CLIMATE CHANGE AND MIXED CONIFER/ ASPEN SYSTEMS IN NEW MEXICO: CONSIDERATIONS FOR MANAGERS

A WHITE PAPER written for the
New Mexico Forestry and Climate Change Workshop,
November 20, 2008 Albuquerque, New Mexico

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Produced with funding from the
Collaborative Forest Restoration Program

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Climate Change and Mixed Conifer/ Aspen Systems in New Mexico: Considerations for Managers

Introduction

Although skepticism about the importance of climate change and its anthropogenic influences still exists throughout the various natural resource professions, the tide seems to have turned with respect to forestry. This shift in opinion is exemplified by the U.S. Forest Service's (USFS) new commitment to the issue. The USFS has recently prioritized climate-based research and Chief Gail Kimbell has stated that "history will judge the leaders of our age by how well we respond to climate change. It is time for a coordinated, agency-wide response to climate change."

In addition, the Society of American Foresters (SAF) recently published an entire issue of the Journal of Forestry that addressed climate change and the impacts on forests (Vol 106, No. 3, 2008). In this issue, the president of SAF, Tom Thompson, commented that "climate change, forest management, and policy-making are mingling in new and important ways". In addition, he indicated that professional foresters have important contributions to make with regard to societal concerns about global climate change.

The Forest Guild, which convened the 2008 New Mexico Forest and Climate Change workshop, has also released an official policy statement on forests and climate change as well as a report entitled "Climate Change, Carbon and the Forests of the Northeast". This report identifies forest conservation and management practices that enhance our forests' capacity to mitigate and adapt to changing climatic conditions, while supporting biotic life and human livelihoods.

In light of the national acceptance of climate change, and a willingness on the part of professional foresters to think about how these changes will affect forest management, clearly it is time for regional and more localized conversations on the topic. In the context of the New Mexico-based climate predictions, our working group has been tasked with an examination of the mixed conifer/aspen systems in the state and how the Gutzler/IPCC predictions will affect this forest type in the coming years. In this paper, we first define the mixed conifer/aspen type and provide observations about historic and current conditions in the drier and wetter mixed conifer forests (primarily Jim Youtz's observations). We then address a range of issues particularly important for higher elevation forests (e.g., sublimation, insect and diseases, aspen decline, wildlife responses). We also attempt to address Millar et al.'s (2007) adaptive strategies (response, resilience, and resistance options) and how these options could be applied in the mixed conifer zone. Finally, we conclude by providing some thoughts on the need for monitoring, adaptive management, and landscape-scale planning.

Considering the nation's current financial strain and the limited resources that will be available in the near future to conduct meaningful landscape-scale restoration, we would like to emphasize the need for all land management entities to carefully prioritize management actions. In a world of limited resources, competing objectives, and complex jurisdictional boundaries, collaborative and multi-jurisdictional planning will be essential to the implementation of the ideas and recommendations found in this paper. Once stakeholders agree on the location and extent of priority areas, we feel that the best initial approach for managers is to promote practices that will result in a more resilient ecosystem. Furthermore, changes in management strategies in future years should be guided by adaptive management that is driven by a carefully designed monitoring program

MIXED CONIFER FORESTS IN THE SOUTHWESTERN U.S.: *A Working Definition for Forest Classification for Land Management Planning and Ecological Restoration*

Introduction

Mixed conifer is a generalized forest type that exists throughout western North America in montane settings. Mixed conifer forests exist along a broad continuum of climatic zones and consist of many different assemblages of tree and understory plant species. Ecological functions and plant community succession varies greatly across this continuum. Despite these differences, mixed conifer forests have often been generally mapped and managed as uniformly similar forests. However, a greater distinction is necessary to examine management alternatives and to design ecologically appropriate forest restoration projects.

This section describes mixed conifer forests in the Southern Rocky Mountains, Colorado Plateau, and Basin and Range regions of the Southwestern U.S. This classification groups different mixed conifer forests together based upon generalized disturbance regimes and climate and plant associations. Using previously described and published plant association habitat types, we infer historic fire regimes that influence forest developmental dynamics.

General description of mixed conifer

Mixed-conifer stands can be found below 6,000 ft in canyon bottoms and on steep north-facing slopes, but most mixed conifer occurs above 7,500 ft in the Southwest (USDA Forest Service, Southwestern Region 1997) and from 6,200 – 9,200 ft on the northern portion of the Colorado Plateau (Youngblood and Mauk 1985). Moisture and temperature are primary factors controlling the site-suitability for mixed-conifer forests. The typical spring and early summer dry season in the Southwest limits the extent of mixed conifer (Jones 1974).

The term mixed conifer refers to a specific forest life zone, generally between the mountain foothills and sub-alpine zones (Burns 1989). Mixed-conifer forests occupy cooler, moister sites than those occupied by ponderosa pine and pinyon-juniper woodland, and they occupy warmer sites than those occupied by spruce-fir forests. Stands composed solely of various species of pine (ponderosa, pinyon, Apache, and Chihuahua) are not considered mixed-conifer stands (Jones 1974), nor is a mixture of ponderosa pine and pinyon-juniper.

The common conifer species found in mixed-conifer stands in the Southwest include: ponderosa pine, Douglas-fir, white fir, blue spruce, corkbark fir, sub-alpine fir, Engelmann spruce, and lesser amounts of southwestern white pine or limber pine. Lodgepole pine is also a component of mixed conifer forests in Colorado. Corkbark fir and southwestern white pine are found throughout mixed conifer forests in Arizona and New Mexico, but are not present in Utah, and only found in limited distribution in southern Colorado. Other sub-dominant non-conifer species such as maple and oak may also be present on some sites. Mixed-conifer stands can consist of a variety of conifer species with as few as two or as many as eight of the conifer species listed above. Stands that consist of a majority of Engelmann spruce, corkbark fir, or sub-alpine fir are considered spruce-fir, not mixed conifer. Spruce-fir forest types commonly integrate with mixed-conifer forests (Jones 1974).

Aspen is an early seral species common to many mixed conifer forests. Aspen can dominate a site after a stand-replacement disturbance event in mixed conifer and spruce-fir; and typically is replaced in time by climax mixed conifer or spruce-fir species (Jones 1974). On the mixed conifer-frequent fire sites (discussed below), aspen will not form a seral forest stage, but will co-dominate the site with early seral conifer species such as ponderosa pine and Douglas-fir (Bradley et al. 1992). On these sites, aspen develops as small clonal patches within a conifer forest matrix. For type mapping purposes, the Intermountain, Rocky Mountain, and Southwestern Regions classify stands as aspen (and not mixed conifer) when a majority of the stand's basal area consists of aspen. If <50% of the basal area is aspen, the stand's cover type is that of the conifer species with a plurality of the basal area.

Two factors that define plant community successional dynamics in mixed conifer forests are relative shade tolerance and fire resistance (Ronco et al. 1984, Table 1). Typically, tree species succession proceeds from shade intolerant seral species to shade tolerant species on sites where infrequent disturbances facilitate a gradual shift in species composition over time. On sites with more frequent disturbance regimes, an ecological dis-climax condition may limit plant community succession from proceeding to climax species composition. Many southwestern mixed conifer forest types can be described as having a "fire dis-climax" ecology derived from a frequent, low-intensity fire regime.

Table 1. Relative Shade Tolerance of Common Forest Tree Species[1]

Intolerant	Intermediate (Moderately Tolerant)	Tolerant
Aspen	Douglas-fir	Corkbark fir
Oak species Ponderosa Pine	Southwestern white pine Blue spruce	Subalpine fir Engelmann spruce
Limber pine		White fir
Lodgepole pine		

[1]Burns and Honkala 1990

Disturbance can manifest itself in abiotic and biotic forms. Wind and fire are the most commonly encountered abiotic agents. The shallow root system and rocky soils associated with mixed conifer stands can render them vulnerable to windthrow, particularly if a harvest opens up a stand in which trees have been growing at high density for many years. Fire has a considerable influence on the forest structure and species makeup of mixed conifer. Ponderosa pine and Douglas-fir are considered fire resistant because of their tolerance to fire effects such as crown scorching and bole char. Southwestern white pine and limber pine are considered intermediate in fire resistance when compared to other species (Ronco et al. 1984, Bradley et al., 1992). Generally, the more shade tolerant species such as spruces and true firs are least fire resistant. Even mature Engelmann spruce, blue spruce, corkbark fir, and sub-alpine fir are highly susceptible to mortality by fire. Seedlings of any of the mixed-conifer species are susceptible to fire, but sapling and pole susceptibility varies by species. In areas where historical wildfires of low intensity and severity occurred frequently, ponderosa pine and Douglas-fir tend to dominate the species mix in mixed-conifer stands (Fule et al. 2003). These frequent-fire mixed conifer stands typically occur at the transition between ponderosa pine and wetter mixed conifer. At higher elevations and on cooler sites, historical fires tended to be less frequent and allow for more true fir and spruce composition in late seral stages. Historical fires in these wetter, colder locations tended to be of mixed severity (low-severity burn areas intermixed with areas of stand-replacement burns). Stands occupying these cooler/wetter mixed-conifer sites typically consist of shade tolerant species in late seral stages. A full discussion of warm versus cool and dry versus wetter sites mixed conifer sites is presented below.

Biotic disturbances in mixed conifer forests include insects and diseases, which can cause long-term weakening, short-term stress, or outright mortality of trees. Bark beetles may take out individual weakened trees or larger groups when stress factors, such as drought or disease, have created vulnerability over a larger area. Defoliating insects are less tied to host condition than are bark beetles, but their impact can range from growth loss (e.g., the recurrent western spruce budworm outbreaks so common in New Mexico) to mortality, as in the case of the Douglas-fir tussock moth. When both disease and insects are present, it may be difficult to determine which was the primary and the secondary contributor to tree mortality. Multiple stressors such as drought, defoliation, and excessive competition can combine to create vulnerability to biotic agents that otherwise would not be lethal. Forest insects and disease are generally specific to certain species and the heterogeneity of a mixed conifer stand means that seldom will an entire stand be lost at once. Bark beetles may also further limit their host preference to a certain size class of tree.

Distinguishing between mixed conifer forest types

The mixed-conifer forest type is a continuum that occupies physiographic sites situated between the drier and warmer ponderosa pine forests to the wetter and colder spruce-fir. The break between frequent and infrequent fire regimes is often not clearly defined, but most sites can be classified using the following procedures. Vegetation community (e.g., Youngblood and Mauk 1985) is a more definitive and useful classification tool for project-level analysis, however forest classification is extremely useful in discussing ecological characteristics and functional processes. Forest classification groupings help to distinguish between mixed conifer-frequent fire and mixed conifer-infrequent fire types, based upon described forest succession patterns (Table 2).

Table 2. Southwestern Forest Types and Characteristic (Historic) Fire Regimes

Forest Type	Fire Regime [1, 2]	Fire Type [2]	Forest Structure	Seral Species	Climax Species
Ponderosa pine	frequent/low intensity 2-17 yrs.	surface	uneven-aged patchy,open	ponderosa pine	ponderosa pine
Mixed conifer/ frequent fire (warmer/drier)	relatively frequent/ low-mod intensity 9-22 yrs.	surface (typic) mixed (rare)	uneven-aged, patchy, open uneven-aged, grouped, open	dominant - ponderosa pine subdominant - aspen and/or oak (sub-stand scale patches)	fire dis-climax historic condition-shade intolerant species: dominant- ponderosa pine; subdominant - Douglas-fir; Southwestern white pine or limber pine
Mixed Conifer/ infrequent fire (cooler/wetter)	relatively infrequent/ mod-high intensity variable, 22-150 yrs.	mixed (typic) stand-replacing (rare)	uneven-aged, grouped, closed even-aged, closed	dominant - aspen or Douglas-fir, depending upon plant association habitat type	shade tolerant species, depending upon plant association habitat type: white fire, blue spruce
Spruce-fir (mixed, lower sub-alpine)	infrequent/ mod-high intensity 150-400 yrs.	mixed/ stand-replacing	even-aged, closed	dominant - aspen or Douglas-fir, depending upon plant association habitat type	shade tolerant species, depending upon plant association habitat type: Engelmann spruce, white fir
Spruce-fir (upper sub-alpine)	infrequent/ high intensity 150-400 yrs.	stand-replacing	even-aged, closed	dominant - aspen, Douglas-fir or Engelmann spruce, depending upon plant association habitat type	shade tolerant species: Engelmann spruce and corbark or sub-alpine fir co-dominate

1 Schussman 2006.
2 Smith 2006.

HISTORIC AND CURRENT CONDITIONS

Dry Mixed Conifer Description and Historic Condition

This potential natural vegetation type (PNVT) spans a variety of dry and semi-mesic environments in the Rocky Mountain and Madrean Provinces. In the Rocky Mountains, montane mixed conifer forests may be found at elevations between 5,000 and 10,000 ft., situated between ponderosa pine, pine-oak, or pinyon-juniper woodlands and spruce-fir or sub-alpine conifer forests. Dry mixed conifer forests occupy the warmer and drier sites within this zone, and are characterized by a relatively frequent historic fire regime resulting in surface fire and infrequently, mixed-severity fire effects. Typically these types are dominated by shade intolerant species such as ponderosa pine, with minor association of aspen, Douglas-fir and Southwestern white pine during early seral stages. Aspen in this PNVT does not develop as a seral stage forest type, but is present in small clonal groups as a subdominant tree species. More shade tolerant conifers such as Douglas fir, white fir and blue spruce are dominant at climax stages. Under characteristic historic disturbance regimes these types infrequently achieved climax species composition. Development of climax forests typically occurred only where local edaphic factors such as aspect, soils and other factors limited the spread of surface fire. Elsewhere the historic composition was dominated by fire-adapted seral species, growing in an open forest structure (canopy cover < 30%).

Dry Mixed Conifer Current Condition

The interruption of the characteristic fire regime and past preferential harvesting of shade intolerant conifers has resulted in widespread changes in the current structure, fuel loading and species composition. In contrast to the historic open forest conditions, much of this type is currently characterized as "closed forest." Forest regeneration on these closed forest sites is currently dominated by climax shade-tolerant species, and seral species regeneration is declining or lacking. Mature shade-intolerant and fire-adapted seral species are declining in vigor and becoming a sub-dominant proportion on many sites in this PNVT. As a result, some stands are currently dominated by fire-intolerant climax species composition, and a continuing shift to climax species dominance is occurring throughout most of this PNVT. Changes in forest structure has resulted in a shift of wildfire characteristics from surface (Fire Regime I) to mixed (Fire Regime III) and lethal (Fire Regime IV) fire effects. Many decades of fuels build-up has shifted much of these sites from Fire Regime Condition Class (FRCC) 1 to FRCC 3.

Although dry mixed conifer forests have generally shifted to conditions described as "closed forests" over time due to fire suppression, drought-related mortality may be playing a role in thinning mixed conifer forests to presumed pre-exclusion conditions. According to John Vankat (personal communication), initial analyses of data obtained from the resampling of 71 historic vegetation plots dating to 1935 and 1984 in mixed conifer forest on the North Rim of Grand Canyon National Park, Arizona, indicate statistically significant decreases in density and basal area of trees ≥10 cm dbh , particularly in the dry-mesic mixed conifer zone.

Wet (infrequent fire) Mixed Conifer w/ Aspen Description and Historic Condition

This forest type includes a variety of dominant and co-dominant species in mesic environments in the Rocky Mountain and Madrean Provinces. In the Rocky Mountains, mixed conifer forests may be found at elevations between 5,000 and 10,000 ft., situated between ponderosa pine, pine-oak, or pinyon-juniper woodlands below and spruce-fir forests above. Dominant and co-dominant vegetation varies in elevation and moisture availability. On higher elevation more mesic sites, ponderosa pine occurs incidentally or is absent. On these wetter sites Douglas-fir, Southwestern white pine, white fir, and Colorado blue spruce are the dominant conifer species. Other species that may be present in sub-dominant proportions include Engelmann spruce or limber pine in some locations. The understory vegetation is comprised of a wide variety of shrubs, grasses, graminoids (sedges, etc.), and forbs; the compositions depends on soil type, aspect, elevation, disturbance history and other factors. Historically this type had over 10% tree canopy cover, with the exception of early, post-fire plant communities.

Under historic disturbance regimes the fire regime is characterized as typically fire regime III (35 to 200 yr frequency, mixed severity). Plant community development undergoes successional patterns that can be described by three simplified phases: aspen, intolerant conifer, and shade tolerant conifer (Table 3).

Table 3. Successional Forest Phases of Infrequent Fire 9wet) Mixed Conifer Forests

Seral	Mid-succession	Late seral
Aspen forest type	Shade intolerant conifer	Shade tolerant conifer
(occasionally Douglas-fir on some sites)	(Dominant species: Douglas-fir, Southwestern white pine)	(Dominant species: white fir, Colorado blue spruce)
Closed canopy (.30%)	Open canopy (,30%)	Closed canopy (.30%)

Wet (infrequent fire) Mixed Conifer Current Condition

Due to the infrequent fire regime characteristic of this type, current forest conditions are less departed from the historic conditions, compared to the drier mixed conifer type. In most cases the current fire regime can be described as fire regime III or IV (35 to 200 yr frequency; replacement severity). Due to lack of disturbances, most of this type is currently in the climax forest phase. Historical evidence suggests that in the past, a higher proportion of this type was represented by the seral and mid-successional forest phases than presently occurs on the landscape. In some locations, elk and other herbivores severely browse aspen regeneration following disturbances, such that the future development of an aspen forest type is jeopardized or eliminated. In such cases, initial forest development is characterized by a shade intolerant conifer mix.

Issues of Particular Concern to Higher Elevation Forests

Sublimation

Conifer canopies intercept a large portion of snowfall and snow caught in canopies sublimates at higher rates than ground level snow (Essery et al. 2003). Rates range from 15 percent to 45 percent of annual snowfall (Hood et al. 1999, Parviainen and Pomeroy 2000, Montesi et al. 2004). Higher temperatures, lower humidity, and greater wind speeds can all increase sublimation rates (Montesi et al. 2004). Snow accumulation can be greater in open areas largely due to a lack of intercepted snow sublimation (Gelfan et al. 2004). The spatial arrangement of trees also affects snow accumulation. Dispersed retention results in greater snow accumulation than grouped retention (Woods et al. 2006). In a mixed conifer forest, aspen stands had a greater peak snow accumulation and a greater water yield than conifer stands (LaMalfa and Ryle 2008). However, increases in water yield for runoff and groundwater recharge in aspen stand were partial offset by greater evapotranspiration than conifer stands (LaMalfa and Ryle 2008). A warming climate may cause snow to melt earlier in the year and therefore decrease sublimation and produce an earlier and larger peak runoff (Dankers and Christensen 2005).

Climate change effects on mixed conifer insects and diseases

A change in climate can directly affect insect or disease incidence, or can influence the condition of the host in a way that affects insect or disease success (Table 4). While it is possible that climate change could adversely affect these biotic agents, it is more likely that given the Gutzler scenarios, a direct influence via host condition will have the greater impact. An example would be that following an unusually warm, dry winter, trees may enter the normally dry spring season in a moisture-stressed condition. Conifers which are moisture-stressed cannot muster the sap pressure required to expel attacking beetles. This condition continues to favor the beetles as they generate offspring under the bark, allowing greater than normal success for brood survival. When this scenario is repeated over several generations, beetle populations can grow to epidemic proportions, easily overcoming tree defenses. The dynamics between defoliators and host trees are less-well understood. However, even if a change in climate has no direct effect on an insect, the stress from defoliation coupled with weather-related stresses can turn what normally would be a tree-weakening agent into a tree-killer by virtue of the cumulative effects of multiple stressors.

In this paper, we have attempted to show examples of pest-tree dynamics in a changed climate scenario, but the most important factor is host condition (Table 4). Reducing inter-tree competition is the most effective tool we have for mitigating the adverse impacts of insects or disease in any climate scenario. While there is much speculation about the current effects of climate change on insect development or distribution, observed insect activity in New Mexico over the past ten years appears to be consistent with historical accounts. Changes in insect impacts appear to be related to unprecedented forest density, structure, and composition.

Table 4. Climate Change Effects on Selected Mixed Conifer Insects and Diseases

Host	Causal Agent	Dry Winter	Warm Winter	Dry Summer	Comments
All conifers	Bark beetles	increase	increase	increase	Dry winters mean no spring snowmelt at the critical time when dormancy is broken and roots need water. Warm winters stress trees by causing evaporative loss while soil moisture is frozen and thus unavailable to roots. Dry summers cause reduced sap pressure, compromising the tree's only defense against bark beetles.
Douglas-fir, white fir, spruce	western spruce budworm	unknown	unknown	unknown	Spruce budworm has been known to flourish when the host flourishes so the relationship between host condition and outbreaks is not well-understood. As a stress agent, could contribute to tree death in combination with other stresses.
Douglas-fir and white fir	Douglas-fir tussock moth	unknown	unknown	unknown	Relationship between outbreaks and weather patterns are not understood. Outbreaks typically last 2-3 years and often cause mortality, particularly where trees were stressed prior to defoliation.
All conifers	Nepytia janetae, a winter defoliating caterpillar of conifers	increase	decrease	increase	Once in outbreak, this species thrives during normally cold winters. Dry summers may be detrimental to natural enemies. Warm winters may favor natural enemies. Outbreaks lasting 2 years are common for this genus. Mortality is possible where trees were drought-stressed before or after defoliation.
Aspen	western tent caterpillar	unknown	unknown	unknown	The effect of climate change is unknown on this insect species, but even if the incidence of its outbreaks remains at historical levels, the effect on the host may be more profound as defoliation will compound the stress the host will endure from climate change.
All species	root diseases	unknown	unknown	unknown	While the projected climate change may have little effect on root disease incidence, other stresses to the host tree could exacerbate the adverse effects of root disease.
Conifers	rusts	unknown	unknown	decrease	Outbreaks (that is "waves" of new infections) depend on moist conditions, but even one wet season in the midst of many drier ones would be enough to promote the spread of rust. Of particular concern would be the spread of white pine blister rust.
Conifers	mistletoe	neutral	neutral	neutral	While the direct effect of the climate change to mistletoe would be negligible, the effect on the host would be more pronounced. High mortality rates among heavily-infected trees can be expected during extended periods of moisture stress.

Aspen decline

In southwestern Colorado and Utah, rapid mortality of mature aspen stands followed by little to no regeneration is thought to be caused by drought and ensuing attacks by insects and disease (Worrall et al. 2008). This "aspen decline" is rapid and does occur in New Mexico but differs from the long-term loss of aspen currently seen throughout the state that has been caused by an altered fire regime (the loss of a mixed severity regime), the regeneration of white fir and other conifers underneath mature clones, and heavy elk browsing of regeneration. The re-establishment of a mixed severity fire regime in regions with large and contiguous patches of late seral mixed conifer forest (that contain an aspen component) would assist the recovery of aspen in many locations across the state.

Fire regime change and wind

Westerling et al. (2006) investigated 34 years of wildfire history in the western US and attempted to evaluate how recent climatic factors were related to wildfire size and intensity. These authors detected a large increase in wildfire activity in the west in the mid-1980s with the greatest increases in mid-elevation forests in the northern Rockies. Increased wildfire frequency, longer fire durations, and longer wildfire seasons were associated with increased spring and summer temperatures and an earlier snowmelt.

In a recent study in California, climatic change resulted in more frequent and more intense fires in the northern regions of the state, where escape frequencies increased by more than 100%. This work was based on relatively conservative general circulation models (GCM) output that predicts warmer and windier conditions in the region (Fried et al. 2004).

If average winter and spring temperatures in New Mexico result in an earlier snowmelt in the mixed conifer zone, this may create favorable fire conditions for longer time periods in the springtime. An additional consideration is the length of the "windy" season in New Mexico. If earlier snowmelt is combined with conditions that are favorable to high winds, the likelihood of stand replacing fires in the springtime will increase.

Wildlife concerns

In February of 2006, the New Mexico State Department of Game and Fish published the state's Comprehensive Wildlife Conservation Strategy, or CWCS, in response to Congressional direction to the states. The CWCS delineates 6 ecoregions in New Mexico following in large part the ecoregional analyses developed by The Nature Conservancy, based on the original Bailey ecoregions

(New Mexico Department of Game and Fish 2006a p. 31). Mixed conifer forests are restricted in New Mexico to the Southern Rocky Mountains Ecoregion, which include the San Juans, Sangre de Cristo and Jemez mountain ranges, and the Arizona-New Mexico Mountains Ecoregion. This second ecoregion includes the mountain ranges of the central and southern portions of the state. In the CWCS, two SWReGap cover types- Rocky Mountain Montane Dry-Mesic Conifer Forest and Woodland, and Rocky Mountain Mesic Mixed Conifer Forest and Woodland were grouped into one habitat called Rocky Mountain Mixed Conifer Forests and Woodland. For the purposes of this section, this combined cover type class will be synonymous with "mixed conifer forest". Within the Arizona-New Mexico ecoregion, mixed conifer forests harbor 37 species of greatest conservation need (SGCN). Mixed conifer forests in the Southern Rocky Mountain ecoregion support habitat for 31 SGCN. Mixed conifer forests are considered one of 9 key terrestrial and 10 aquatic habitats for wildlife listed in the CWCS .Key habitats were those land cover types that one or more of these characteristics:

- Important to the biodiversity of New Mexico,
- Important to endemics or obligate species of New Mexico,
- Captures a broad range of indicative species,
- Adds unique species to state fauna,
- Hosts a variety of scarce or threatened wildlife,
- Threatened by land uses/management practices
- Limited or has been significantly reduced in New Mexico,
- Habitat type is unique to New Mexico, Southwest, US, or worldwide,
- Key breeding or foraging habitat for species of concern,
- Hosts wide-ranging species that are not found in other habitats,
- Supports species with isolated or relict distributions in New Mexico,
- Habitat functions as a refuge or indicator of the quality of the system, and
- Functioning habitat; habitat has greater ecological value

The expected effects of climate change on wildlife species of mixed confer forests are individualistic, based on each species' biological characteristics and habitat requirements. In general, NMDGF suggests the following:

"The effects of climate change on ecosystems and species are likely to be exacerbated in areas that have already been substantially affected by human activities…Habitat fragmentation decreases the ability of plant and animal species to migrate in response to changing conditions or species requirements…Climate change may act as a form of disturbance creating opportunities for invasive species to colonize and displace native species…when suitable habitat conditions disappear or shift faster than populations can adjust, the likelihood of species extirpation or extinction increases…" (New Mexico Department of Game and Fish 2006a, p 78)

As a measure of current conditions, NMDGF conducted an analysis that provided a comparative index of threats across the state's key habitats. NMDGF evaluated key terrestrial habitats by their "cumulative magnitude scores" created by combining the number, and the degree of severity and extent of factors believed to be detrimental to wildlife species or their habitat. (New Mexico Department of Game and Fish 2006a, p. 18). A maximum possible index score was 344 (highest possible extent and severity over 43 factors). Mixed conifer habitat received a score of 75. For comparison, the low score for key terrestrial habitats was 39 - Rocky Mountain Alpine-Montane Wet Meadow, and the high 156 for Riparian Habitats. Aquatic habitats scored higher than terrestrial habitats overall, with the highest scores of 165 and 158 given to ephemeral natural catchments and Perennial Marsh/Cienega/Spring/Seep, respectively. Although this paper addresses terrestrial forest habitats, it is worth pointing out that riparian habitats embedded within all forested environments provide critical habitat and that their at risk status and potential response to changing climate should be evaluated and addressed as our management strategies develop.

Within the mixed conifer system, for both the Southern Rocky Mountain and Arizona-New Mexico ecoregions, analyses based on the scientific literature and NMDGF staff opinion indicates that the associated effects of climate change, drought, changes to natural fire regimes, and insect attacks are the factors most adversely affecting Rocky Mountain Montane Mixed-Conifer Forest and Woodland habitats. As is stated elsewhere in this paper, factors like fire, drought and insect attacks may occur with more frequency or severity with predicted changes in the climatic regime.

Two species of interest within the mixed conifer forests of New Mexico provide examples of climate impacts on wildlife and potential management options: Mexican spotted owl (MSO) and Jemez Mountains salamander. Since its federal listing as a threatened species in 1993, forest managers have worked to integrate their silvicultural activities into recovery objectives for the MSO. The owl prefers forests with relatively complex structure and higher canopy cover for its nesting and roosting habitat. In comparison with the more extensive ponderosa pine forests, mixed conifer forests provide more preferred habitat important to owls especially for nesting and roosting. Although they have a broad geographic range in the Southwest, this range is disjunct, co-occurring with our isolated mountain ranges and canyons (USDI Fish and Wildlife Service 1995, p. 21). A potential increase in catastrophic fire is considered a threat to the survival of the spotted owl.

Prather and others (2008) recommend a landscape approach to reducing fire risk to both owls and human communities. They contend that the perceived conflict between fuel reduction and owl habitat can be lessened when planning occurs on a larger landscape scale. In an analysis of an 811,000 ha ponderosa pine landscape in northern Arizona, less than 1/3 of the area had potential real conflicts between active management and species habitat preservation. Further, they found that within areas where conflicts could be expected, the majority of the area could be treated to reduce fire hazard without eliminating owl habitat. They found in their study that debates over fire hazard reduction vs. species habitat are often pursued in "an abstract, aspatial and largely theoretical context" and further that "Spatial analysis puts the perceived conflict 'on the map' and allows all parties to see where and how much imperiled species' habitat is placed at risk by planned restoration actions". It is important to note that landscapes dominated by mixed conifer forests may pose a greater challenge than this ponderosa pine example because a greater proportion of the area may support MSO PACs or suitable habitat.

Skinner (2007) points out that increasing fires will make it more difficult to sustain habitat unless managers pay greater attention to landscape pattern, geographic context and the realities of climate. He also suggests that moister, north-facing slopes and the lower slopes of canyons are more likely to retain old-growth characteristics longer than other parts of the landscape as a whole. Mixed conifer ecosystems are made up of a mosaic of dry and moist communities, and their inherent variability should be accounted for when planning active management.

As a group, amphibians appear to be suffering a global decline. While habitat destruction is the most damaging, climate change and an emerging chytrid fungal disease are also key factors (Amphibiaweb 2008). One species, the Jemez Mountains salamander, Plethodon neomexicanus, is endemic to north-central New Mexico where it is found only in the Jemez Mountains. This salamander is listed as endangered by the state. It occurs from 7,200-11,256 ft elevation in mixed conifer habitat with abundant rotted logs and surface rocks. It is rarely observed on the surface or encountered under surface litter or aspen logs. It is most often encountered under and inside well-rotted Douglas-fir logs or under rocks. Projected climate change, and the potential for larger and more severe fires is likely to affect the species because of these specific microhabitat needs.

The 2006 biennial review of the status of SGCN (New Mexico Department of Game and Fish, 2006b) listed threats that were effectively fragmenting habitat within the salamander's range. The review noted that there was significantly elevated microhabitat temperatures on habitat severely burned during the Cerro Grande and Dome fires. There is a continued threat of additional negative impacts to populations of Jemez Mountains salamanders from future fires. Salamander populations are known to be susceptible to fire related effects, including decreased forest humidity, desiccation of habitat, loss of microhabitat (such as downed logs and litter), erosion, and filling in (by runoff) of subterranean habitat utilized by salamanders. Post-fire management actions that have negatively impacted Jemez Mountains salamanders and their habitat include the mulching and reseeding of occupied habitat with soil-binding, non-native grasses.

The need for a moister microclimate and relatively small structures such as downed logs, points out the importance of understanding individual species' biology at a scale relevant to the animal. Stand level analysis has proven to be useful for describing silvicultural conditions. However, managers need to look at both large landscapes and within stand conditions to more accurately project effects of activities on wildlife. There is much that is not yet understood about wildlife species needs and their potential response to changing conditions. A good first step is to improve our understanding of species' current status through research and further investments in monitoring. Using the best existing habitat information, improving existing conditions where we can, and planning through nested scales of analysis are strategies that can be used now to maintain biological diversity while managers strive to create more resilient forests and adapt to future change.

Management Strategies and Managerial Recommendations

As we previously mentioned, competing objectives, limited financial resources, and complex jurisdictional boundaries already present significant challenges to implementing landscape-scale restoration in New Mexico. According to the Gutzler/IPCC predictions, steadily increasing temperatures will only contribute to uncertainty for managers in the coming 100 years. Since we cannot accurately predict the full extent of our climate in the long-term (longer spring, windier spring, warmer winter, etc.), we feel that the best initial approach for managers is to promote a more resilient ecosystem, but that the response and resistance options (from Millar et al. 2007) also have application in New Mexico. In the following section, we attempt to provide managerial recommendations based upon these three adaptive strategies. We also provide a short list of constraints that managers will face in implementing some of our suggestions.

Resilience option

Restoration of Dry Mixed Conifer
In dry mixed conifer, moisture stress is a significant factor for part of the year and managers should consider changes that make your forests more resilient. A goal under the resilience option in the dry mixed conifer type involves the restoration of conditions so that the forest is resilient to disturbances within the historic range of variation (HRV). Resiliency requires forest characteristics such as fuel loading, species composition and stand structures be compatible with restoration of frequent surface fire functional processes. Under this goal of creating resiliency in the dry mixed conifer type, some desired changes would include the following:

- Reduced tree density to restore open forest conditions.
- Restore dominance of seral fire-adapted species (e.g., ponderosa pine).
- Promote regeneration of shade intolerant seral species.
- Reduce understory and overstory dominance of shade tolerant species (e.g., white fir).
- Reduce fuel loading to levels commensurate with re-introduction of frequent surface fire (fire regime I condition).
- Restoration of frequent surface fire as a functional ecological process.

Restoration of Wet (infrequent fire) Mixed Conifer
In the wetter mixed conifer type, the short-term goal would be to restore conditions so that the forest is resilient to disturbances within the historic range of variation (HRV). In these wetter zones, resiliency requires a balance of forest successional phases patterned as landscape mosaics. Restoration of these conditions will increase vegetation diversity and reduce the potential for landscape scale and uncharacteristic stand-replacing fire effects. Desired changes would include the following:

- Reduce proportional representation of climax forest phases
- Increase proportional representation of seral and mid-successional forest phases.
- Reduce landscape continuity of homogenous forest conditions that facilitate stand replacement fire effects (especially climax forest phases).
- Restore landscape structural patterns that facilitate mixed severity fire effects.
- Promote and protect aspen regeneration to restore representation of this forest type on the landscape.

Restoration of burned areas
After a site has experienced an uncharacteristically hot fire, managers should conduct a site specific evaluation and think carefully before investing in reforestation. Survival rates may be very low, and funds might be better used to treat more acres before they are deforested by other fires. Although reforestation in New Mexican mixed conifer will not likely ever be possible on large acreages, there are examples such as the Cerro Grande fire where little regeneration occurs in the years following the fire, and where targeted replanting would aid in the re-establishment of the preferred species. We feel that this targeted reforestation would be most beneficial on the dry mixed conifer sites and would involve planting or direct seeding of ponderosa, Douglas-fir, and southwestern white pine. On the wetter sites, hotter fires would likely shift late seral mixed conifer to early seral mixed conifer and would not require artificial regeneration if elk browsing was limited or not a factor.

This potential use of artificial regeneration emphasizes the importance of zonal seed collection and the maintenance of regional seed banks in New Mexico. This material would be used in nurseries, for direct seeding, or for preservation of genetic material that is either 1) disease resistant (e.g., southwestern white pine) or 2) grows and competes in special circumstances (e.g., ponderosa pine on wet sites).

Response option

Dry mixed conifer
According to Millar et al. (2007), the response option intentionally accommodates change rather than resisting it and treatments should mimic, assist, or enable ongoing natural processes. In dry mixed conifer, we feel that a suitable response option is the conversion of sites dominated by white fir and Douglas-fir to a ponderosa/Douglas-fir/white pine mix (i.e., a conversion from late successional to the dry seral which was historically present). This style of management would focus on maintaining groups of trees in a clumpy mosaic of openings, old trees, pole sized trees, and regeneration.

In addition, elevational gradients are an important consideration. Forests in places most vulnerable to the effects of climate change, such as low-elevation ecotones, may be a relatively low priority for ecological restoration or long-term conservation. Given the high likelihood of loss, management resources might be better applied elsewhere. Instead of seeking to perpetuate low-elevation forests in their current form, managers could follow a course of facilitating their replacement with native vegetation that is presently found at lower, drier sites. For low-elevation mixed conifer, this may mean facilitating a transition to pine or pine-oak forests.

Wet mixed conifer
In the wetter mixed conifer forests, we feel the conversion of large acreages of late seral mixed conifer to a mosaic of patches in different successional stages is an adequate response option. For example, managers would focus on creating and maintaining early, mid, and late seral stages equally across the landscape.

Forests at the upper, wetter end of the mixed conifer elevational range are best positioned to survive climate change and to serve as the leading edge of upward migration. Treatments based on historical reference conditions characteristic of lower-elevation sites could help facilitate the transition. In the southern range of fire-adapted pines, the upper ecotone is usually a wet mixed-conifer or aspen/spruce/fir forest that historically burned with surface to mixed-severity or severe fire. Application of surface fire, perhaps coupled with thinning of mesic taxa (Abies, Picea), will favor pine dominance with enhanced resistance to severe fire, shifting the surface/lethal fire boundary uphill. In sum, it may be logical to apply historical reference data from lower, southerly, and drier sites to places that are higher, northerly, and currently wetter sites. This may enhance vegetation transition and reduce the probability of severe disturbance with invasion by native and non-native ruderal species.

Resistance option

One management option that should be considered is the effort to forestall the undesired effects of a change in climate and thus creating a resistance to change. For some wildlife species that utilize the mixed conifer zone, it may be necessary to adopt a protective strategy in the near future. For example with the MSO, managers may want to thin around (outside of) known nesting sites to decrease the possibility of crown fire entering the denser, multi-story stands used by owls. In addition, managers may want to strategically preserve MSO type stands in connected patterns across the landscape perhaps by intensively thinning in forest stands downhill from MSO habitat.

For some tree species, the resistance option may serve to protect valuable genetic material. For instance, southwestern white pine that is resistant to blister rust will merit protection since we have evidence that there is natural resistance to the infection in New Mexico. The identification of these resistant trees and their maintenance and protection will be important if warmer conditions affect the spread of blister rust in New Mexico. In addition to white pine protection, ponderosa pine that has grown and maintained itself on wetter mixed conifer sites also deserves attention. These isolated trees may have a different genetic potential compared to ponderosa pine on drier sites, thus it merits special attention and protection from removal.

Constraints in implementing these recommendations

Land managers operate in an environment where constraints frequently prevent them from implementing preferred options, we recognize these limitations and have developed a list of constraints that we feel will impact New Mexican land managers in their efforts to meet some of our recommendations in the mixed conifer zone. These constraints include the following:

- Housing developments and fragmentation of private property
- Need for management on small private parcels in the WUI
- Limited access, road infrastructure and steep slopes
- Limited funding for management projects, monitoring programs, NEPA clearances
- Lack of markets for small diameter products
- Limited supply of thinning and logging crews
- Smoke management
- Multi-jurisdictional planning and coordination
- Impacts of lower elevation management on higher elevation forests
- Widespread nature of late seral stage mixed conifer stands
- Slash management and insect build-up during drought

Conclusions

The following recommendations are relevant whether a manager is considering options to deal with a forest that is outside the historic range of variation or an impending change in climate.

- Determine if you are working in a dry or wet mixed conifer forest because the response, resistance, and resilience options will vary according to your site
- With limited resources available, focus efforts where your budget will have the most impact
- Focus on creating a mosaic of seral and structural stages across the landscape
- For smaller land tracts, consider the creative employment of openings instead of evenly spaced basal area reductions which may dry the forest floor an surface soils
- Although they are not specific to the mixed conifer zone, use the New Mexico Forest Restoration Principles as part of the managerial tool set
- Design and implement a cost-effective monitoring program to track treatment effectiveness

In addition, we strongly feel that there is a need for landscape-scale analyses and multi-jurisdictional projects to accomplish our goal of creating a mosaic of seral and structural stages across the mixed conifer zone in New Mexico. This landscape style of planning has precedence in the southwestern United States and two recent examples include the Forest ERA wood supply analysis for the Mogollon Rim (www.forestera.nau.edu) and the Prather et al. (2008) examination of landscape scale analyses of Mexican spotted owl habitat. These large-scale analyses of wood supply, owl habitat, and other competing values will help bring conflicted parties to the negotiating table and will likely result in agreement over the size and extent of treatable mixed conifer acres in the state. In addition, the pursuit of these large-scale analyses will also help build capacity in New Mexico so that we can develop the techniques and expertise to deal with our dynamic climate, increasing human population, and the other issues that will continue to challenge forest managers in the years ahead.

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New Mexico Forest and Watershed Restoration Institute

The New Mexico Forest and Watershed Restoration Institute at New Mexico Highlands University is dedicated to providing state-of-the-art information about forest and watershed restoration to the public, federal and state agencies, tribes, and private landowners in New Mexico. To accomplish this, the Institute collaborates with citizen stakeholders, academic institutions, NGOs, and professional natural resources managers to establish a consensus concerning prescriptions and monitoring protocols for use in the restoration of forests and watersheds in an ecologically, socially, and economically sound manner. Through research and collaboration, the Institute promotes ecological restoration and forest management efforts in ways that 1) will keep New Mexican homes and property safe from wildfire, 2) will lead to a more efficient recharge of New Mexican watersheds, and 3) will provide local communities with employment and educational opportunities.