gases in NEPA

The 2023 interim CEQ guidance (88 FR 1196) provides guidance for climate adaptation and GHGs in NEPA development. Federal proposals may also be affected by climate change so they should be designed in consideration of adaptation to a changing climate. Major federal actions may result in substantial GHG emissions or emissions reductions so that having federal leadership informed by sound analysis is crucial to addressing the climate crisis. **Agencies should analyze GHG emissions and climate adaptation design issues early in the planning and development of proposed actions under their substantive authorities. NEPA reviews should quantify proposed actions' GHG emissions, place GHG emissions in appropriate context, disclose relevant GHG emissions and relevant climate impacts, and identify alternatives and mitigation measures to avoid or reduce GHG emissions.** Specific CEQ recommendations:

- That agencies leverage early planning processes to integrate GHG emissions and climate change considerations into the identification of proposed actions, reasonable alternatives (as well as the no-action alternative), and potential adaptation and mitigation measures;
- That agencies quantify a proposed action's projected GHG emissions or reductions for the expected lifetime of the action, considering available data and GHG quantification tools that are suitable for the proposed action;
- That agencies use projected GHG emissions associated with proposed actions and their reasonable alternatives to help assess potential climate change effects;
- That agencies provide additional context for GHG emissions, including using the best available social cost of GHG (SC-GHG) estimates, to translate climate impacts into the more accessible metric of dollars, allow decision makers and the public to make comparisons, help evaluate the significance of an action's climate change effects, and better understand the tradeoffs associated with an action and its alternatives;
- Discuss methods to appropriately analyze reasonably foreseeable direct, indirect, and cumulative GHG emissions;
- Guide agencies in considering reasonable alternatives and mitigation measures as well as addressing short- and long-term climate change effects;
- Advise agencies to use the best available information and science when assessing the potential future state of the affected environment in NEPA analyses and providing up to date examples of existing sources of scientific information;
- That agencies use the information developed during the NEPA review to consider reasonable alternatives that would make the actions and affected communities more resilient to the effects of a changing climate;
- Outline unique considerations for agencies analyzing biogenic carbon dioxide sources and carbon stocks18 associated with land and resource management actions under NEPA;
- Advise agencies that the "rule of reason" inherent in NEPA and the CEQ Regulations should guide agencies in determining, based on their expertise and experience, how to consider an environmental effect and prepare an analysis based on the available information; and

- Remind agencies to incorporate environmental justice considerations into their analyses of climate-related effects, consistent with Executive Orders 12898 and 14008.

This guidance is applicable to all federal actions subject to NEPA with a focus on those for which an EA or EIS is prepared. Agencies also should apply this guidance to consider climate impacts and GHG emissions in establishing new categorical exclusions (CEs) and extraordinary circumstances in their agency NEPA procedures (Figure 26). This guidance does not establish any particular quantity of GHG emissions as "significantly" affecting the quality of the human environment.

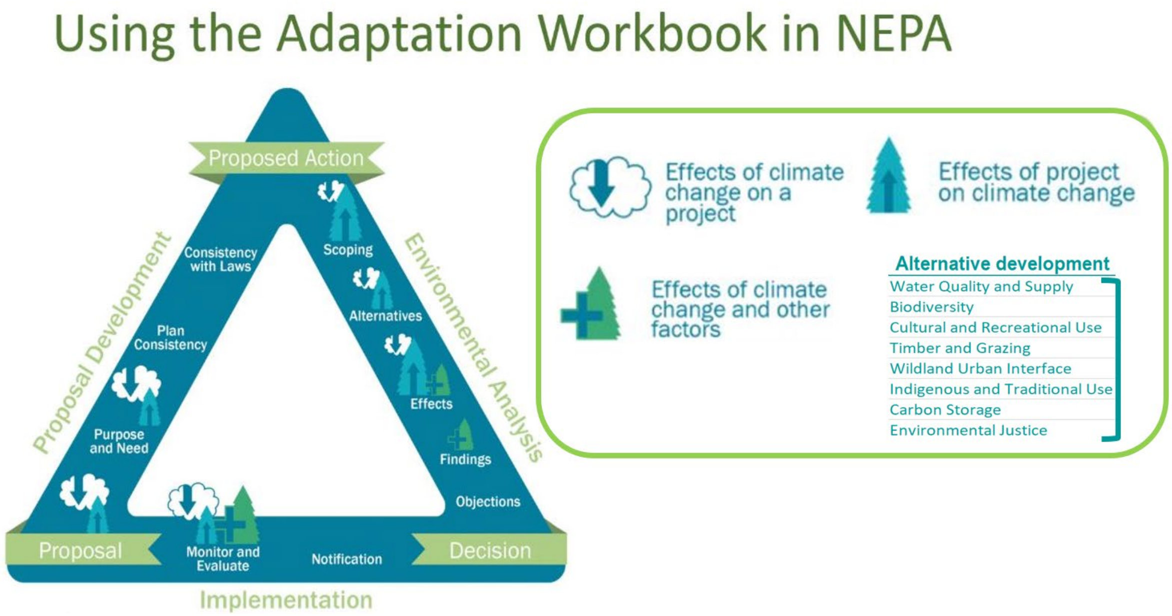


Figure 26. Interactions among NEPA processes and climate adaptation considerations.

Overview of VAN NEPA Framework

This section is an adaptation of the VAN Framework (v1) developed collaboratively by the USFS Pacific Northwest Region, USFS Pacific Northwest Research Station and Western Wildland Environmental Threat Assessment Center (WWETAC), and the USDA Northwest Climate Hub

The Climate Change Vulnerability and Adaptation NEPA Framework (VAN Framework) will help administrative units address priorities for tackling climate change, including those in the Regional Climate Action Plan (Forest Service Southwestern Region) and those outlined in the 2021 Executive Order on Tackling the Climate Crisis at Home and Abroad (EO 14008) and the 2021 USDA Action Plan for Climate Adaptation and Resilience. The USDA Action Plan identifies five broad vulnerabilities facing the USDA: decreased agricultural productivity, threat to water quantity and quality, disproportionate impacts on vulnerable communities, shocks due to extreme climate events, and stress on infrastructure and public lands. Vulnerability assessments for the Southwest document how these vulnerabilities manifest in the region, and this framework facilitates project-level consideration of specific climate vulnerabilities. The USDA Action Plan identifies several broad adaptation actions, including to build resilience to climate change across landscapes with investments in soil and forest health. Applying this framework will help units in the documentation of vulnerability, climate adaptation in project design, and effects analysis. Further revisions of this guidance will be made to ensure continued alignment with agency direction and regional priorities.

The VAN framework was developed for the consistent development and documentation of environmental compliance and disclosure and climate adaptation in project-level work[2]. The framework incorporates several key outcomes of the Climate Adaptation Workbook to this point including location, timeframe, and management goals (Step 1); climate change vulnerability and impacts (Step 2); management objectives and purpose and need (Step 3); and likely adaptation options and desired conditions (Step 4). It also includes a process for documenting specific adaptation tactics and design features (Step 5) including considerations from the adaptation menus. The framework helps interdisciplinary project teams apply climate change vulnerability assessments and document their considerations of vulnerability and adaptation in project planning by focusing on four thematic areas of project planning and National Environmental Policy Act (NEPA) analysis:

- **Assessment** – Information on the vulnerability of resources to climate change, including maps, can help managers assess project areas in light of climate change, identify key vulnerabilities, and prioritize treatments.
- **Project design** – Adaptation strategy and tactics can be incorporated into project design to ensure that proposed actions build resilience to climate change and help achieve adaptation goals.
- **Documentation** – Information in CCVAs helps interdisciplinary teams (IDTs) consider climate change vulnerability and adaptation and document these considerations in project design and analysis.
- **Integration in NEPA documents** – Documentation of climate change considerations can then be integrated into project-level NEPA documents.

The following sections outline a process for considering climate change vulnerability and adaptation with Box 7 providing an overall checklist to include in your project and administrative record to further document how the project considered climate change. We recommend that IDTs work through this process as teams.

Assessment

This step helps IDTs understand potential climate impacts at the project scale through synthesis of the vulnerability information gathered in Step 2, aided by the checklist in Box 7 and the following steps:

- Consult your local vulnerability assessments to identify historical and projected changes in temperature and aridity due to climate change;
- Consult your local vulnerability assessments, agency guidance, and more recent scientific literature to identify specific impacts expected for key resources (e.g., vegetation types, species, recreational activities, carbon, GHGs, local communities) in your project area;
- Look at spatial information from your local vulnerability assessments (e.g., CCVA, ARCCVA, SEVA) for impacts on changes in peak flows, stream temperature, vegetation type changes, flood vulnerable roads and infrastructure, etc. to understand the relative vulnerability of the project area.
- Consider recent and ongoing changes, stressors, and disturbances related to climate change (e.g., drought, fires, flooding, insect outbreaks) that are affecting current conditions in the project area; and
- Summarize information on vulnerability and potential impacts
  - What resources are most vulnerable to climate change effects?
  - What vulnerabilities are most relevant to the project area?

[2] While this document is focused on project-level planning, it may also be useful for other types of strategic and programmatic planning (e.g., Watershed Restoration Action Plans, 5-year integrated restoration plans).

- How are climate-driven changes, stressors, and disturbances affecting current conditions in the project area?

Project Design

Identify adaptation options, desired conditions, and specific tactics that address vulnerabilities identified in Step 2 and the Assessment phase of VAN. Consider specific impacts described for Step 2 and consult the adaptation menus and the Adaptation Library for ideas. IDTs may also want to reference the scientific literature to identify adaptation measures.

For developing management alternatives, the goal is to craft multiple and diverse alternatives to address the management objectives, the adaption options selected, and the desired conditions for the project area. While it is preferable that all alternatives are climate smart, it is likely that as some managers transition into a climate adaptation paradigm that only one or some alternatives integrate climate adaptation in earnest – but it would at least be a start. The challenge under a climate adaptation paradigm is to create alternatives that represent the full range of potential solutions rather that a set of possible actions that are too narrow. This new paradigm demands novel approaches to the circumstances and uncertainties of climate trends and for which a conventional restoration paradigm may be counterproductive to promoting change (Transition) or at least allowing for change (Resilience). Though broad and creative brainstorming may impose a process burden, developing alternatives with a fuller breadth of thought and possibilities may put managers in a better place for understanding the eventualities of climate change and more likely to capture meaningful solutions. There are constructive ways to limit unmanageable proliferation of alternatives with a structured and collaborative process.

Summary questions to consider for project design:

- What adaptation measures do management alternative and the proposed action include?
- Do you need to modify the timing, intensity, or location of your proposed action to better adapt to climate change?
- What additional adaptation measures could management alternatives include to address vulnerabilities identified in Step 1and to ensure that the project achieves its purpose and need?

Documentation of Climate Change Considerations

Develop a statement that summarizes how you are considering climate change vulnerabilities and adaptation in your project. The template below will help you develop a statement that is 2-4 paragraphs in length; however, you may want to develop a shorter or longer statement depending on your specific needs.

> Climate change is currently affecting forests and rangelands and is expected to intensify in the future. For the [*National Forest*], climate change projections suggest that temperature will increase by [*XX–XX°C*] over the 21st century. Precipitation patterns are also expected to change, but the direction and magnitude of precipitation changes are more uncertain [(cite vulnerability assessment*); consider modifying this sentence if you know specifics about climate effects on precipitation (e.g., changes from snow to rain)*]. The peer-reviewed climate change vulnerability assessment, [*insert title of vulnerability assessment*], analyzed how these changes will impact valued ecological, hydrological, and social resources on the [*National Forest*]. Information from the assessment informed the development and analysis of the project area's proposed action.

Use information from the Assessment step of the framework process to describe the climate change vulnerability of the project area and/or its associated resources.

Example (reword/edit as needed): The [*Project Name*] project area is located in [*watershed, vegetation type, elevation, etc.*] where [*vegetation conditions, aquatic conditions, resource X*] is/are currently experiencing stress from [*recent climate changes, recent disturbance or stressor, past management legacy, etc.*]. *[Add a sentence describing recent changes, disturbances, stressors]*. Projections indicate the project area is exposed to several climate change vulnerabilities that further places the [*project area and/or key resources*] at risk [*(cite vulnerability assessment or other scientific literature)*].

Key vulnerabilities of [*project area or key resources*] to climate change include:

- [*List vulnerabilities and anticipated impacts; be specific; consider connecting vulnerabilities to current conditions and recent/ongoing stressors/disturbances*]
- [***Example:*** *Increased disturbance potential*]
- [***Example:*** *Increased peak stream flows*]
- [***Example:*** *Increased stream temperatures*]
- [*etc.*]

Specific adaptation options and tactics included in the proposed action include:

- [*List adaptation options and tactics that are included in the project*]
- [***Example:*** *Reduce stand density to reduce impacts by drought and other disturbances and to allow for Passive Transition*]
- [***Example:*** *Replace undersized culverts to reflect expected changes in peak stream flows*]
- [***Example:*** *Restore vegetation providing stream shading to help regulate stream temperatures*]
- [*etc.*]

These adaptation actions align with adaptation options, desired conditions, and tactics identified for the project. [*Add a sentence on how project design includes adaptation measures or was modified to address climate change vulnerabilities.*] [*(Cite vulnerability assessment or other scientific literature)*].

[*Paragraph to include for projects that contribute to the goal of building climate adaptation.*] Executive Order 14008 Tackling the Climate Crisis at Home and Abroad (EO 14008) establishes a government-wide approach for addressing the risks posed by climate change. The USDA Action Plan for Climate Adaptation and Resilience and the Regional Climate Action Plan identify actions that can be implemented to reduce vulnerability and bolster adaptation to climate change. Specifically, the USDA Action Plan identifies shocks due to extreme weather events and stress to infrastructure and public lands as two key vulnerabilities facing the US Forest Service and other land management agencies. The plan also identifies building for climate adaptation across landscapes with investments in soil and forest health. This project addresses these vulnerabilities and contributes to the goal of climate adaptation by *[insert text; e.g., promoting species adapted to more frequent fire, reconnecting streams and floodplains in areas where flooding is to become more impactful, restoring streamside vegetation to maintain low stream temperatures].*

Box 7

Checklist for Documenting Climate Vulnerability and Adaptation in Project NEPA

This checklist can be added to your record to further document how the project considered climate change.

Assessment

Identify your local vulnerability assessments and use them to address the following	*[Insert reference for vulnerability assessments]*
How have temperatures changed in the past century?	*[E.g., number of degrees increase since 1970]*
How much are temperatures projected to increase?	*[XX-XX by Year]*
What are the key vulnerabilities and expected impacts for the project area or associated resources?	*[Describe key climate vulnerabilities and impacts; include page references to vulnerability assessments or other scientific literature, if applicable]*
Consult spatial information on climate vulnerability assessments (or from other sources)	*[Identify vulnerability assessment maps that you considered; include page or figure # references]* *[note your conclusions from maps]*
In addition to future impacts, consider how climate change is affecting recent and ongoing changes, stressors, and disturbances.	*[Identify recent/ongoing changes, stressors, and disturbances that may be affected by climate change (e.g., fire, flooding, and drought events)]*

Project Design

Identify adaptation measures (i.e., options and tactics) that address vulnerabilities identified in **Step 1**. Consult the impacts section of this strategy, the adaptation menus, the Adaptation Library, and scientific literature for ideas.	*[Describe adaptation options and tactics that are relevant. Include page references to your vulnerability assessment or other scientific literature, when relevant.]*
What adaptation measures do your management alternatives include?	*[Respond to question.]*
Do you need to modify the timing, intensity, or location of your proposed action to better adapt to climate change?	*[Respond to question.]*
What additional adaptation options, desired conditions, or tactics could your proposed action include to address vulnerabilities and impacts identified in **Step 1** and to ensure that the project achieves its purpose and need?	*[Respond to question.]*

Documentation of Climate Change Considerations

Using the previous steps and the climate change considerations template, develop a statement that summarizes how you are considering climate change impacts and adaptation measures in your project.	*[Write statement using template; include written statement at the end of this document]*

Integration in NEPA Documents

Insert template statement in its entirety in the Project Background or Introduction sections. Also consider including portions of your statement in:	*Check the sections of the NEPA document where you included climate change information and the climate change considerations template.*
Purpose and need	*[ ]*
Proposed action	*[ ]*
Affected environment	*[ ]*
Environmental consequences. Include text from the template in describing climate change effects. Make sure to include the language from the carbon impacts section (Step 2 of this workbook).	*[ ]*
When relevant, consider including in scoping, project design criteria, and decision elements of NEPA	*[ ]*

Integration in NEPA Documents

Overview of NEPA Process

Include your statement from the template above in its entirety in the Project Background or Introduction section of your NEPA document. This allows for easy identification of projects for Climate Action Tracker reporting. Consider including parts of your statement from the template in other sections including:

- Purpose and need – If the project purpose and need statement includes climate adaptation, be clear about that and make sure to cite your vulnerability assessment.
- Management alternatives and proposed action – Consider including adaptation options and tactics identified in the template in the description of management alternatives for the project. Cite your vulnerability assessment. Interim 2023 guidance from the Council on Environmental Quality (CEQ) includes a recommendation for agencies to leverage early planning processes to integrate greenhouse gas (GHG) emissions and climate change considerations into the identification of management alternatives and proposed actions and potential mitigation measures (88 FR 1196).
- Affected environment – Include discussion of climate vulnerability and projected impacts from the template. For each alternative, analyze and document the environmental effects including likely climate impacts with and without climate adaption (no-action alternative) in terms of magnitude, duration, and significance. Figure 27 shows an overview of indicator-based analysis of affected environment and environmental consequences. Remember that climate trends can be a threat multiplier (Figure 28). The interim CEQ guidance also states that agencies should **consider: (1) the**

potential effects of a proposed action on climate change, including by assessing both GHG emissions and reductions from the proposed action; and (2) the effects of climate change on a proposed action and its environmental impacts.

- Environmental consequences – Consider including text from the template in describing effects of climate change on the project. Make sure to include language from the carbon impacts section (Step 2 of this workbook) on carbon and greenhouse gases.

More on Affected Environment and Environmental Consequences (interim CEQ guidance)

Analysis for NEPA should consider the ongoing impacts of climate change and the foreseeable state of the environment, especially when evaluating project design, siting, and reasonable alternatives (CEQ 88 FR 1196). In addition, climate adaptation is an important consideration for agencies contemplating and planning actions. In considering the effects of climate change on a proposed action, the agency should **describe the affected environment for the proposed action based on the best available climate forecasts which often project at least two possible future emissions scenarios. The temporal bounds for the description of the affected environment are determined by the projected initiation of implementation and the expected life of the proposed action and its effects**. The analysis also should:

- Consider how climate change can make a resource, ecosystem, human community, or structure more vulnerable to many types of effects and lessen its resilience to other environmental effects.
- Summarize and incorporate by reference relevant scientific literature concerning the physical effects of climate change.
- Remain aware of the evolving body of scientific information as more refined estimates of the effects of climate change, both globally and at a localized level, become available. Use the most up-to-date scientific projections available, identify any methodologies and sources used, and where relevant, disclose any relevant limitations of studies, climate models, or projections they rely upon.
- Identify and use information on future projected GHG emissions scenarios to evaluate potential future impacts (such as flooding, high winds, extreme heat, and other climate change-related impacts) and what those impacts will mean for the physical and other relevant conditions in the affected area
- Consider climate change effects on the environment and on proposed actions in assessing vulnerabilities and resilience to the effects of climate change such as increasing sea level, drought, high intensity precipitation events, increased fire risk, or ecological change.
- Consider the likelihood of increased temperatures and more frequent or severe storm events over the lifetime of the proposed action, and reasonable alternatives (as well as the no-action alternative).

Figure 27 shows the stepwise approach for selecting indicators, analyzing effects, determining consequences, and documenting the process. The R3 Ecosystem Analysis Framework includes core indicators representative of the four pillars of composition, structure, connectivity, and process (Weisz et al. 2009, Triepke et al. 2016; FSH 1909.12, CHAP. 40, SEC. 43.12) as a basis for assessing ecological integrity and the influence of current and future climate on the proposed action and its environmental impacts.

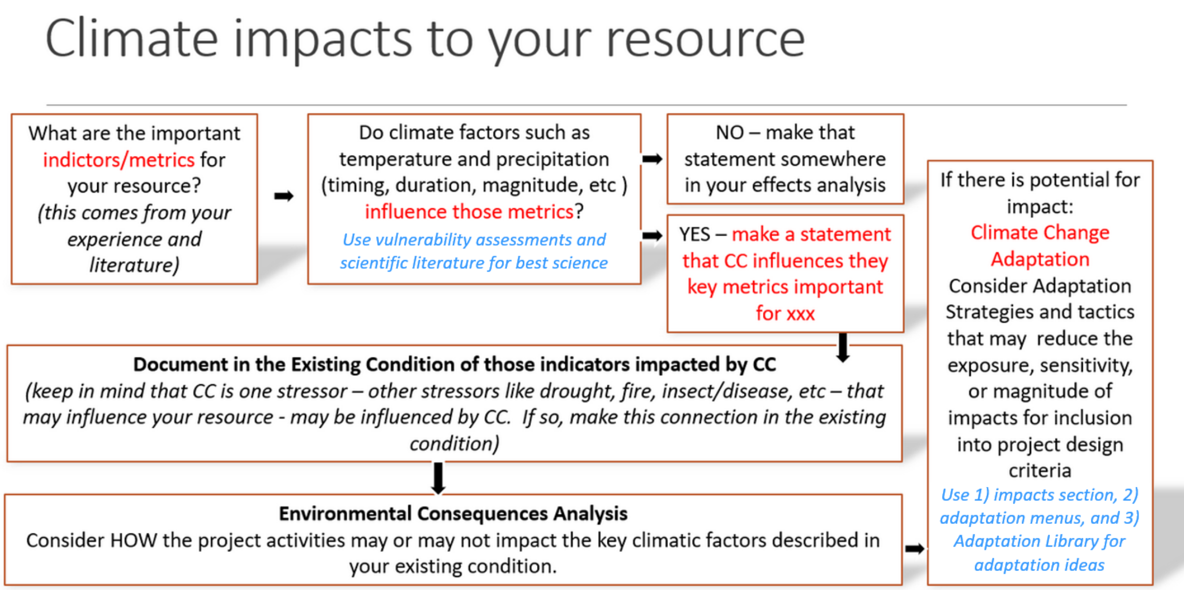


Figure 27. Overview or process in determining environmental consequences and the need for climate adaptation.

The SEVA could also be relevant when assessing benefits and impacts of the proposal to vulnerable communities, particularly when environmental justice has been a focus of the management objectives or purpose and need. Agencies should consider their ongoing efforts to incorporate environmental justice principles into their programs, policies, actions, and activities, including the environmental justice strategy required by Executive Orders 12898 and 14008, and consider whether the effects of climate change in association with the effects of the proposed action may result in disproportionately high and adverse effects on any local communities (Figure 28).

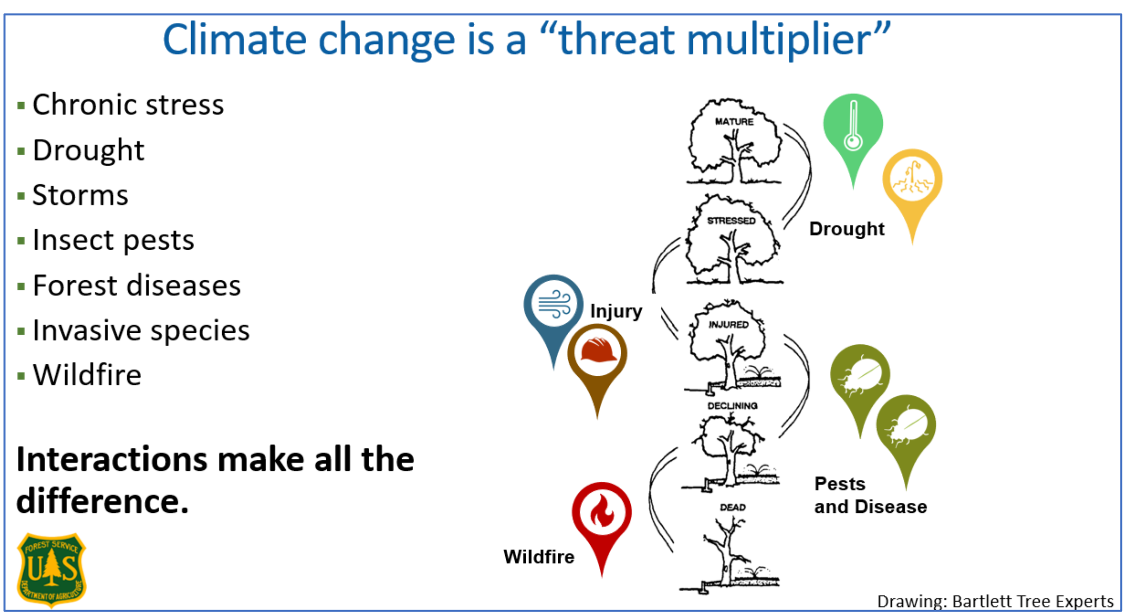


Figure 28. Stressors that may interact with the climate change and the proposed action to impact ecosystems and local communities and contribute to cumulative effects.

Where the analysis identifies climate-related risks to a proposed action or to the area affected by the proposed action, the agency should consider possible climate adaptation options and tactics as well as existing State, Tribal, or local adaptation plans (Appendix E) that could be employed to manage those effects. The agency should indicate whether the proposed action includes measures to adapt to climate change and, if so, describe those measures and the climate projections that informed them and consider whether any potential measures undertaken to address a proposed action's climate risk could result in any undesirable or unintended consequences.

Document the expected effectiveness of adaptation measures and consider what climate-specific BMPs could come into play. Also consider adaptive management, which would be appropriate for any proposal when effects of potential adjustments identified are included in the estimated effects. Documentation of the alternative development process and the conclusions of the effects analysis are useful to the decisionmaker and to the public in understanding trade-offs and consequences of management actions planned and deferred. Additional explanation and disclosure will be needed for novel climate adaptation terms, concepts, and analysis involving vulnerability, impacts, and adaptation options and tactics. A preferred alternative is then selected from among the alternatives developed and analyzed in the lead up to a decision and implementation of the project.

Broad Programmatic NEPA Review to Incorporate by Reference

In the context of long-range energy, transportation, natural resource, or similar programs an agency may decide that it would be useful and efficient to provide an aggregate analysis of GHG emissions or climate change effects in a programmatic analysis and then incorporate it by reference into future NEPA reviews. These broad analyses may occur through programmatic NEPA documents or they may occur through other processes by which agencies conduct analyses or studies at the national or other broad scale level (e.g., landscape, regional, or watershed) to assess the status of one or more resources or to determine trends in changing environmental conditions. In appropriate circumstances, agencies may rely on programmatic analyses to make project-level NEPA reviews more efficient by evaluating and analyzing effects at an earlier stage and at a broader level than project-specific actions. Agencies also can use programmatic analysis to analyze emissions from related activities in a given region or sector, or to serve as benchmark against which agencies can measure site-specific actions. Examples of project- or site-specific actions that may benefit from being able to tier to a programmatic NEPA review include: siting and constructing transmission lines; siting and constructing wind, solar or geothermal projects; conducting wildfire risk reduction activities such as prescribed burns or hazardous fuels reduction; approving grazing leases; granting rights-of-way; and approving site-specific resilience or climate adaptation actions.

IMPLEMENT Adaptation Strategy (Workbook Step 5)

This step covers aspects of implementation, including the final phases of proposal development and analysis in a NEPA project (Table 1 and Figure 26), and processes for linking the strategy to specific adaptation tactics.

Adaptation tactics are actions taken for a project to implement adaptation options and the selected management alternative. Tactics occur in lead up to and during project or program implementation and can begin with design features or the selection of treatments. Tactics may be expressed in management prescriptions, fuels planning, range management plans, the implementation of BMPs, or other on-the-ground measures aimed at achieving desired conditions.

A tactical level guide will be developed separately from this strategy in partnership with managers and scientists of the region.

Common Tactics and Design Features – Upland Ecosystems

Each adaptation option is coupled with active or passive management to achieve desired conditions for selected ecosystem characteristics. Tactics are identified for active management. Below is a listing of general treatment categories previously used by the Southwestern Region for ecosystem modeling and contrasting management alternatives. This listing may be useful in thinking about different types of tactics and how they might service climate adaptation and selected management alternatives.

All ERUs

- Prescribed burning
- Wildfire
- Revegetation and planting
- Grazing timing
- Grazing authorized use

Forest and woodland ERUs

- Intermediate harvest, thinning
- Commercial thin
- Uneven-aged management harvest (group or individual tree selection)
- Regeneration harvest, shelterwood
- Regeneration harvest, clearcut or seed tree
- Coppice stand clearing
- Sanitation or individual tree harvest
- Mechanical fuels treatment (lop and scatter, hand thinning, pile burning, mastication, mowing, prescribed burning prep)

Woodland, shrubland, grassland ERUs

- Fuelwood harvest or removal
- Mechanical woody removal
- Chemical woody removal
- Herbicide vegetation control

Many tactics will be shared among adaptation options of RRT and their particular application is likely to be further driven by current, desired, and future conditions. An adaptation tactic is practicable if it is both effective (if it will help meet desired conditions) and feasible, with both of these qualities increasing the likelihood of success. Consider the benefits, drawbacks, and barriers associated with each tactic in order to determine the practicability of meeting management objectives and desired conditions using that tactic.

New or modified management tactics may be needed to address challenges to ecosystem management brought about by climate change. The PNW Climate Adaptation Library (http://adaptationpartners.org/library.php), the Fire Menu (Sample et al. 2022; Box 4), Indigenous knowledge (e.g., NNDFW 2018, NCAI 2022), and A Tribal Adaptation Menu (TAMT 2019) are excellent resources for exploring the interplay among climate impacts, adaptation approaches, and tactics.

Drought Tactics – Rangelands

Livestock grazing is the most widespread use of public lands in the Southwest and an important ecosystem service to local economies. Vulnerability and impacts identified in Step 2 indicate the need for flexibility in stocking rates, herd size, herd movement, the use of supplemental feed and other tactics:

- Flexibility in cattle numbers, grazing periods, and type of operation could help to address changes in production while anticipating increasing variability in precipitation;
- During drought animal numbers could be reduced in response to lower forage production and to avoid competition among producers for forage alternatives;
- Changing the seasonality of use to avoid the greatest temperature exposures, developing shade, or minimizing distances to water sources may work to alleviate heat stress on livestock;
- Utilization of forage should never exceed 60 percent (Sprinkle 2011);
- If forage is limited during drought supplemental feed may be necessary to provide sufficient protein and to increase weaning weights and conception rates;
- Maintaining several water sources to provide sufficient water to mitigate drought and heat effects on livestock;
- Placing water sources in areas that are infrequently grazed will increase overall forage supply since cattle will use 80% of allowed forage up to one mile distance from a water source, but only 40% at one and a-half miles and 20% at two miles distance (Sprinkle 2011); and
- Changing to cattle breeds that are more heat tolerant (e.g., Brahman or Criollo) or changing livestock species (e.g., cattle to goats) may offer suitable adaptation in some instances for increased temperatures, greater aridity, and reduced forage production.

In a 2013 drought workshop among ranchers in southern Arizona, ranchers considered these and other tactics. The ranchers generally agreed that drought has become the norm and that maintaining stocking rates below carrying capacity favors resilience (Brugger et al. 2013). Other adaptation measures and implementation issues summarized at the workshop are listed in Table 10.

Table 10. Drought management tactics implemented by southern Arizona ranchers and implementation issues (adapted from Brugger et al. 2013)

Herd Management	Pasture Management	Water Management	Issues
Stock below carrying capacity	Add water sources to use more pasture	Increase number of water points	Reliable water sources
Flexibility in terms of numbers	Flexible pasture rotation	Use wells, solar pumps, and pipelines	Lack of flexibility in land management agencies
Quality of livestock over quantity	Low utilization	Deepen dirt tanks to reduce evaporation	Cost and labor to improve infrastructure
Maintain core herd with genetics and behavior adapted to the area	Rest pastures; one-year drought reserve of forage	Line dirt tanks to reduce leakage	Lack of agency-rancher communication
Different classes of livestock (spring and fall calves, yearlings, and stockers)	Off-ranch grazing	Haul water	
Provide several different water sources to disperse the herd			

Livestock operators should consider long-term climate and drought projections in their range management plans and implement monitoring to gauge success of the plan and to facilitate adaptive management (Reeves et al. 2014). Forage production and quality should be included in the monitoring to assess whether the nutritional requirements of livestock are being met.

Considerations for Climate-Smart Tree Planting

Background

Without climate adaptation in reforestation, the combination of rapid climate change and increased fire activity suggest that can expect higher rates of planting failure (e.g., Koehn et al. 2022) and simpler, less diverse landscapes. These conditions will lead to decreased ecosystem services such as loss of viable seed sources at the site level, soil loss, decreased site productivity, and compromised watershed quality, net loss of carbon storage (sinks to sources), and a net loss of animal and plant habitat. Socioeconomically vulnerable communities may be disproportionately affected by decreased ecosystem services.

Given wildfire trends and the need to augment tree planting on public lands, Congress passed the Repairing Existing Public Land by Adding Necessary Trees or REPLANT Act into law in November of 2021. This act includes a clear mandate to address post-wildfire and other reforestation needs and increased resources for tree planting by removing the funding cap of the Reforestation Trust Fund. The Forest Service subsequently increased funding and capacity for tree planting per direction set forth in the June 23rd, 2022, Secretary's Memorandum:

(3) Scale up and Optimize Climate-Smart Reforestation.

By April 22, 2023, and in accordance with EO 14072, develop strategic guidance and an implementation plan to:

(a) Immediately increase climate-informed afforestation, agroforestry, and reforestation (planting and natural regeneration) including critical consideration given to climate-informed reforestation in areas such as fire scars that can help avoid carbon loss from forest soils; and

(b) Increase federal cone and seed collection, and seed and seedling nursery capacity sufficient to meet anticipated demand, including collaboration with additional USDA agencies, and other federal, state, and local government, Tribal and private-sector partners.

The Forest Service is updating reforestation policy within the silviculture manual (FSM 2470) to make clear allowances for climate-smart reforestation and assisted migration (climate smart). The need for revising the manual was deemed "significant" by the OMB with implementation guidelines to be developed and applicable across the agency. Reforestation policy in the current silviculture manual is vague regarding planting across seed zones, yet the assumption is that in most instances the seed collected at a specific elevation zone will no longer be adapted to that elevation zone, even more the case with greater levels of climate vulnerability. Revision of the manual will provide explicit allowance for assisted migration when the balance of scientific information indicates that current seed zones may lead to maladapted forests.

Regeneration and Forest Ecology

Multiple observational studies show potential for range contractions in western conifers and that forest extent is declining at the same time there are changes in which species regenerate on a given site (Bell et al. 2014, Hill and Field 2012, Parks et al. 2019). Other studies tracking elevational trends suggest rapid upward shifts in plant populations of 15m or more per decade (Brusca et al. 2013, Guida et al. 2014, Kelly and Goulden 2008) that is corroborated by climate records that show an increase in mean annual temperature of 1.6ºF for the region over the past century (Gonzalez et al. 2018) and an increased rate of warming (Gutzler and Robbins 2010). On average the recruitment of tree species in the western US now occupies a smaller footprint than their conspecific adults with greatest differences represented at the range margins of climate maxima such as lower elevations and southern extents (Dobrowski et al. 2015).

Predictive models that are calibrated only to climate envelopes likely forecast greater declines than those that also consider forest structure (Dowbrowski et al. 2015) owing to the ability of mature tree canopies to mitigate declines inferred by climate alone. The importance of the overstory as a seed source and in buffering microclimates to overarching warming trends hinges on the absence of stand replacement disturbance that could otherwise trigger rapid and permanent range shifts and tree composition changes (Elias et al. 2015, Hill and Field 2021). Trends in climate and large fire events, as with the 2022 season in the Southwest, favor extensive and large treeless openings. Paleoecology suggests that, without assistance, the current rate of climate change is outpacing the landscape's rate of adjustment, with late-seral species taking even longer to adjust (Axelrod 1958, Cole 2010) and with high-severity fire catalyzing long-term change with each event. Figure 29 shows the climatic timeline as a backdrop for a tree planted in the year 2022.

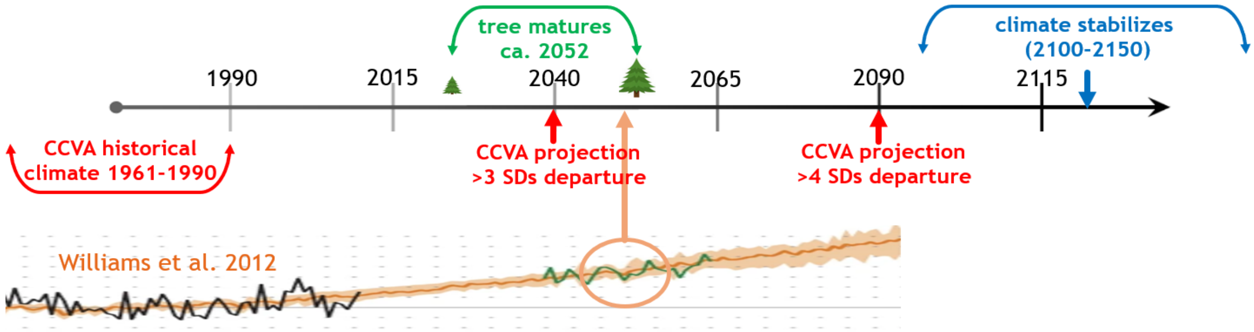


Figure 29. An approximate timeline of unfolding climate circumstances in the 21st century as context for tree planting in the near term including an excerpt from Williams et al. 2013.

The reference climate for CCVA was the 30 years leading up to 1990. Future departure shown as three and four standard deviations later in the 21st century and with climate not expecting to stabilize until late in the century or early the following century. Assuming no mortality, a tree planted in 2022 will take about 30 years to mature and develop resistance to scorching and other threats including drought. Just before the tree matures in the timeline of Figure 29, it is expected that summer temperatures will depart the historical range of variation altogether (Williams et al. 2013) and at about the same time that a site rated as 'very high' reaches three standard deviations departure from the reference climate. Figure 30 shows the shifts between the current (circa 2017) distribution of life zones and the hypothesized future distribution based on CCVA to suggest a climate-driven loss of forested area of about 3.3% decade and concentrated at the lower elevational margins of forest-woodland life zones and not accounting for fire-driven type conversions (Guiterman et al. 2022); however, **this projection likely overestimates the rates of species migration (Laughlin et al. 2011) and, without intervention, vegetation patterns are likely to become simpler and less diverse** with greater propensity for endemism.

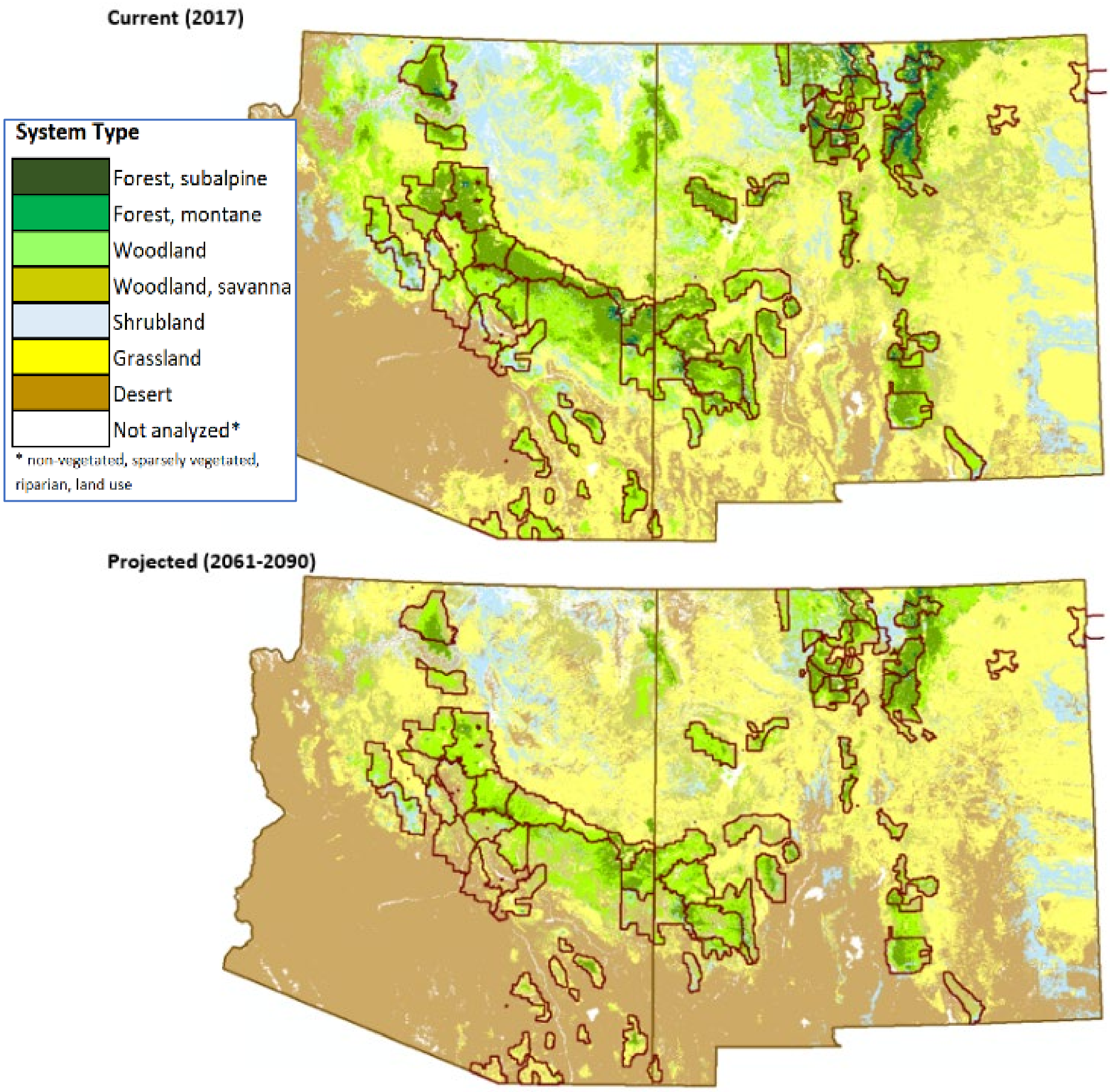


Figure 30. Life zone mapping for the Southwest showing the current life zone distribution (top) (Moreland et al. 2017) and the hypothesized distribution of life zones according to CCVA (bottom).

Shifting Site Potential

Climate records for the Southwest show an increase in mean annual temperature of 1.6°F over the past century (Gonzalez et al. 2018). The rate of warming has since increased and another two-degree change is expected by late 21st century (Gutzler and Robbins 2013). Temperature changes translate to an estimated life-zone shift of about 12m upward per decade at the turn of last century to an eventual 50m per decade by late 21st century according to established temperature-life zone relationships (USDA Forest Service 1986). These changes are corroborated through observation and resampling of old vegetation transects and plots (Kelly and Goulden 2008, Brusca et al. 2013, Guida et al. 2014) that indicate an upward shift in site potential of at least 15m per decade. Validation of the CCVA with independent assessments and observational data (Triepke et al. 2019) likewise suggest shifts in community composition and structure consistent with warming and trailing edge conditions.

A preliminary analysis of tree planting records on Forest Service lands of the Southwest also suggests a trend in shifting site potential in montane forests. All planting data in the agency's Forest Activity Tracking Systems (FACTS) were obtained and processed to assess survival relative to climate vulnerability predictions and life zone position:

- FACTS data were extracted for planting monitoring for the Southwestern Region (n=1,863)
- Repeat monitoring data were eliminated to focus only on the most recent survival survey at a given location (n=832)
- The dataset was further winnowed to plantings for ponderosa pine (n=617) and Douglas-fir (n=56) since sample numbers for all other species was too low (n<14)
- Ponderosa pine data were stratified by life zone (Ponderosa Pine Forest and Ponderosa Pine-Evergreen Oak (n=430) and Mixed Conifer - Frequent Fire (n=163)
- Monitoring data were placed in survival categories, either low (<33%), moderate (33-66%), or high (>66%) survival, to facilitate chi square analysis with CCVA data.
- Monitoring data were attributed by CCVA vulnerability ratings, either low, moderate, or high+. Only 8 samples occurred in low vulnerability so that low and moderate vulnerability categories were combined for analysis.
- **Our working hypotheses were that 1) survival is greater in the mixed conifer life zone than in lower montane (ponderosa pine) and 2) there is an inverse relationship between survival and climate vulnerability predictions**
- Analysis results were derived through basic statistics and chi square
- The analysis procedure was repeated to confirm methods and consistent results

The planting records do not constitute a statistical sample and this was the first time CCVA was validated with sources other than a probability sample (FIA) or independent census data (e.g., tree canopy cover). An assessment of the dataset showed that 1) sample proportions for vulnerability categories in the monitoring data large align with regionwide CCVA proportions and 2) low CV values (coefficient of variation) in ponderosa pine and moderate CV for Douglas-fir suggest that the data may have value for hypothesis testing.

Comparison of CCVA Map Area and Survival Database

Data Source	Low Vulnerability	Moderate Vulnerability	High+ Vulnerability
Database sample %	2%	38%	60%
CCVA regionwide map %	5%	43%	52%

Average survival was 56% for ponderosa pine plantings and 49% for Douglas-fir. Life-zone stratification of the data showed greater survival for ponderosa pine seedlings in the mixed conifer zone than in the lower montane (and higher still in the spruce-fir zone but low sample numbers preclude reporting).

Sample Numbers and Survival by Species

Species Planted	n	Avg Survival	SD	CV
Engelmann spruce	13			
Ponderosa pine	617	56%	26%	46%
Colorado blue spruce	1			
Quaking aspen	11			
Douglas-fir	56	49%	35%	72%

Ponderosa Pine Survival

ERU	Overall Survival
Ponderosa Pine Forest	54%
Mixed- Conifer Frequent Fire	65%

Sample numbers limited chi square analysis to ponderosa pine planting in the lower montane. Results for 'high survival' show that low-moderate vulnerability settings have 47% greater than expected survival and high vulnerability settings have nearly a third less than that of expected. The hypothesized inverse relationship between vulnerability and survival is also substantiated by looking across deviation from expected values for the remaining survival categories (e.g., 'low survival' is -29% less than expected).

PLANTING SUCCESS (USDA Forest Service FACTS database tree planting records as of 2019)
Ponderosa Pine (Ponderosa Pine Forest and Ponderosa Pine-Evergreen Oak ERUs)

Tree Planting Survival	Observed **Low-Mod Vuln**	Observed **High+ Vuln**	Observed **Total n**	**Expected Percent**	Deviation from Expected **Low-Mod Vuln**	Deviation from Expected **High+ Vuln**
Totals	172	258	430			
Low Survival (<33%)	27	68	95	22%	-29%	19%
Moderate Survival (33-66%)	72	139	211	49%	-15%	10%
High Survival (>66%)	73	51	51	12%	47%	-31%

While the analysis did not control for site conditions (e.g., soils, slope, aspect) the strength of the results suggest an increasingly small probability of coincidence for the hypotheses tested. Slope values in the database appear to be less than 30%. Analysis results in summary:

- Planting survival data provide an additional validation of CCVA projections and tree regeneration relationships
- Areas rated higher in vulnerability reflect lower planting success. The results align with earlier CCVA validation using FIA that showed much greater likelihood for the recruitment of species of lower life zones in higher vulnerability settings and vice versa for low vulnerability settings.
- The results corroborate patterns of both shrinking ranges and changes in which species are regenerating successfully at a given area (Bell et al. 2014, Hill and Field 2021).

Taken together, this information substantiates the use of CCVA to support climate adaptation in planting and provide an additional hedge for planting success. Conventional reforestation that assumes the adaptive capacity of ponderosa pine or that seed collected at a given elevation zone will still be adapted to that elevation zone, let alone with additional warming, is likely to result in greater planting failure than reforestation that is at least climate-informed. Figure 31 shows CCVA vulnerability predictions for the Ponderosa Pine Forest ERU and that vulnerability generally increases to the south and west, consistent with expectations for the Southwest (Elias et al. 2015).

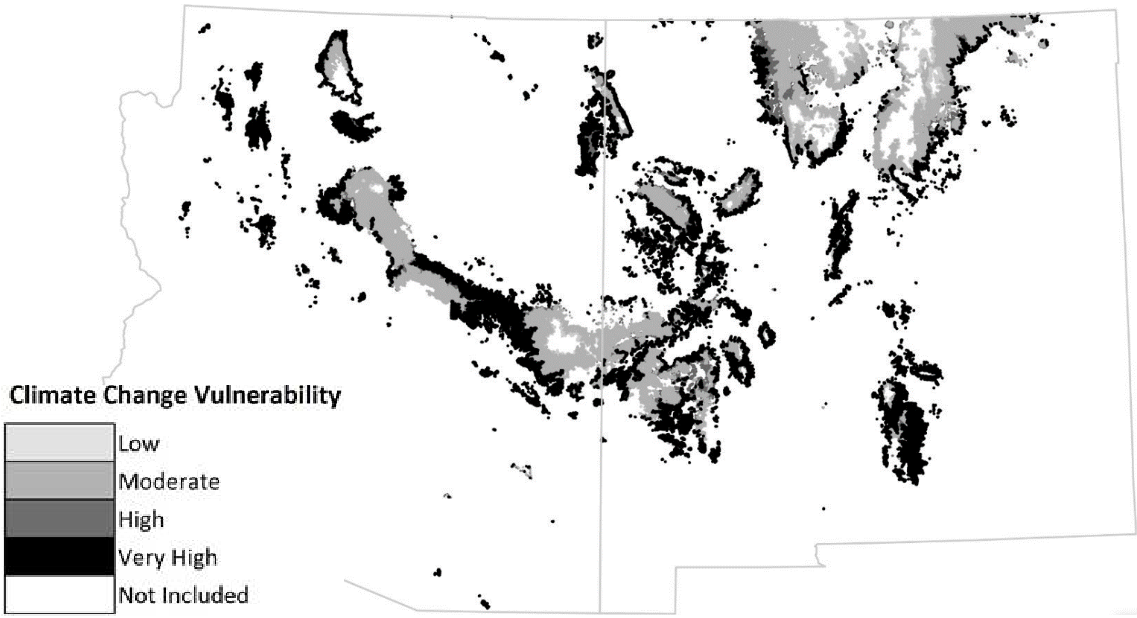


Figure 31. The CCVA vulnerability predictions for Ponderosa Pine Forest in Arizona and New Mexico.

The preliminary planting survival results shared here further dispel anecdotes that envelope-based assessments may have less value for reforestation purposes owing to the moderating effects of forest overstory, already dispelled by signals in the FIA for natural regeneration. While there is great value for regeneration in having overstory structure that buffers microclimates from overarching warming trends (Dobrowski et al. 2015), this strategy depends on the absence of severe disturbance, with wildfire only hastening range shifts that are already in motion. Even under heightened pace and scale of restoration, increasingly warm and arid conditions are expected to increasingly outweigh the influence of fire severity and seed availability on tree regeneration (Davis et al. 2023). **There is growing evidence that conventional tree planting strategy is less suited to the long-term success of reforestation and that, in lieu of climate adaptation measures, areas of high vulnerability should be deferred for planting** (climate informed). In the case of ponderosa pine, planting survival is likely to be greater in the mixed conifer zone than in the lower montane. If planting in the lower montane, consider concentrating efforts at the upper ecotone (i.e., TEUI climate step 5-0 rather than over 5 -1) and other site factors that favor moisture availability. These and other considerations for climate adaptation are included in Box 8 as strategic guidance for climate adaptation in reforestation.

Climate Adaptation Paradigm

Assisted migration is the human-assisted movement of species, populations, or genotypes outside of their characteristic geographic distribution for purposes of maintaining ecosystem diversity and function (Richardson et al. 2009, Schwartz et al. 2012). Assisted migration is either a preemptive or responsive Transition tactic and, for vegetation, has been categorized as either *assisted population migration*, a*ssisted range expansion*, or *assisted species migration* (Figure 32).

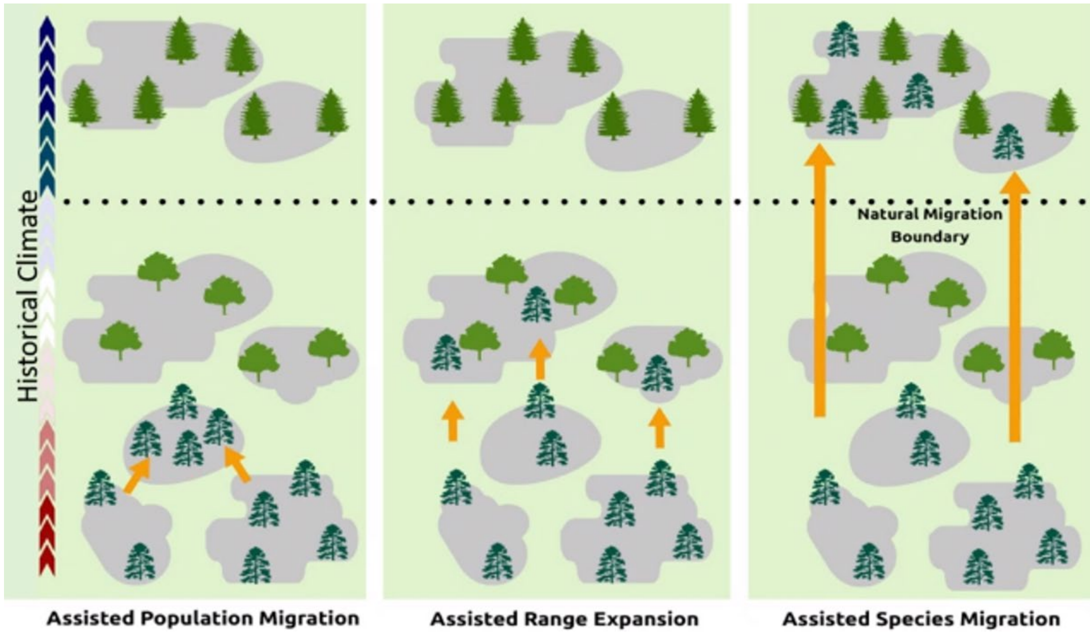


Figure 32. Categories of assisted migration with seed zones represented in gray and arrows representing human intervention and the movement of plant materials to new locations that are typically cooler-moister zones upslope of characteristic seed zones (Williams and Dumroese 2013).

The three types of assisted migration are explicitly addressed in the draft revision of Forest Service reforestation directives including when their use may be appropriate. The draft policy recommends using assisted migration and assisted range expansion as lower risk tactics and using species migration (higher risk) only in specific circumstances and on small areas. The new policy will require that justification for assisted migration be documented in silvicultural prescriptions and monitoring plans when non-local seed sources are used for reforestation. While the new policy is still in draft (as of the writing of this adaptation strategy) managers can nevertheless **move forward now with cross-zone seed collection and outplanting knowing that reaching scale for future reforestation work could take five years from the date of collection.** Forest Service Regions 4 and 9, and perhaps others, have begun taking steps to implement forms of assisted migration. Box 8 is a reforestation guide based on Stevens et al. (2021) that encompasses assisted migration along with approaches that favor regeneration success and leverage key regional science and data sources.

Box 8

Climate Adaptation and Tree Planting (adapted from Stevens et al. 2021)

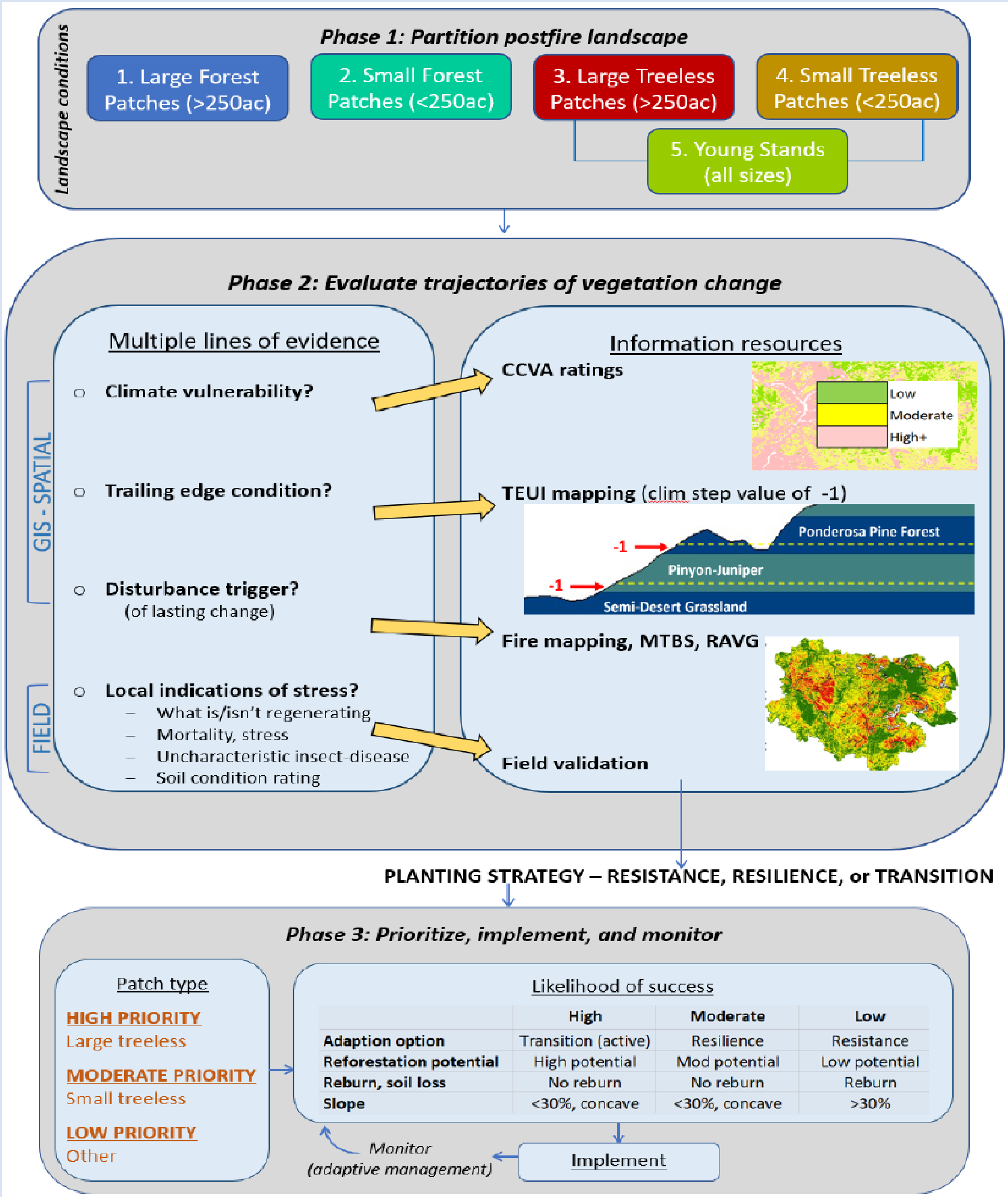
Increasing fire incidence, drought, and other stressors in the West are requiring foresters to think outside convention and traditional operating procedures. An increasing proportion of forests and woodlands in the Southwest has recently burned, leaving complex mosaics of burned areas and surviving forested patches. Large, high-severity patches present numerous challenges to conifer regeneration, even plantations. Surviving forested patches are increasingly recognized for their value in reforestation along with site conditions and regeneration potential. Knowledge about climate trends and vulnerability are also used to inform tree planting strategy and favor survival under warming climate and repeat fire.

This box is guidance for strategy and decision-making with reforestation that was adapted from 'Postfire Landscape Management in Frequent-Fire Conifer Forests of the Southwestern United States' (Stevens et al. 2021) and is especially tooled for postfire landscapes. The guide exercises adaptation options of Resistance, Resilience, and Transition and relies upon on an initial spatial assessment of the landscape which includes multiple inputs on trends in site potential, regeneration potential and site conditions, and burn severity. The guide is summarized in the following schematic of Box 8 and encompasses several key factors:

- Large, high-severity openings pose the greatest challenge to reforestation. Severity mapping provides an objective spatial solution for the initial prioritization for planting operations;
- Climate vulnerability predictions provide a sense of where shifts in site potential are most likely, and an additional means to determine where planting could be prioritized or deferred. The CCVA forecasts should be verified with additional lines of evidence from other vulnerability assessments (e.g., Rehfeldt et al. 2012, Elias et al. 2015, Comer et al. 2019) or by field truthing for stressors and local regeneration patterns;
- Trailing edge conditions for a given type such as the lower ecotone of the ponderosa pine life zone. On Forest Service lands these extents are identified through TEUI mapping and a climate step assignment of "-1" to denote the warm-dry end of a given life zone.
- The presence of disturbances that are likely to trigger long-term type conversion such as high-severity fire. Severity mapping (RAVG, MTBS) provide an objective spatial solution to begin identifying zones where type conversion is most likely;
- Reburn history as informed by severity and fire history mapping;
- Additional indicators of stress such extensive tree mortality and regeneration patterns in nearby unburned stands along with uncharacteristic insect or disease outbreaks; and
- Soil survey ratings for regeneration potential.

Guidance here is aimed at optimizing the allocation of limited management resources and improving long-term regeneration success.

The selection of tree species and provenance for a given planting project may represent an optimization of current cold extremes related to cone and seed production and ongoing climate trends and increasing temperature and aridity. Frost damage to seed production and seedling establishment may constitute the lesser risk when considering the likelihood of drought- and heat-induced tree mortality in the longer term (Sáenz-Romero and Tapia-Olivares 2008).



Landscape conditions
Phase 1: Partition postfire landscape
1. Large Forest Patches (>250ac)
2. Small Forest Patches (<250ac)
3. Large Treeless Patches (>250ac)
4. Small Treeless Patches (<250ac)
5. Young Stands (all sizes)
Phase 2: Evaluate trajectories of vegetation change
Multiple lines of evidence
GIS - SPATIAL
FIELD
Climate vulnerability?
Trailing edge condition?
Disturbance trigger? (of lasting change)
Local indications of stress?
– What is/isn't regenerating
– Mortality, stress
– Uncharacteristic insect-disease
– Soil condition rating
Information resources
CCVA ratings
Low
Moderate
High+
TEUI mapping (clim step value of -1)
Ponderosa Pine Forest
Pinyon-Juniper
Semi-Desert Grassland
-1
-1
Fire mapping, MTBS, RAVG
Field validation
PLANTING STRATEGY – RESISTANCE, RESILIENCE, or TRANSITION
Phase 3: Prioritize, implement, and monitor
Patch type
HIGH PRIORITY
Large treeless
MODERATE PRIORITY
Small treeless
LOW PRIORITY
Other
Likelihood of success
High
Moderate
Low
Adaption option
Transition (active)
Resilience
Resistance
Reforestation potential
High potential
Mod potential
Low potential
Reburn, soil loss
No reburn
No reburn
Reburn
Slope
<30%, concave
<30%, concave
>30%
Monitor (adaptive management)
Implement

Conclusion

An inescapable conclusion when considering the current science and observations of tree regeneration is that human assistance will be needed to realign natural tree populations to the shifting climate for which they are adapted. Proactive reforestation programs will involve massive seed collection from existing tree populations where the resulting seedlings are planted on sites where suitable climate is predicted (Rehfeldt et al. 2002, Tchevakova et al. 2005, Rehfeldt and Jaquish 2010, Joyce and Rehfeldt 2013).

However, it is likely that some land managers will only gradually integrate climate adaptation into reforestation strategy. In the near term, managers may take a more generalized response of careful site selection and expanded genotypes that favor provenance of warm-dry population extremes as a hedge for future conditions (Hamann et al. 2011, Tepe and Meretsky 2011, Bower et al. 2014, O'Neill et al. 2014). Planting a genotype or species outside its current distribution (assisted migration) is quickly becoming less controversial than it was a few years ago given the rapid rate of change in climate and landscape conditions, planting failure observations, vulnerability forecasts and predicted species distributions, and given the need to sustain critical ecosystem services linked to forest cover. A study of postfire communities by Coop (2022) showed that familiar patterns of recovery were associated with cooler and more mesic sites within proximity to forested refugia. Shifts to shrub and grass cover types were most common in warmer-dryer extents distant from forested refugia. Modeling that incorporates future climate scenarios shows decreased postfire resilience and increased shrub and herb cover. In this modeling conversion to non-forest vegetation was partially offset in circumstances of reduced burn severities and the availability of forested refugia. A heightened scrutiny of site conditions, including moisture availability and forest refugia, will also favor planting survival and Box 8 provides a basic checklist.

Careful site selection, planting timing, and enhanced provenance will help to offset the likelihood of type conversion, but climate and wildfire trends in the Southwest are clear signals that pre-fire tree composition will occupy an increasingly smaller space on the landscape, compelling a paradigm shift in forestry to accommodate rapid ecological change. In lieu of assisted migration, proactive measures include establishing seed banks that encompass genetics from the largest possible natural distribution, and starting assisted migration trials to test the realignment of natural tree populations with their adapted climate that is beginning to shift towards higher elevations (Sáenz-Romero et al. 2015).

MONITOR, LEARN, and COMMUNICATE Effectiveness (Workbook Step 6)

Step 6 is to monitor, learn, and communicate the effectiveness of management with on-the ground observations, evaluation, and the Forest Service Climate Action Tracker (scorecard) process to inform future adjustments and share knowledge in a science-management community of practice.

Monitoring is critical for understanding what changes are occurring because of climate change as well as whether selected actions were effective in meeting management objectives and desired conditions for realigning ecosystems to future conditions. This step helps to identify indicators that will be used to monitor whether management goals are achieved in the future and to determine whether the recommended adaptation options and tactics were effective. The outcome of this step is a realistic and feasible monitoring scheme that can be used to help determine whether management should be altered in the future to account for new information and observations. Also, the Climate Action Tracker provides a consistent and objective means to assess progress at the administrative unit level for the application of the adaptation framework.

There are several types of monitoring and many efforts are underway to monitor some indicators in the region, particularly with the implementation of land management plans or adaptation strategy (Appendix E). Most of these efforts are not designed to specifically monitor climate change, but they can still be useful in the context of climate change. Drawing upon and contributing to existing monitoring efforts will help to detect changes that may not be detectable at smaller spatial scales and also may require fewer resources to implement. Consider standard indicators, as those listed in Step 4, and what monitoring efforts and protocols already exist, for example:

- R3 Soil Quality Assessment
- Remote sensing (INREV[3], REV[1], LiDAR, National Agricultural Imagery Service, Rangeland Analysis Platform (RAP 2022), Rangeland Production Monitoring Service (RPMS 2022))
- R3 Aquatic-Riparian Inventory
- Local riparian-aquatic assessment (e.g., PFC, RASES)
- Springs/GDE surveys
- Annual Range Monitoring
- Forest Inventory & Analysis
- Project monitoring

Determine if existing monitoring resources or inventory-monitoring protocols need to be modified to service climate adaptation work. After sizing up existing monitoring resources and potential changes, describe how and when monitoring information will be gathered (e.g., “monitoring seedling survival every summer for five years after planting”), stored, and cycled an adaptive management framework. **Anderson et al. (2021) offers a balanced set of indicators for climate change monitoring along with specific metrics and data sources (Table 11).**

[3] www.fs.usda.gov/detail/r3/landmanagement/gis

Table 11. The 11 indicators of Anderson et al. (2021) for monitoring change on contemporary landscapes including recommended metrics and data sources.

Indicator Theme	Indicator	Metrics	Data Sources
Forestland Area and Extent	Forest extent	- Forestland area by land use - Forest area based on forest cover only	FIA and NLCD
Forest Biomass Density	Structure and function	- Aboveground live tree biomass per unit area - Deadwood mass per unit area	FIA
Diversity/Abundance of Forest-Associated Floral and Faunal species	Ecosystem services	- Forest tree biodiversity status and trends - Forest fauna biodiversity status and trends	Floral: FIA Fauna: US Breeding Bird Survey
		Forest fauna biodiversity status and trends	Fauna: US breeding bird survey
Forest Growth/Productivity	Structure and function	- Net annual forest growth - Forest net primary production (NPP)	Forest Growth: FIA NPP: MODIS
Wildfire Effects	Disturbance	- Burned area - Number of large fires - Fire severity	MTBS, RAVG, and NIFC
Forest Insect and Disease Damage	Disturbance	Area affected by insects and diseases	ForWarn; Forest Health Protection
Water Balance Deficit- An Indicator of "Plant Relevant" Drought	Biophysical indicator	Water balance deficit (calculated as a difference between potential and actual evapotranspiration)	gridMET
US Wildland-Urban Interface	Extent and human domain indicator	- Area of wildland-urban interface - Population residing in wildland-urban interface	Integration of US Census and NLCD according to Federal Register definition
Cost to Mitigate Wildfire Risk	Climate impacts on human domain via forests	- Expenditures on fire suppression activity - Expenditures on forest treatments to mitigate fire risk - Total payments for insurance premiums for policies against damage from forest fire	NIFC
Energy Produced from Forest-based Biomass	Human domain influences on climate domain via forest	Energy produced, domestically or in export markets, from biomass harvested in US forests	US DOE, USFS FIA Timber Products Output Database, and US International Trade Commission
Outdoor Recreation	Human domain and ecosystem services	- Number of US ski/snowboarder visits - Revenue of ski areas - Participation days in cross-country skiing	National Ski Areas Association and others National Visitor Use Monitoring Program

Public lands and local communities are facing multiple stressors in combination with a warming climate that may act as a threat multiplier (Figure 28). The climate indicators of Table 11 and indicators like them can help to support a sustained assessment effort. The indicator list resulted from a comprehensive conceptual model which recognized natural landscapes for services associated with ecosystems, economic, and land use. This particular set of indicators cover key features including forest extent, ecosystem functions such as productivity, processes including drought and disturbance, structural components including biomass, and services such as recreation and biodiversity. Human-ecosystem interactions are captured with indicators focused on wildland-urban interface, cost to mitigating fire risk, and energy from forest biomass. Climate monitoring indicators are meant to inform program strategy and project assessment, analysis and research needs, and adaptive management.

A foundational component of the climate adaptation strategy is *adaptive management*. Several aspects of adaptive management are evident in working through monitoring solutions, including explicit acknowledgment and consideration of uncertainty, iterative learning, and awareness of late-breaking science to improve understanding and reduce uncertainty, integration of monitoring, and a focus on continued improvement to achieve desired outcomes (Larson et al. 2013, Williams et al. 2009). In particular, the intentional use of monitoring to evaluate the effectiveness of adaptation actions helps to inform future management decisions.

Adaptive management is enhanced through deliberate efforts to learn and communicate within the science-management partnership. Learning will take place through the careful assessment of monitoring information and observing management effectiveness, an ongoing synthesis of available research, and careful inquiry and listening to practitioner experiences, tribal knowledge, and those with knowledge of ecological complexities. Continued learning also involves the careful selection and testing of predictive models in open, un-biased settings, using the best available science for parameterization and data inputs. Finally, the Fire Menu (Sample et al. 2022) will be an effective tool for broader educational efforts about the benefits of fire for climate adaptation and for addressing uncharacteristic and unacceptable fire in an era of extraordinary wildfire patterns as a consequence of land use and changing climate. As we work to adapt management to a dynamically changing climate, it is important that we apply the concepts of adaptive management to the task at hand and course-correct along the way.

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Appendix A: Climate Adaptation Strategy Workbook – Quick Guide

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Climate Adaptation Strategy Workbook – Quick Guide

USDA Forest Service, Southwestern Region

The Regional Climate Adaptation Strategy provides guidance to help managers incorporate climate adaptation and carbon considerations and set priorities in project and program planning. The strategy will aid in the selection of adaptation options and project-level tactics and is outlined on themes of *Resilience*, *Resistance*, and *Transition* (RRT) as categories of management intent in combination with vulnerability assessments and the goals of resource programs, project teams, and stakeholders. The stepwise process was adapted from Swanston et al. (2016)[1], with content from Peterson et al. (2011) and dozens of science references, tools, templates, and workshop outcomes for the Southwest.

Step 1: DEFINE location, time frame, and management goals

- Define the location and timeframe for a project or program and take an initial look at management goals.
- Consider established management plans, stakeholder or tribal agreements, and other existing sideboards to identify an area and time of interest for the workbook process.
- Use *integrated landscape prioritization* to assist in targeting landscapes based on the combination of climate vulnerability patterns and existing initiatives such as the Watershed Condition Framework.

Note: After gaining a better understanding of climate vulnerability and impacts in Step 2, the initial management goals will be narrowed to specific objectives in Step 3. Because Step 1 serves as a starting point for subsequent workbook steps, the location, timeframe, and goals should be as specific as possible.

Workbook items – Project or program area, management goals, time frame

Step 2: ASSESS climate change vulnerabilities and potential impacts

- Consider climate vulnerability information and the likely impacts of climate trends in the Southwest – this provides a means to evaluate both *intrinsic* and *climate-induced* risk.
- Couple vulnerability information with local knowledge and experience to evaluate how specific landscapes, ecosystem elements, or socioeconomic values may be vulnerable to climate change. Local understanding of site conditions and stressors will help in identifying promising management responses.

Note: There will be a wide variety of climate impacts on the landscape and not all areas and resources will respond alike. It is essential to think about broad vulnerability patterns in the region AND to consider how specific areas or elements could be affected.

Workbook items – What are the vulnerabilities and likely impacts to areas or resources of interest?

Step 3: EVALUATE management objectives

- Determine management objectives given the goals from Step 1 and the projected impacts from Step 2. Objectives should also reflect the management challenges associated with climate change.
- Evaluate objectives for their feasibility under current management and then refine to account for anticipated climate impacts.

Note: Step 3 is the middle step between identifying the broader management goals and then exploring more specific adaptation options. This step provides the required backdrop for Step 4 and will likely include initial discussions on adaptation options and desired conditions under a changing climate.

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[1] Swanston, C.W., M.K. Janowiak, L.A. Brandt, P.R. Butler, S.D. Handler, P.D. Shannon, A.D. Lewis, K. Hall, R.T. Fahey, L. Scott, A. Kerber, J.W. Miesbauer, L. Darling, L. Parker, and M. St. Pierre. 2016. Forest adaptation resources: Climate change tools and approaches for land managers, 2nd ed. USDA Forest Service Gen. Tech. Rep. NRS-GTR-87-2. Northern Research Station, Newtown Square, PA, USA. 161 pp. http://dx.doi.org/10.2737/NRS-GTR-87-2.

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Climate Adaptation Strategy Workbook – Quick Guide

USDA Forest Service, Southwestern Region

Workbook items – Management objectives, purpose and need, opportunities, and feasibility

Step 4: IDENTIFY adaptation options and desired conditions

Identify adaptation options and desired conditions for resolving ecosystem characteristics to climate change.

Note: Step 4 is the core of the workbook while steps 1-3 have helped to narrow adaptation options and desired conditions under specific management objectives for a program or project area.

Workbook items – Understand the range of adaptation options (RRT); explore important questions about vulnerability patterns at the context scale; identify adaptation options; describe desired conditions and develop management alternatives based on likely adaptation options, desired conditions, tactics, and indigenous knowledge.

All Vegetation Types

Example	Resistance	Resilience	Transition
Shifts in structure and composition	Limit	Allow	Encourage
Risk*	High	Moderate	Low

Fire-Dependent Forests and Woodlands

Example	Resistance	Resilience	Transition
Rx burning	Encourage	Encourage	Encourage
Risk*	Low	Low	Low

Semi-Desert Grassland

Example	Resistance	Resilience	Transition
Rx burning	Allow	Allow	Limit
Risk*	High	Moderate	Low

** - Risk to loss in ecosystem services over the long term. Resistance may be low risk in the short term.*

Step 5: IMPLEMENT adaptation strategy

Step 5 includes aspects of implementation and the final phases of proposal development and analysis in a NEPA project and linking strategy to particular adaptation tactics. An adaptation tactic is practicable if it is both effective (meets desired conditions) and feasible.

Workbook items – Selection and description of design features and tactics

Step 6: MONITOR, LEARN, and COMMUNICATE effectiveness

Step 6 is to monitor, learn, and communicate the effectiveness of management with on-the ground observations, evaluation, and the Forest Service Climate Action Tracker (scorecard) process to inform future adjustments and share knowledge in a science-management community of practice. This step helps to identify indicators that will be used to monitor whether management goals are achieved in the future and to determine whether the recommended adaptation options and tactics were effective.

Workbook items – Evaluate and build upon existing monitoring efforts, develop monitoring scheme, cycle monitoring and learning in an adaptive management framework

Appendix B: Desired Conditions Worksheet for Southwest Ecosystems

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Desired Conditions Worksheet

Ecological Response Unit: ______________________

Likely future ERUs: ______________________

	Ecosystem Characteristic	RESISTANCE	RESILIENCE - TRANSITION		Management Implications
STRUCTURE	Seral state diversity				
COMPOSITION	Tree composition				
PROCESS	Fire regime				
CONNECTIVITY	Patch size				

Desired Conditions Worksheet

Ecological Response Unit: ______________________

Likely future ERUs: ______________________

Ecosystem Characteristic	RESISTANCE	RESILIENCE - TRANSITION		Management Implications

Appendix C: Table Summary of Rangeland Drought Vulnerability Assessment of Wyndham et al. (2018) for Southern Arizona and New Mexico

This appendix is a partial synthesis of ‘Drought Vulnerability Assessment to Inform Grazing Practices on Rangelands in Southeast Arizona and Southwest New Mexico’s Major Land Resource Area 41’ (Wyndham et al. 2018) with tabular information on select rangeland attributes from the assessment. **The reader is referred to the full report available (https://naldc.nal.usda.gov/catalog/6818230).** Results of this assessment, in combination with on-site visits and other references (e.g., Ecological Site and TEUI reports, CCVA, RAP, and RPMS), provide an understanding of exposure, sensitivity, and adaptive capacity of rangeland resources with value for similar aridland types elsewhere in the region.

Increased temperatures and climate variability forecast for the Southwest indicate lower soil water availability, decreased plant productivity, and changing species composition affecting forage conditions, a primary ecosystem service of the region. Understanding vulnerability, likely impacts, and potential climate adaptation measures is important to ecological and socioeconomic sustainability. Modifications to stocking rates, intensity, and timing along with changes in livestock breeds are among adaptation measures considered to cope with increased aridity, climate variability, and interacting stressors. The USDA Southwest Climate Hub and the NRCS developed this vulnerability assessment based on an Ecological Site stratification within the Major Land Resource Area 41 (Figure 33) to help natural resource agencies and landowners develop adaptation options and tactics to support decision-making and mitigate drought effects.

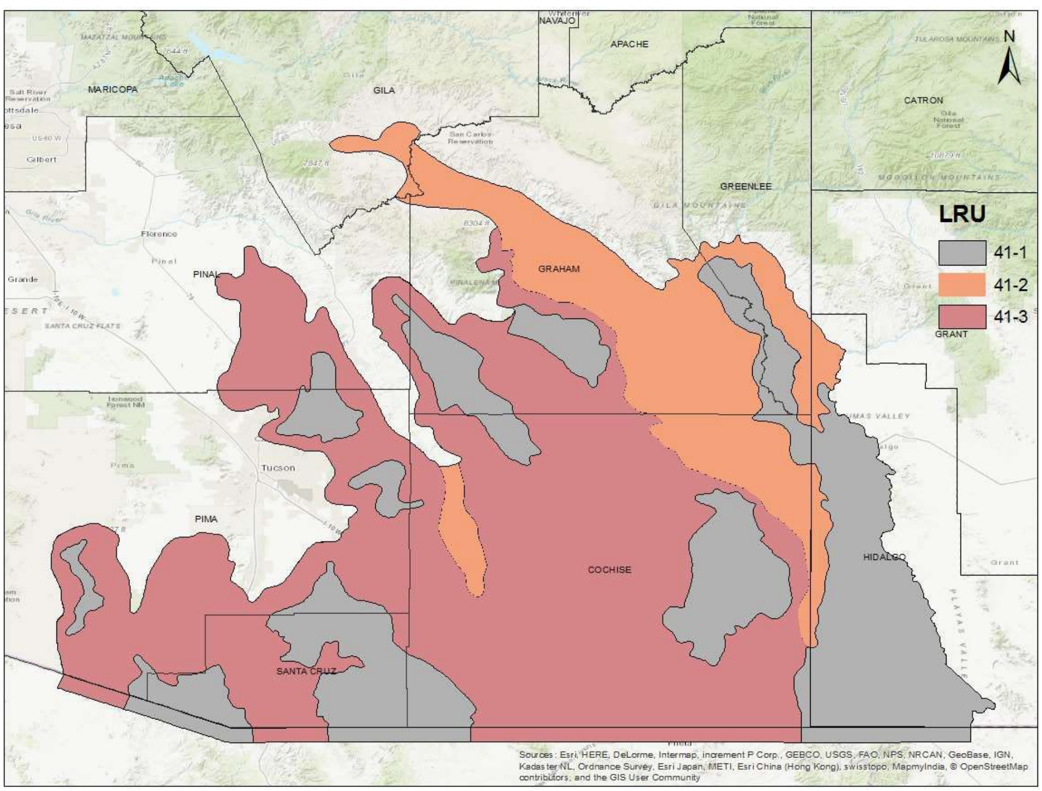

Figure 33. Major Land Resource Area 41 and Land Resource Units located in southeastern Arizona and southwestern New Mexico (Wyndham et al. 2018).

Woodland Savanna (Madrean Oak Savanna – Land Resource Unit 41-1)

Woodland savannas are those plant communities with characteristically low tree cover, often less than 10% tree cover, that occur just above the grassland life zone. The 'Madrean Oak Savanna' Land Resource Unit (41-1) is made up of over 1.2 million acres of which approximately 68% is rangeland and 31% is forested. Plant dominants include blue grama (Bouteloua gracilis), sideoats grama (B, curtipendula), plains lovegrass (Eragrostis intermedia), Arizona white oak (Quercus arizonica), Emory oak (Q. emoryi), and Mexican blue oak (Q. oblongifolia). This type averages 406-508mm of annual precipitation with about 60% occurring in the growing season months. Drought occurs naturally and can cause significant grass mortality usually followed by cycles of increased precipitation and recovery. Within the LRU, Wyndham et al. (2018) assessed 15 Ecological Sites and multiple site variables according to their tendency to increase or decrease vulnerability to drought (Table 12).

Table 12. Site variable influences on drought vulnerability for Ecological Sites of the Madrean Oak Savanna Land Resource Unit.

Ecological Site	Landform Position	Production	Veg. Root Depth	Soil Depth	Salt Content	Land Use	Soil Surface Texture	Avail. Water Hold Cap	Rock Fragments	Overall Vulnerability
Loamy Bottom	decrease	decrease	decrease	decrease	n/a	decrease	decrease	decrease	n/a	low
Loamy Swale	decrease	decrease	decrease	decrease	n/a	decrease	decrease	decrease	n/a	low
Sandy Bottom, Woodland	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	decrease	low
Sandy Wash, Woodland	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	decrease	low
Limy Upland	increase	increase	decrease	increase	increase	increase	decrease	increase	decrease	high
Shallow Upland	increase	increase	increase	increase	n/a	increase	decrease	increase	decrease	high
Sandy Loam Upland	increase	decrease	increase	decrease	n/a	increase	decrease	decrease	n/a	moderate
Loamy Upland	increase	decrease	increase	decrease	n/a	increase	decrease	increase	decrease	moderate
Clay Loam Upland	increase	increase	increase	decrease	n/a	decrease	increase	decrease	decrease	high
Clayey Upland	increase	increase	increase	decrease	n/a	decrease	decrease	decrease	decrease	high
Shallow Hills	increase	decrease	increase	increase	n/a	increase	decrease	increase	decrease	high
Limestone Hills	increase	decrease	increase	increase	increase	decrease	decrease	increase	decrease	high
Volcanic Hills	increase	decrease	increase	increase	n/a	decrease	decrease	increase	decrease	high
Loamy Slopes	increase	increase	increase	decrease	n/a	increase	decrease	decrease	decrease	moderate
Limy Slopes	increase	increase	increase	decrease	increase	decrease	decrease	increase	decrease	moderate

Semi-Desert Grassland (Southern AZ Semidesert Grassland – Land Resource Unit 41-3)

Semi-desert grasslands are those plant communities with historically low tree and shrub cover that typically occur below woodland savanna types and above the desert life zone. The 'Southern AZ Semidesert Grassland' Land Resource Unit (41-3) is made up of over 4.5 million acres with nearly 90% occurring as rangelands and the remainder as agricultural, urban, or barren lands. Plant dominants include grama grasses (Bouteloua spp.), tobosagrass (Hilaria mutica), big sacaton (Sporobolus wrightii), cane beardgrass (Bothriochloa barbinodis), curly-mesquite (Hilaria belangeri), burrowed (Isocoma tenuisecta), broom snakeweed (Gutierrezia sarothrae), and mesquite (Prosopis spp.). This type averages 305-406mm of annual precipitation in eastern zones and higher amounts to the west and at higher elevations with the majority of precipitation occurring in late summer months, usually as brief and intense thunderstorms.

Within the LRU, Wyndham et al. (2018) assessed over two dozen Ecological Sites and multiple site variables by their tendency to either enhance or buffer vulnerability to drought (Table 13).

Table 13. Site variable influences on drought vulnerability for Ecological Sites of the Southern AZ Semidesert Grassland Land Resource Unit.

Ecological Site	Landform Position	Production	Veg. Root Depth	Soil Depth	Salt Content	Land Use	Soil Surface Texture	Avail. Water Holding Capacity	Rock Fragments	Overall Vulnerability
Loamy Bottom	decrease	decrease	increase	decrease	decrease	increase	decrease	decrease	n/a	low
Loamy Swale	decrease	decrease	increase	decrease	decrease	increase	decrease	decrease	n/a	low
Clayey Swale	decrease	decrease	increase	decrease	decrease	increase	increase	decrease	n/a	moderate
Saline Bottom	decrease	decrease	decrease	increase	increase	increase	decrease	decrease	n/a	moderate
Sandy Wash	decrease	decrease	decrease	decrease	decrease	increase	decrease	increase	decrease	low
Sandy Bottom, Woodland	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	n/a	low
Loamy Bottom, Woodland	decrease	decrease	decrease	decrease	n/a	increase	decrease	decrease	n/a	low
Sandy Upland, Saline	decrease	increase	decrease	decrease	increase	decrease	decrease	increase	n/a	moderate
Saline Upland	decrease	increase	decrease	decrease	increase	decrease	decrease	decrease	n/a	moderate
Limy Upland	increase	increase	increase	increase	increase	decrease	decrease	increase	decrease	high
Limy Upland, Deep	increase	increase	decrease	decrease	increase	decrease	decrease	increase	decrease	moderate
Shallow Upland	increase	increase	increase	increase	n/a	increase	decrease	increase	decrease	high
Sandy Upland	decrease	increase	decrease	decrease	n/a	decrease	decrease	increase	n/a	low
Sandy Loam Upland	increase	decrease	decrease	decrease	n/a	increase	decrease	decrease	decrease	low
Sandy Loam Upland, Deep	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	decrease	low
Loamy Upland	increase	decrease	decrease	decrease	n/a	increase	decrease	decrease	decrease	moderate
Clay Loam Upland	increase	increase	decrease	decrease	n/a	increase	decrease	decrease	decrease	moderate
Clayey Upland	increase	decrease	decrease	decrease	n/a	increase	increase	decrease	n/a	moderate
Limy Fan	increase	decrease	decrease	decrease	increase	increase	decrease	increase	decrease	moderate
Limestone Hills	increase	increase	decrease	increase	increase	decrease	decrease	decrease	decrease	high
Shallow Hills	increase	increase	decrease	increase	n/a	decrease	decrease	decrease	decrease	high
Volcanic Hills, Loamy	increase	increase	decrease	increase	n/a	decrease	decrease	decrease	decrease	high
Volcanic Hills, Clayey	increase	increase	decrease	increase	n/a	decrease	decrease	decrease	decrease	high
Loamy Slopes	increase	decrease	increase	decrease	n/a	decrease	decrease	decrease	decrease	moderate
Limy Slopes	increase	decrease	increase	decrease	increase	decrease	decrease	decrease	increase	moderate
Clayey Slopes	increase	decrease	increase	decrease	n/a	decrease	decrease	decrease	decrease	moderate

Desert Scrub (Chihuahuan Desert Shrub – Land Resource Unit 41-2)

Desert scrub are those plant communities that occur below semi-desert grasslands in life zone position and that are characteristically dominated by scrub species and succulents, with forbs common in the understory along with occasional perennial grasses. The 'Chihuahuan Desert Shrub' Land Resource Unit

(41-2) is made up of over 1.3 million acres with approximately 94% still used as rangeland, with the remainder occurring mostly as farmland or barren lands. This type averages 203-305mm of annual precipitation with the majority of precipitation occurring in late summer months, usually as brief and intense thunderstorms. Within the LRU, Wyndham et al. (2018) assessed twenty-two Ecological Sites and multiple site variables according to by their tendency to either enhance or buffer vulnerability to drought (Table 14).

Table 14. Site variable influences on drought vulnerability for Ecological Sites of the Chihuahuan Desert Shrub Land Resource Unit.

Ecological Site	Landform Position	Production	Veg. Root Depth	Soil Depth	Salt Content	Land Use	Soil Surface Texture	Avail. Water Holding Capacity	Rock Fragments	Overall Vulnerability
Sandy Wash	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	decrease	low
Saline Bottom	decrease	increase	decrease	decrease	increase	increase	increase	decrease	n/a	moderate
Loamy Swale	decrease	decrease	decrease	decrease	n/a	increase	decrease	decrease	decrease	low
Clayey Swale	decrease	increase	decrease	decrease	increase	decrease	increase	decrease	n/a	moderate
Sandy Bottom, Woodland	decrease	decrease	decrease	decrease	n/a	increase	decrease	increase	decrease	low
Loamy Bottom, Woodland	decrease	decrease	decrease	decrease	n/a	decrease	decrease	decrease	n/a	low
Saline Bottom, Woodland	decrease	decrease	decrease	decrease	increase	increase	decrease	decrease	n/a	low
Saline Upland	increase	increase	decrease	decrease	increase	decrease	increase	decrease	n/a	moderate
Limy Fan	increase	increase	decrease	decrease	increase	increase	decrease	increase	decrease	moderate
Limy Upland	increase	increase	increase	increase	increase	increase	decrease	increase	decrease	high
Gypsum Upland	increase	increase	decrease	decrease	increase	decrease	increase	decrease	n/a	high
Sandy Upland	increase	increase	decrease	decrease	n/a	increase	increase	increase	n/a	moderate
Deep Sandy Loam Upland	decrease	increase	decrease	decrease	n/a	increase	decrease	decrease	decrease	low
Sandy Loam Upland	increase	increase	decrease	decrease	n/a	increase	decrease	decrease	decrease	low
Loamy Upland	increase	increase	increase	decrease	increase	decrease	decrease	decrease	decrease	moderate
Clay Loam Upland	increase	increase	increase	decrease	n/a	decrease	decrease	decrease	decrease	moderate
Clayey Upland	increase	increase	increase	decrease	increase	decrease	increase	decrease	n/a	high
Shallow Hills	increase	increase	increase	increase	n/a	decrease	decrease	increase	decrease	high
Basalt Hills	increase	increase	increase	increase	increase	decrease	decrease	increase	decrease	high
Clayey Slopes	increase	increase	increase	decrease	increase	decrease	decrease	decrease	decrease	moderate
Gypsum Slopes	increase	increase	decrease	decrease	increase	decrease	decrease	decrease	n/a	high
Limy Slopes	increase	increase	decrease	decrease	increase	decrease	decrease	increase	decrease	moderate

Appendix D: Climate Vulnerability of Upland Ecosystems on the Coronado NF

Overview

The Climate Change Vulnerability Assessment project (CCVA) was developed as an ecosystem-based evaluation of the potential vulnerability of Southwest ecosystems to the projected climate of late 21stcentury. The CCVA for the Coronado NF includes a vulnerability surface for the Forest (Figure 34) and tabular summary of vulnerability estimates for the Forest's major upland Ecological Response Units (ERUs). Note that the CCVA does not include the desert ERUs due to issues encountered in the initial interpretation of results owing to low sample numbers. Desert types will be included in a future update of CCVA now in development. Reporting was generated at local and context scales (see context-scale discussion in Step 2). Considering vulnerability patterns at multiple scales provides useful insights for interpretation of climate change vulnerability results.

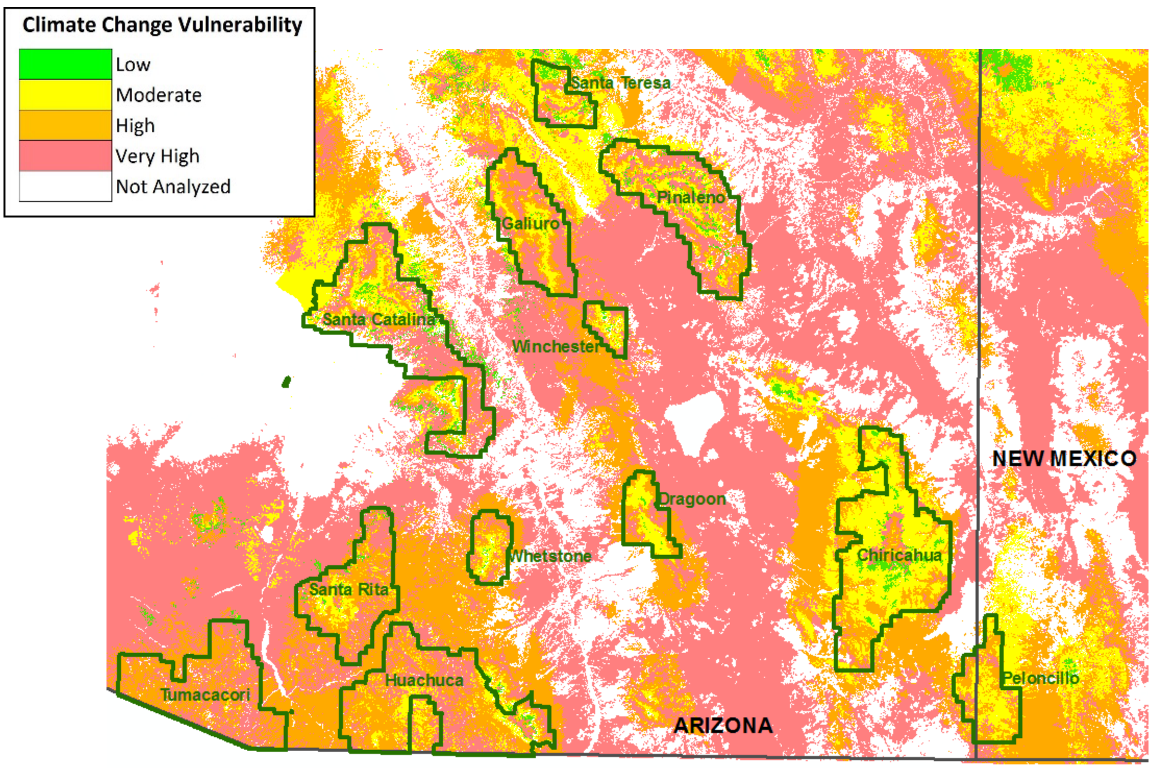

Figure 34. Vulnerability patterns on the Coronado NF and surrounding lands of southeastern Arizona and southwestern New Mexico. The Coronado NF and its local-scale units are represented by extents within the dark green borders.

Vulnerability and Initial Adaption Options

Table 15 lists the major upland ERUs of the Coronado NF along with their relative contribution to area. A total of 10 major upland ERUs are included in reporting here. Minor ERUs, including wetland and riparian, represent about 4% of the Forest. The Madrean Encinal Woodland makes up the largest portion of the Coronado, at 41%, with the remaining upland ERUs representing between 1 and 24%. Vulnerability information for minor upland types is available but not included here.

Table 15. Climate vulnerability and uncertainty estimates for the Coronado NF and major Ecological Responses Units along with initial climate adaptation options.

All ERUs

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	2%	0%	2%	0%	Restoration
Moderate	27%	3%	16%	8%	Resilience
High	38%	0%	38%	0%	Transition
Very High	33%	32%	1%	0%	Transition
Uncertainty total		35%	57%	8%	

Interior Chaparral (IC) + Apacherian-Chihuahuan Upland Scrub (ACU) *65,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	12%	4%	8%	0%	Restoration
Moderate	51%	5%	46%	0%	Resilience
High	36%	0%	24%	12%	Transition
Very High	1%	0%	1%	0%	Transition
Uncertainty total		9%	79%	12%	

Juniper Grass (JUG) *128,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	0%	0%	0%	0%	Restoration
Moderate	2%	0%	1%	1%	Resilience
High	30%	0%	30%	0%	Transition
Very High	68%	68%	0%	0%	Transition
Uncertainty total		68%	31%	1%	

Mixed Conifer - Frequent Fire (MCD) (dry mixed conifer) *49,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	2%	0%	2%	0%	Restoration
Moderate	18%	1%	12%	5%	Resilience
High	28%	0%	28%	0%	Transition
Very High	52%	52%	0%	0%	Transition
Uncertainty total		53%	42%	5%	

Mixed Conifer w/ Aspen (MCW) (wet mixed conifer) *8,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	1%	0%	0%	1%	Restoration
Moderate	27%	1%	20%	6%	Resilience
High	39%	0%	39%	0%	Transition
Very High	33%	33%	0%	0%	Transition
Uncertainty total		34%	59%	7%	

Madrean Encinal Woodland (MEW) *731,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	2%	0%	2%	0%	Restoration
Moderate	19%	1%	10%	8%	Resilience
High	31%	0%	31%	0%	Transition
Very High	48%	47%	1%	0%	Transition
Uncertainty total		48%	44%	8%	

Madrean Pinyon-Oak (MPO) *212,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	5%	0%	5%	0%	Restoration
Moderate	45%	8%	27%	10%	Resilience
High	37%	0%	37%	0%	Transition
Very High	13%	12%	1%	0%	Transition
Uncertainty total		20%	70%	10%	

PJ Evergreen Shrub (PJC) *39,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	7%	1%	6%	0%	Restoration
Moderate	64%	14%	49%	1%	Resilience
High	24%	0%	23%	1%	Transition
Very High	5%	3%	2%	0%	Transition
Uncertainty total		18%	80%	2%	

Ponderosa Pine - Evergreen Oak (PPE) *22,000ac*

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	13%	0%	12%	1%	Restoration
Moderate	49%	10%	30%	9%	Resilience
High	26%	0%	26%	0%	Transition
Very High	12%	12%	0%	0%	Transition
Uncertainty total		22%	68%	10%	

Semi-Desert Grassland (SDG) 443,000ac

Vulnerability Category	Vulnerability %	Low Uncertainty	Moderate Uncertainty	High+ Uncertainty	Initial Adaption Option
Low	0%	0%	0%	0%	Restoration
Moderate	24%	1%	15%	8%	Resilience
High	63%	0%	62%	1%	Transition
Very High	13%	12%	1%	0%	Transition
Uncertainty total		13%	78%	9%	

The CCVA results infer vulnerability based on the projected climate departure from the historical climate envelope for a given ERU and location. In broad terms it may be helpful to think of future climate simply as a potential stressor of significant change (i.e., on structure, composition, function), with the vulnerability rating on par with risk or probability of stress, either low, moderate, high, or very high. In more specific terms, vulnerability can be considered the 'relative probability of type conversion'. Vulnerability is a consequence of at least three factors:

- Breadth of the envelope for a given ERU;
- Current climate status at a given location relative to its ERU envelope; and
- Magnitude of projected climate change.

The thematic resolution is similar among ERUs and the ERU framework itself was refined to ensure normal distributions for key climate variables, mostly through the application of ERU subclasses (e.g., Juniper Grass – Mild). As a consequent of these measure result, the breadth of the climate envelopes is fairly similar among ERUs. That said, all else equal an ERU with a relatively broad envelope is inherently less vulnerable, keeping in mind that climate departure also depends on the projected climate for a given location and on the local climate of a plant community relative to its envelope. The vulnerability of riparian, aquatic, and watershed resources was evaluated separately through ARCCVA and other vulnerability assessment for the Southwest (e.g., Smith and Friggens 2017).

Context Scale Findings

Vulnerability needs to be understood at both local and context scales to adequately inform steps 3 and 4. The context scale represents broader extents such as Ecoregions (e.g., figures 5 and 6) (Cleland et al. 2007) that provide meaningful bounds for evaluating vulnerability at local scales. An ERU with high local vulnerability and low context vulnerability may warrant different management than an ERU with low local vulnerability and high context vulnerability. In order to apply climate adaptation, it is important to understand local vulnerability patterns relative to vulnerability patterns as a whole.

A context-scale evaluation of vulnerability patterns was conducted for the Coronado NF. The Coronado ERUs that make up less than 1% of the context scale (Ecological Section 321A) were identified for the Forest (Figure 6):

- Spruce-Fir Forest (SFF)
- Mixed Conifer w/ Aspen (MCW)
- Mixed Conifer – Frequent Fire (MCD)
- Ponderosa Pine – Evergreen Oak (PPE)
- PJ Grass (PJG)
- Gambel Oak Shrubland (GAMB)
- Montane / Subalpine Grassland (MSG)

The CCVA shows, for instance, that the Pinaleno Mountains (Pinaleno Management Areas of the Safford Ranger District) have a substantial area in low-moderate vulnerability for both Mixed Conifer w/ Aspen and Mixed Conifer - Frequent Fire ERUs that may have value for prioritizing restoration and developing long-term climate refugia.

Coronado NF Climate Adaptation Workshop, March 2022

On March 22-23, 2022, a climate adaptation workshop was convened for the Coronado NF by the Ecological Restoration Institute (ERI) of Northern Arizona University and by the Forest Service Western Wildland Environmental Threat Assessment Center (WWETC) and the Southwestern Region. Managers from the Coronado NF and subject matter experts came together to share best available science on climate change and to discuss climate impact on the Coronado, priorities for climate adaptation, and potential adaptation tactics. The brief summary below captures major themes discussed over the two days and includes vulnerabilities and impacts, adaptation options, and tactics identified by discussion groups.

Climate Change, Vulnerability, and Impacts

Fire

- Increasing size and severity of fires
- Effects of multiple burns/reburns
- Post-fire restoration is time intensive and expensive
- Cascading effects of fire across resources and systems

Compounding disturbances and cascading effects

- Fire, erosion, and water quality
- Indirect effects to wildlife, loss of habitat

Type conversion and loss of system types that are rare on the landscape

- Forest systems – type conversion of spruce fir, and woodlands converting to shrublands
- Aquatic systems, water scarcity, and extreme events
- Grassland systems expanding into woodland systems, but with non-native species
- Increases in invasive species – African grasses (e.g., buffelgrass, lovegrass), bullfrogs
- Impacts to wildlife with loss of habitat
- Loss of culturally important species (e.g., Emory oak)

Impacts to water resources

- Loss of and damage to aquatic systems
- Water rights issues
- Water availability

Infrastructure

- Costs associated with rebuilding roads in vulnerable areas
- Risks to public safety (e.g., flooding)
- Trail maintenance as impacts increase
- Increasing population in public inholdings and WUI

Social and economic impacts

- Vulnerable communities and environmental justice
- Water storage and forage issues for range permittees

Potential Impacts and Adaptation Tactics

Impact: Type conversion of mixed conifer types to Ponderosa Pine - Evergreen Oak

- **Adaptation option:** Maintain desired species composition and structural diversity through active treatment for resilience.
- **Tactics:** Identify and prioritize treatment for high-risk areas that haven't seen management or disturbance, implement fuels thinning at a regular frequency fir fuel reduction (e.g., 5 to 7 years), maintaining structural and age-class diversity

Impact: Post-fire disturbance impacts to watershed health

- **Adaptation option:** Reduce post-fire impacts for resilience
- **Tactics**: Plant for regeneration in areas that have had high severity fire, maintain erosion control measures to maintain watershed health, and assess and monitor beetle kill impacts in areas with high value (e.g., Endangered species habitat, highly visited recreation areas)

Impact: Communities at risk due to fire, flooding, and loss of resources

- **Adaptation option:** Resilience and resistance by reducing risk
- **Tactics**: Increase public outreach and education to build support for active management, foster cooperative work with public and private landowners, especially on adjacent lands, and engage recreation groups in restoration (e.g., trail restabilization, riparian planting)

Impact: Expansion of perennial non-native grasses (e.g., buffelgrass in the Sonoran desert, and to a lesser degree, lovegrasses)

- **Adaptation option:** Resistance. Limit expansion of invasive annuals.
- **Tactics**: Seasonal herbicide treatments, public education with partners to address non-native expansion from adjacent lands, prioritizing key high value areas for treatment (areas of high dispersal, areas of high value)

Impact: Loss of culturally important springs and vegetation

- **Adaptation option:** Resistance, protecting specific species and values, and resilience
- **Tactics**: Collaborate with tribes to capture traditional ecological knowledge, historical use, and prioritize sites. Use existing restoration initiatives to protect remaining areas of cultural importance, by reducing disturbance events and vulnerability to disturbance events with treatment. Acknowledge traditional use of the landscape, educate public in partnership with tribes.

Impact: Loss of recreation infrastructure due to extreme disturbances and increasing use pressure

- **Adaptation option:** Resistance for high value sites, transition for sites that can be moved while still providing services
- **Tactics**: Develop a recreation specific vulnerability assessment to inform management planning and implementation (forest plan includes tactics for moving high risk roads). Implement watershed protection projects upstream of reservoirs (which cannot be moved), adjust reservoir access, and implement seasonal closures following fires and floods to reduce risk to recreationists.

Challenges to Implementing Climate Adaptation

Landscape scale and ecosystem context is necessary; resources are all connected

Capacity constraints

- Lack of key positions; vacant program manager positions, vacant silviculture positions, vacant botanist positions. Positions that are key for active planning and implementation are vacant.
- Innovative management approaches are needed, but managers find that it is difficult to be proactive with reduced capacity

Leadership priority

- Participant quote: "If Line isn't on board or willing to adjust, then it's kind of a moot point"
- Top-down direction is desired, especially on priorities

Funding; upgrades and adjustments to infrastructure are costly

Appendix E: Listing of Some Climate Action Plans for the Southwest

Federal

National Park Service Climate Change Action Plan

The Climate Change Action Plan articulates a set of high-priority no-regrets actions that the National Park Service is currently undertaking or committed to undertake. The Action Plan acknowledges how changing social and environmental conditions, including advances in science and information technology will require new thinking and new approaches. The plan is divided into three sections:

- Context for Action
- Identifying Near-term priorities
- Preparing for new challenges and opportunities

Read more: Climate Change Action Plan 2012–2014 (nps.gov)

National Park Service Climate Change Response Strategy

NPS will collaborate with partners to identify and monitor climate change effects in parks and to apply accurate and relevant science to management and policy decisions. The agency will also adapt through the development of feasible and actionable scenarios and create a flexible framework for dealing with impacts. They plan to reduce their carbon footprint through energy-efficient and sustainable practices and integrate the practices into planning and operations. The strategy components include:

- Science
- Mitigation
- Adaptation
- Communication

The agency recognizes that as climate change is likely to create conditions and ecosystems unlike anything found today, the upholding of their mission will require updating interpretations of policy, mandates, and approaches to resource stewardship.

Read more: National Park Service Climate Change Response Strategy (nps.gov)

Grand Canyon National Park

This plan describes measures the park will take to reduce its greenhouse gas emissions. In addition to implementing these measures, Grand Canyon National Park will:

- Utilize the Environmental Management System to measure progress with respect to reducing emissions and preserving natural and cultural resources and infrastructure.
- Identify additional actions to reduce greenhouse gas emissions and preserve natural and cultural resources and infrastructure, as necessary.
- Periodically assess and revise this action plan to strengthen existing actions and include additional actions.

The Grand Canyon NP intends to:

- Reduce greenhouse gas emissions from park operations by 30% below 2008 level by the year 2020.
- Plan and implement measures that best allow the Park's natural and cultural resources to adapt to the impacts of climate change.

To meet these goals, the park will implement strategies in this plan that relate to the Park's current and future emission inventories. The four strategies recommended are:

- Reduce GHG emissions resulting from activities within and by the park
- Develop and implement a plan to adapt to current and future impacts of climate change
- Increase climate change education and outreach
- Monitor progress and identify areas for improvement

Read more: Grand Canyon National Park Climate Action Plan (nps.gov)

USDA National Institute of Food and Agriculture Climate Adaptation & Resilience Plan

The key vulnerabilities identified center around water, agroecosystem sustainability, food and nutrition security, resilience to extreme weather, and continuity of operations. The actions that emerged involve: Programs & RFAs (Requests for Applications), Strategic Planning, Organizational Effectiveness, and Stakeholder Outreach. NIFA anticipates that positive climate change adaptation impacts can be achieved by adopting an adaptive management framework.

Read more: NIFA Climate Adaptation & Resilience Plan (usda.gov)

EPA Climate Adaptation Action Plan

The EPA has revised their 2014 plan under new guidance from President Biden on Executive Order 14008, *Tackling the Climate Crisis at Home and Abroad.* This new plan will accelerate action and focus the agency's attention on priority actions it will take to fulfill their mission and increase human and ecosystem resilience even as the climate changes. Agency-wide climate adaptation priorities include:

- Integrate climate adaptation into EPA programs, policies, rulemaking processes, and enforcement activities.
- Consult and partner with states, tribes, territories, local governments, environmental justice organizations, community groups, businesses, and other federal agencies to strengthen adaptive capacity and increase the resilience of the nation, with a particular focus on advancing environmental justice.
- Implement measures to protect the agency's workforce, facilities, critical infrastructure, supply chains, and procurement processes from the risks posed by climate change.
- Measure and evaluate performance.
- Identify and address climate adaptation science needs.

Read more: Climate Adaptation Action Plan: October 2021 (epa.gov)

Department of Defense Climate Adaptation Plan

The Department of Defense has modified CEQ's (Council on Environmental Quality) format on their climate adaptation strategic framework to better reflect the scope and scale of the Department's activities as well as terminology common to DOD planning efforts. The DOD has selected the following focus areas:

- Climate Informed Decision Making
- Train and Equip Climate-Ready force
- Resilient built and natural infrastructure
- Supply chain resilience and innovation
- Enhance adaptation and resilience through collaboration

There are what the Department considers four enablers that support and integrate across all five focus areas. These include:

- Continuous monitoring and data analytics
- Aligning incentives to reward innovation
- Climate literacy
- Environmental justice

Read more: Department of Defense Climate Adaptation Plan

Department of the Interior Climate Action Plan

The Department of the Interior will integrate climate change risk, mitigation, adaptation, and resilience in its policies, planning, programs, and operations. The DOI will prepare for the effects of climate change on its responsibilities through the following themes:

- Promote Climate-Resilient Lands, Waters, and Cultural Resources
- Advance Climate Equity
- Transition to a Resilient Clean Energy Economy
- Support Tribal and Insular Community Resilience
- Empower the next generation of conservation and resilience workers

To implement Executive Order 14008, the DOI commits to:

- Approving and implementing the Department's Climate Action Plan
- Use best available science and traditional knowledge
- Mainstream adaptation
- Tackle inequity and environmental justice
- Build strong partnerships
- Maximize Co-Benefits
- Enhance climate literacy
- Apply risk management methods
- Apply nature-based solutions and ecosystem-based approaches
- Continuously evaluate performance and practice adaptive management

Read more: Department of the Interior Climate Action Plan (doi.gov)

US Fish & Wildlife Service – Climate Change Action Program

This document describes how the agency has developed the Climate Change Coordinating Group to respond to climate change by working with programs and external partners to apply the best available science and collaborate to address complex conservation challenges. Implementation of this program will allow the Service to strengthen its capability to manage and direct the effects of climate change. This document describes the seven elements of the Climate Change Action program (CCAP). They go as follows:

- Infuse climate adaptation and resilience throughout the management of Service trust resources, ensuring conservation outcomes have a lasting impact.
- Interpret and collaborate on climate science so that state of the art science is produced and applied to meet the urgent needs for conservation implementation.
- Develop a national conservation adaptation strategy.
- With attention to social and environmental justice, the Service will work collaboratively with partners to address climate change impacts to shared priority natural resources.
- Enhance the Service's role in climate mitigation by achieving zero net emissions by 2050 and by working with partners to increase our carbon sequestration capacity to benefit fish, wildlife, plants, and their habitats.
- Review and revise existing regulations and policies, as well as create new regulations and policies, to ensure climate adaptation and resiliency are incorporated into all our work.
- Develop a climate literate workforce that has the knowledge, skills, and abilities to successfully address climate adaptation and mitigation needs throughout all programs and regions of the Service.

US Fish & Wildlife Service Strategic Plan for Responding to Accelerating Climate Change

Outlined in this strategic plan are some key climate change principles:

- Priority Setting
- Partnership
- Best Science
- Landscape Conservation
- Technical Capacity
- Global Approach

The strategic plan's primary purposes are to (1) lay out the vision for accomplishing the mission to "work with others to conserve, protect, and enhance fish, wildlife, and plants and their habitats for the continuing benefit of the American people" in the face of accelerating climate change and (2) provide direction for our own organization and its employees, defining our role within the context of the Department of the Interior and the larger conservation community.

The goals and objectives of the Strategic Plan are nested under three major strategies:

- Adaptation: Minimize impact of climate change on fish and wildlife through application of cutting-edge science in managing species and habitats.
- Mitigation: Reducing levels of greenhouse gases in the Earth's atmosphere
- Engagement: Joining forces with others to seek solutions to the challenges and threats to fish and wildlife conservation posed by climate change.

- Read more: [CCStrategicPlan.pdf (lta.org)]

Tribal

Climate Adaptation Plan for the Navajo Nation

The Navajo Nation climate change vision statement is used to prepare the Navajo Nation to adapt to the changing climate, and implement strategies that will preserve and enhance natural resources and provide a resilient future for Navajo communities by:

- Protecting and enhancing native species of both vegetation and animals, and;
- Establish and manage their natural habitats.
- Reduce, Reuse, and Recycle.
- Implement and enforce sustainable, long-term livestock management goals.
- Recognize vulnerable areas and prepare for natural disasters
- Provide sustainable healthy food sources for a healthier lifestyle
- Take advantage of advanced technology to encourage innovation and create a more efficient and livable community
- Protect and enhance watersheds
- Clean polluted areas
- Implement natural resource management plans (fire, erosion, etc.)
- Educate the public

The Navajo Nation Department of Fish and Wildlife established the Climate Change Program and team. A professional team was developed to create a priority list of natural resource concerns and adaptation strategies. The priority list goes as follows in order of priority:

- Water
- Feral horses
- Communication
- Enforcement/Compliance
- Pollution, Air Quality, Illegal Dumping
- Grazing management

Concerns from tribal members include neglect and loss of traditional practices due to climate stress.

Read more: Climate Adaptation Plan for the Navajo Nation (nndfw.org)

Mescalero Apache

This document highlights the climate driven initiatives undertaken by the Mescalero Apache Tribe. The Mescalero Apache Tribe currently does not have a specific climate change program or policy regarding climate change adaptation. Some highlighted initiatives include landscape conservation through the removal of exotic species and fuels treatments. Energy efficiency and renewable energy projects include energy efficient woodstoves, solar energy experiments, and wind energy projects. Water quality and fisheries management projects include water quality improvement and nutrient recycling at the Mescalero Tribal fish hatchery, spring water captures, and more. Sustainability initiatives include the development of community gardens, recycling, repurposing, moving towards Xeriscapes, and more.

Read more: tribes_Mescalero.pdf (nau.edu)

Arizona

[Central Arizona Project]

The Central Arizona Project provides renewable water supply to central and southern Arizona, where about 80% of the population of Arizona resides. Recent drought, as well as studies on the potential impacts of climate change, have put a fine point on the need for the Central Arizona Project to be prepared for changing conditions. The purpose of this adaptation plan is to investigate the potential effects of climate change across the Central Arizona Project departments and develop a plan to increase resiliency of the project. Approaches used for the Central Arizona Project Climate Adaptation Plan:

- Develop focal questions and assemble the team.
- Develop drivers and scenarios. The team identified potential drivers, or forces externally that could impact future operations or conditions.
- Develop implications
- Develop adaptation strategies
- Develop robust solutions
  - "No regrets" strategies are those that provide a benefit with no or minimal downside of implementing, even if the future envisioned does not come to pass.
  - "Low regrets" strategies are those that are generally easy to implement, but the benefit to the organization is greater when the future envisioned does come to pass. Additionally, low regrets actions can preserve an opportunity for future implementation.
  - "Conditional" strategies are those that could be implemented in the future, under specific conditions.

Components of the Central Arizona Project Climate Adaptation Plan include:

- Central Arizona Groundwater Replenishment District (CAGRD)
- Colorado River Programs
- Communications
- Engineering
- Environmental, Health, and Safety
- Financial Planning and Analysis
- Human resources
- Information Technology
- Legal Services
- Maintenance
- Operational Technology
- Protective services
- Public Affairs
- Resource Planning & Analysis
- Risk and Liability Management
- Water Operations & Power Programs

Read more: CAP-Adaptation-Plan-2018.pdf (cap-az.com)

University of Arizona

The Office of Sustainability is developing the University of Arizona's first ever Sustainability and Climate Action Plan which will be released in 2023. This plan will align with the United Nations' Sustainable Development Goals and will integrate metrics from the Association for the Advancement of Sustainability in Higher Education's (AASHE) Sustainability, Tracking, Assessment and Rating System (STARS) framework. The STARS framework is a methodology that colleges and universities around the world can use to capture the full spectrum of their sustainability activities and measure advancements over time and across institutions. Beyond integrating the two mentioned international efforts, this plan will also include comprehensive internal initiatives across the University's research, academic, and operational sectors.

It is thought that this tool will assist the university in reducing its greenhouse gas emissions while advancing progress in other sustainability metrics in a cost-effective yet robust way. This plan will clear a path towards carbon neutrality and broader sustainability, with incremental goals and opportunities to celebrate advancements and progress along the way.

Read more: Sustainability & Climate Action Plan | Office of Sustainability (arizona.edu)

Northern Arizona University

Northern Arizona University has had a Climate Action Plan since 2010 and has had revisions since, with 2021 being the most recent. A majority of ongoing sustainability initiatives ae student driven through the Office of Sustainability, the Green Fund, and the Environmental Caucus, along with staff and faculty work in the Sustainable Campus Ecosystem Initiative and the Coordinating Committee for Sustainability. This plan will use current information to establish consensus support for programs and initiatives and an administrative structure to further guide the transition of campus culture in support of climate change adaptation and mitigation by activating the living laboratory concept. The NAU 2021 climate action plan satisfies the university's four goals for this study. These are:

- NAU Flagstaff Mountain Campus will realize carbon neutrality in the next ten to thirty years.
- NAU Flagstaff Mountain Campus will be a campus community whose academics, research and operations collaborate to address climate change adaptation and mitigation.
- NAU Flagstaff Mountain Campus will align and collaborate with the City of Flagstaff to meet university and city climate goals and objectives.
- The NAU 2021 climate action plan will position NAU Flagstaff Mountain Campus to commit to Second Nature's Climate Commitment.

Read more: NAU_cap_report_draft2.pdf

City of Phoenix

In 2015, Phoenix voters supported an ambitious vision to become the most sustainable desert city on the planet. The Phoenix City Council adopted the 2050 Sustainability Goals that set long-term outcomes necessary to fulfill this vision. Significant climate actions included in this report are:

- Create an inclusive and equitable city, prioritizing investments in previously underserved communities, proactively seeking community unput on all major climate policy and related budget decisions and embedding equity in all climate actions.
- Lead by example by transitioning city operations electrical use to carbon neutral by 2030 through energy use reduction and implementation of local and utility scale solar projects.
- Reduce community carbon emissions from buildings, transportation, and waste to move toward becoming a carbon neutral city by 2050.
- Support increased energy efficiency, renewable energy and new electric vehicle charging requirements in building codes, to achieve carbon neutral buildings city-wide by 2050 with all new construction being net-positive in both energy and materials by 2050.
- Attract businesses that turn waste into resources and create a thriving Resource Innovation campus by 2030 to put the city on the path to zero waste by 2050.
- Support and prepare for 280,000 electric vehicles in the city by 2030 and rapidly expand bus and High-Capacity Transit (Light rail and Bus Rapid Transit) to achieve carbon neutral transportation by 2050.
- Support new land use and development tools, such as the Walkable Urban Code, to prioritize people arriving by walking, biking, or using transit, thereby reducing dependence on gasoline fueled single occupancy vehicles; particularly within and connecting to Transit Oriented Development Districts, Village Cores and Centers by the year 2050
- Become a top tier Heat-read City by 2025 – implementing the Tree and Shade Master Plan by 2030 and building a network of 200 "cool corridors" by 2050
- Continue to lead international into water stewardship – providing a clean and reliable 100-year water supply.
- Create and maintain a healthy, sustainable, equitable, and thriving local food system with healthy, affordable, and culturally appropriate food for all Phoenix residents by 2050.
- Significantly improve air quality in the region to meet federal air quality standards.

Read more: 2021ClimateActionPlanEnglish.pdf (phoenix.gov)

City of Tucson

This plan outlines the City's roadmap to reduce greenhouse gas emissions, as well as how to adapt and build community-wide resilience to the current and future impacts of climate change. This plan centers around equity and environmental justice because the impacts of climate change are unfairly distributed towards the frontline communities of Tucson. This plan lays out strategies that both reduce emissions and strengthen community resilience to climate change. The five areas of focus for strategies and actions are:

- Governance and leadership
- Energy
- Transportation and land use
- Community resilience
- Resource recovery and management

This plan also identifies how it will equity is at the front of mind. Four dimensions of equity have been established as:

- Procedural equity requires that authentic, inclusive, and accessible community engagement be embedded in the development of policies and programs.
  Distributional equity requires that policies and programs equitably distribute the benefits and burdens across all communities.
- Structural equity requires a recognition of the historic, cultural, and institutional dynamics that lead to inequalities in climate action and impacts.
- Transgenerational equity refers to the contemplation of the impacts of policies and programs on future generations.

  Read more: Resilient Together | City of Tucson Climate Action Hub (tucsonaz.gov)

City of Flagstaff

This adaptation plan strives for Flagstaff to have thriving local ecosystems that are resilient to climate change, publicly accessible, and store carbon dioxide by 2030. Major themes of concentration in this plan are:

- Maintaining a natural environment
- Water resources
- Energy
- Transportation and land use
- Waste and consumption
- Public health, services, facilities, and safety
- Economic prosperity and recreation

Under each category are nested goals with corresponding strategies and indicators as to how the themes will go towards meeting the 2030 goal.

  Read more: Flagstaff-Climate-Action-and-Adaptation-Plan_Nov-2018_Strategies-and-Actions (az.gov)

City of Sedona

The City of Sedona's vision is to have a community that nurtures connections between people, encourages healthy and active lifestyles, and supports a diverse and prosperous economy, with priority given to the protection of the environment. In an effort to realize this vision, the climate action plan has set a goal to reduce Sedona's greenhouse gas emissions by 50% by 2030. Sedona is taking a "two-pronged approach" to climate change through mitigation and adaptation. Recognized benefits of climate action within this community have been noted as boosting the local economy, creating a healthier environment, saving money, and keeping skies clear and landscapes beautiful. The plan is organized into the following sectors:

- Buildings & energy
- Transportation & land use
- Materials & consumption
- Water & natural systems
- Climate resilience

Each sector presents the strategies and actions for reducing climate pollution and fostering climate resilience in Sedona.

Read more: [Climate Action Plan Sedona (sedonaaz.gov)]

City of Mesa

The City of Mesa's climate action plan establishes a commitment to proactively and responsibly protecting and conserving Mesa's environment and natural resources. The plan will lower climate impact, serve as a guidance for sustainable growth, and build resiliency by reducing carbon pollution within the community. The document begins by measuring Mesa's impact and an inventory of the greenhouse gas emissions and sources to help set a baseline of known gases to develop strategies to reduce emissions and track progress. There are four 'Aspirational goals' that are used as a guide for the vision for the future. These goals are:

- Carbon neutrality
- Renewable energy
- Materials management
- Climate ready community

There are also six goals outlined as 'Focus Areas' for the plan

- Energy
- Air quality
- Heat mitigation
- Water stewardship
- Materials management
- Food systems

This will be a living document that will evolve as new strategies, resources, technologies, and collaborations come to light.

Read more: [Mesa's Climate Action Plan by City of Mesa, AZ - Issuu]

City of Tempe

The City of Tempe recognizes the need to be more urgent as the window to take climate action this decade is critical, welcome transformation and embrace clean energy and transportation economy, increase funding, and collaborate more in this most updated climate action plan. Two performance measures have been adopted that guide this plan. These include community carbon neutrality and municipal carbon neutrality by 2050. This climate action plan updates the 2019 version to include new data, stakeholder agendas, and updated investments and funding proposals. This update is guided by five principles: fiscal responsibility, enterprise, equity, engagement, and evidence.

Read more: [showdocument (tempe.gov)]

City of Scottsdale

While not climate change specific, the City of Scottsdale has a draft Sustainability Plan in the works. The official document has not been released. Primary challenges linked to advancing sustainability within the City of Scottsdale have been listed as: funding limitations, siloed operations, policy gaps, and gaps in measuring the progress of social and environmental impacts. It is hoped that the development of this plan will help municipal departments and the wider community communicate a shared understanding of sustainability strategy ad goals. This plan must promote holistic sustainability action but also incorporate a community-wide and community-informed "why" to help motivate their citizens and community participation. Key sustainability elements that are being considered include:

- Being clear and comprehensive
- Inclusive
- Actionable

Read more: [Scottsdale+Sustainability+Scan+Report.pdf (scottsdaleaz.gov)]

New Mexico

New Mexico Climate Strategy

This strategy begins by highlighting climate action progress across the state of New Mexico. The New Mexico Climate Change Task Force began developing climate action plans aimed at reducing greenhouse gas emissions at least 45% below 2005 levels by 2030 in accordance with Governor Lujan Grisham's Executive Order 2019-003. Moving forward, the climate action plans established by this task force will be five years long, covering 2023-2028. This plan is set to put New Mexico on the path to net-zero emissions by 2050. This strategy acknowledges that while New Mexico has implemented policies, there remains a significant gap in achieving the 2030 goals. Support is received from the US Climate Alliance and the Rocky Mountain Institute in helping collect and analyze data to evaluate policy goals for the climate action plan. The sectors highlighted for concentration on reducing greenhouse gas emission levels include:

- Industrial
- Transportation
- Electricity
- Built environment
- Natural & Working Lands

Read more: NMClimateChange_2021_final.pdf

City of Albuquerque

Following the release of the 2021 Albuquerque Climate Action Plan, achievements such as:

- Completion of Solar Direct with the Jicarilla Apache Nation, one of the region's largest utility-scale solar fields, to now utilize 88% renewable energy for city government has been accomplished
- Advanced projected date for 100% municipal renewable energy use to 2025
- Hired new full-time staff to lead and implement sustainability priorities

- Completed the American Cities Climate Challenge funded by Bloomberg Philanthropies
- Named a top five large city in America for most solar installed per capita

The City of Albuquerque distributed a city-wide survey to gauge public priorities on issues of climate and sustainability and formed a climate action task force of community members. The task force developed 50 strategies with input from stakeholders, city employees, and the public. The 50 strategies were subsequently adopted by City Council and are organized under the following categories:

- Sustainable buildings
- Renewable energy
- Clean Transportation
- Waste & recycling
- Economic development
- Education & awareness
- Climate conscious neighborhoods and resources

The 2022 implementation plan includes a plan to address gaps and barriers to continued climate progress.

Read more: 2022-cap-ir-eng-web.pdf (cabq.gov)

City of Las Cruces

The City of Las Cruces climate action work benefits all community members equitably and does not incur negative outcomes for any community members is a top priority. The climate action Steering Committee developed a list of community values through intentional conversation regarding what is currently happening in the community, ways in which climate action work may impact equity, and how equity could be enhanced through the climate action work. The community values for climate action are as follows:

- Illustrate a comprehensive commitment to mitigation and local resiliency
- Improve health and local food systems for vulnerable populations
- Support a circular economy and equitable, higher quality, less impactful products
- Implement innovative technologies that promote water, energy, and resource efficiency
- Improve equitable access to safe, clean forms of transportation
- Create green jobs and workforce opportunities

Read more: Climate Action Plan City of Las Cruces

City of Santa Fe

With the proposed federal Green New Deal, the City of Santa Fe has created the 25-Year Sustainability Plan which is a collection of objectives, targets, and strategies to lead to carbon neutrality by 2040. The Santa Fe Plan encompasses the same goals as the Green New deal but is more comprehensive by establishing goals to eleven specific areas and provides detailed strategies to help accomplish them. Priority recommendations are:

- Ensuring City government accountability, leadership, and advocacy
- Coordinating education and outreach

- Maximizing energy efficiency
- Accelerating renewable energy
- Maximizing water conservation
- Developing/redeveloping in a more sustainable way
- Increasing options for affordable and workforce housing
- Transforming the transportation system
- Enhancing resiliency and regeneration of natural systems and processes
- Reinvesting in the local economy
- Empowering the next generation

The Santa Fe established four keys to success:

- Carbon neutrality
- Quality of Life a& social equity
- Ecological resilience
- Economic vitality

Read more: [Sustainable Santa Fe_October_Printsm.pdf (santafenm.gov)]

Town of Silver City

This plan is both a municipal and a community plan. Recommendations within the plan include actions for the municipality and others that require public/private partnerships to implement. The categories that are addressed include:

- Community Outreach, Education, and Support
- Systems and Planning Areas
- Climate/Severe Weather
- Conservation of Resources

This plan doesn't directly address housing or the local economy, however both are recognized as important components of town resiliency. Key policy recommendations identified for the successful preparation of developing a well-informed and motivated public include:

- Providing outreach, education, and support for the municipality and the community on a unified (public/private) and ongoing basis
- Build, sustain, and leverage local and regional partnerships
- Identify vulnerable populations
- Incorporate flexibility of design into infrastructure development
- Allocate municipal resources necessary to adapt the municipality's physical design and operations, and to participate at varying levels in all the public/private partnerships. Fiscal resources saved through conservation could be redirected towards these efforts.

Read more: [Silver-City-Sustainability-Plan-2030-PDF (townofsilvercity.org)]

Appendix F: Climate-Informed WRAP Template

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USDA Forest Service Watershed Condition Framework
TEMPLATE FOR CLIMATE-INFORMED
WATERSHED RESTORATION ACTION PLAN
[UNIT NAME]

1. Summary

a. **Watershed Name and HUC:**
b. **General Location:**
c. **Total Watershed Area:** ____ acres **NFS area within watershed:** _____%
d. **Watershed Characterization:**
   - **General Physiography:**
   - **Land Use:**
   - **General Overview of Concerns:**
   - **Important Ecological Values:**
   - **Current Condition Class (WCC):** ________ **Target Condition Class:** ________

e. **Key Watershed Issues**
   - *Climate prompt: Consider and record climate change impacts that may affect attributes/indicators below (see Climate Adaptation Strategy STEP 2).*
   - *Climate prompt: Consider adding attributes/indicators that are currently good but at risk of deterioration due to climate change (ARCCVA indicators include change in stream flow timing, change in stream temperature, change in annual stream flow, change in summer stream flow).*

Attributes/indicators within FS control to affect adaptive capacity (ARCCVA indicators include beaver dam capacity, percent natural vegetation cover, percent protected lands) and exposure (road crossing density, diversion density, wildfire risk, well density, dam density).

Attributes/ Indicator	Reason for Rating

Attributes/Indicators that require other parties to address

Attributes/ Indicator	Reason for Rating

2. **Watershed Characteristics and Conditions**
   a. **General Context/Overview of the Watershed**
   b. **Watershed Conditions**
      - *Climate prompt: Describe watershed climate vulnerability (see Climate Adaptation Strategy STEP 2 and ARCCVA)*
        - *What climate change impacts may have the greatest influence on the watershed?*
        - *What watershed characteristics may increase exposure and sensitivity to climate changes over time?*
        - *What characteristics may buffer changes?*
      - *Climate prompt: Assess relative risk to watershed and specific project areas*
      - *Tip: You can consult regional vulnerability assessments for information on the anticipated effects of climate change on ecosystems in a particular region (see ARCCVA www.fs.usda.gov/detailfull/r3/landmanagement/gis/?cid=stelprdb5201889&width=full and Vulnerability Assessments Dashboard).*

3. **Restoration Goals, Objectives, and Opportunities**
   a. **Goal Identification and Desired Conditions**
      - *Climate prompt: What management challenges and opportunities may occur as a result of climate change?*
      - *Climate prompt: Do any of your management objectives need to change, given the projected climate impacts listed above?*
   b. **Objectives**
      i. Alignment with National, Regional, or Forest Priorities
      ii. Alignment with State or local goals
   c. **Opportunities**
      i. Partnership Involvement
      ii. Outcomes/Output
         a) Performance Measure Accomplishment
         b) Socioeconomic Considerations:
   d. **Specific Project Activities (Essential Projects)**
      Climate prompts for Essential Project development:
      - *Consider climate threats, challenges, and opportunities related to these projects.*
      - *Include adaption options (Resistance, Resilience, Transition), approaches, and tactics to address climate change (see workbook steps in Regional Climate Adaptation Strategy).*
      - *Consider benefits, drawbacks, and feasibility in light of climate change.*
      i. Essential Project #1
         a) Attribute/Indicator Addressed
         b) Project Description
         c) Partners Involvement
         d) Timeline: Starting in _____ and continuing for ____ years
         e) Estimated costs and associated Budget Line Item

ii. Essential Project #2
   a) Attribute/ Indicator Addressed
   b) Project Description
   c) Partners Involvement:
   d) Timeline: Starting in _____ and continuing for ____ years
   e) Estimated costs and associated Budget Line Item

iii. Essential Projects Continued (list all projects)…

e. Costs:

$ Source	Planning	Design	Implementation	Project Monitoring
FS Contribution				
Partner Contribution (both in kind and $)				
Total				

f. Timelines and Project Scheduling

FY	Task	FS Cost	Partner cost

g. Other Partners

4. Restoration Project Monitoring and Evaluation

- *Climate prompt: What monitoring items can tell you whether the adaptation tactics had the intended effect?*
- *Climate prompt: How can we leverage existing monitoring efforts to assess effectiveness of our actions?*

a. The forest will monitor:

b. Monitoring will be done in cooperation with:

Action Plan Date: ____________________

Reviewing Official and Title: ___________________

The Forest/Unit Supervisor's signature signifies:

- approval of the priority watershed
- the validity of the planned essential projects
- verification that all watershed condition class attribute ratings in the WCATT database for this watershed accurately reflect the assessment results.

Forest/Unit Contact Information: ____________

WRAP and Climate Adaptation Workbook Crosswalk

Template Section	Workbook Steps	Template Section	Connection
Sections 1, 2, 3a-3b	**Step 1**: DEFINE Location, Time Frame, and Management	Sections 1, 2, 3a-3b	Identify baseline conditions – already part of WRAP process
Sections 1e and 2	**Step 2**: ASSESS Climate Change Vulnerabilities and Potential Impacts	Sections 1e and 2	Identify climate impacts on watershed conditions
Sections 3a, 3b, 3c	**Step 3:** EVALUATE Management Objectives	Sections 3a, 3b, 3c	Evaluate watershed management goals, objectives, desired conditions in light of climate impacts (big picture)
Sections 3d, 3e, 3f	**Step 4:** IDENTIFY Adaptation Options and Desired Conditions	Sections 3d, 3e, 3f	Identify and evaluate strategies, approaches, and tactics to address climate impacts through specifications (add/modify Essential Projects)
Section 4	**Step 5:** MONITOR, LEARN, and COMMUNICATE Effectiveness	Section 4	Identify needed monitoring, including conditions that would trigger adaptive management action

Download the Regional Climate Adaptation Strategy publication at:
https://www.fs.usda.gov/main/r3/landmanagement/resourcemanagement