

Statement of
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Good morning Chairman Bingaman. I am pleased to be here today to discuss an important set of issues facing the intermountain West—the emerging impacts of climate change on drought, forest stress, wildfire, and ecosystem change.

My name is Dr. Craig D. Allen. I am a research ecologist with the Fort Collins Science Center of the U.S. Geological Survey. I am also the Station Leader of the Jemez Mountains Field Station based at Bandelier National Monument here in northern New Mexico, where I have conducted ecological fieldwork continuously since 1982. My research largely has focused on the ecology and environmental history of Southwestern landscapes, working with networks of colleagues on intensive local landscape studies that scale up to address regional and global-level issues. My testimony today will present information from a variety of sources in the scientific literature, with a focus on the Southwest, and particularly including observations from my home landscape of the Jemez Mountains.

The messages I hope to leave with you are these: There is a high level of scientific confidence that, as a result of drought impacts coupled with warmer temperatures, forests in the Southwest are at increasing risk of severe wildfire and tree mortality. Currently observed trends are indicative of early-stage ecosystem reorganization in response to climate stress and land management practices.

Recent climate trends of warming and drying conditions have corresponded to major increases in the extent and severity of forest die-off in the Southwest. The close linkages among patterns of climate, tree growth and mortality, and fire are particularly well-documented in the scientific literature for this region, using multiple lines of strong evidence that extend back many thousands of years. This evidence includes information unlocked from the tree-rings of ancient wood that records past patterns of precipitation, temperature, stream flow, tree growth, and fire; plant pollen, other plant remains, and charcoal deposited in layers of sediment at the bottoms of lakes and bogs; and plant macrofossils and pollen preserved in the middens, or waste heaps, of ancient packrat nests.

Given that substantially warmer temperatures and greater drought stress are projected for the Southwest in coming years (Seager and Vecchi 2010; Gutzler and Robbins 2010), we should expect even greater increases in mortality of drought-stressed trees, high severity fire (Williams et al. 2010), and ultimately conversion of current forests into different ecosystems, ranging from grasslands and shrublands to new forests dominated by different tree species (Williams and Jackson 2007; Jackson et al. 2009). Increasingly frequent and severe droughts and fires favor plant life-forms that can survive above-ground stem dieback and fire damage by resprouting from below-ground tissues. Many grass and shrub species can do this. After high severity fires, successful regeneration of the main tree species in the Southwest primarily depends upon the local survival of enough mother trees to serve as seed sources.

There are several studies and recent observations that document the risks of post-fire type conversions from forest to non-forest ecosystems (Barton 2002, Savage and Mast 2005; Goforth and Minnich 2008). These conversions can be caused by the ever larger, high-severity fire patches where essentially all tree seed sources are killed across tens of thousands of acres, as observed in some recent fires (Fig. 1). This greatly limits the rate of recolonization by some of the most common tree species such as piñon pine, ponderosa pine, and Douglas-fir, allowing dense grasslands or shrublands of resprouting species to achieve dominance before trees can re-establish. It is also beginning to be observed that once large areas of resprouting shrubs, like Gambel oak, become mixed in and around surviving post-fire conifer tree populations, a hot reburn through the shrubs can then kill nearly all of those adult survivors. Tree seed sources are thereby eliminated in sequential fashion (Fig. 2). The growing extent and severity of recent forest disturbances in this region, and the lack of tree regeneration on some sites after disturbances, are evidence that we already may be reaching tipping points of forest ecosystem change, changes which are new to the historical era.

Similar patterns of recent climate-amplified tree mortality and fire activity also are occurring more broadly in western North America, as well as in many other portions of the world. For example, a group of 20 co-authors from around the world recently conducted the first global overview of drought and heat-induced tree mortality (Allen et al. 2010), which documented many examples of extensive forest die-off in all major forest types worldwide, from tropical rainforests in the Amazon to African savannas and Mediterranean pine forests to boreal forests in Canada and Alaska (Fig. 3). But while we observe that all major forest types worldwide are vulnerable to high levels of tree mortality during periods of drought and heat stress, we cannot yet determine if forest die-off is increasing overall at a global scale due to the absence of long-term baseline information on global forest health conditions, and the continued absence of a globally coordinated observation system (Allen et al. 2010). A recent experiment on piñon pine, however, showed unequivocally and unsurprisingly that when warmer temperatures accompany drought, trees die much faster (Adams et al. 2009). This is to say, there is not only observational evidence that tree mortality is on the rise, but also experimental results showing that mortality is temperature sensitive. As climate continues to warm we can expect more tree die-off events like those we have recently observed. Changes in climate and human land uses also are driving increasingly severe fire activity in many regions around the world (Bowman et al. 2009 & 2011, Pechony and Schindell 2010, O'connor et al. 2011).

Every plant species has a particular range of climatic conditions in which it can grow, so as local climates, and associated disturbances like fire and beetle outbreaks, shift beyond the tolerance limits of the currently dominant species, today's dominant plants will die, thereby opening space for new species that can tolerate the altered climate conditions. There is, however, a major gap in scientific information about precisely how much drought and heat stress various tree species can tolerate before dying. In other words, scientists do not yet know how to "kill" trees in models with the accuracy necessary to project how much change in climate conditions they can tolerate before widespread mortality occurs (McDowell et al. 2008 & 2011, Allen et al. 2010). Our understanding of climate change risks to forests in this region is enhanced by cutting-edge experimental research on the physiological effects of drought and heat stress on trees which is being conducted locally by Dr. Nate McDowell of Los Alamos National Laboratory. Dr. Park Williams, another colleague also at Los Alamos National Laboratory, is leading new research that demonstrates the risks that warming temperatures could drive forest drought stress in the Southwest to unprecedented levels by the 2040's, which likely would render large areas of current forest climatically unsuitable for their present dominant tree species. Park's work also shows strong correlations between forest drought stress and area affected annually by high-severity fires and bark beetle infestations in this region,

consistent with known climate-disturbance linkages in western North America (Westerling et al. 2006, Raffa et al. 2008, Littell et al. 2009, Bentz et al. 2010, Hicke et al. 2012).

Given projections of substantial further warming and increased drought stress for the Southwest in the coming decades (e.g., Seager and Vecchi 2010), the recent ramp-up in the extent and severity of climate-related forest disturbances (Breshears et al. 2005, Westerling et al. 2006, Raffa et al. 2008, Allen et al. 2010, Williams et al. 2010) may indicate that forests in this region are now approaching tipping points such that we are beginning to see substantial reorganization of ecosystem patterns and processes into new configurations (Williams and Jackson 2007, U.S. Climate Change Science Program 2009, Jackson et al. 2009, Barnosky et al. 2012).

If the climate projections of rapid warming for the Southwest are correct, then by the middle of the twenty-first century our Southwestern forests as we know them today will experience significant vegetation mortality and can be expected to reorganize with new dominant species (Littell et al. 2009, Bentz et al. 2010, Williams et al. 2010).

Long-term Perspective

The Southwest United States has an abundance of paleo-ecological records that make this one of the best places in the world to determine past patterns of climate, vegetation, and fire, using multiple lines of evidence. For example, scientists here in New Mexico have used information locked in the tree-rings of ancient wood to precisely reconstruct past patterns of precipitation, temperature, stream flow, drought stress, and tree growth and death going back as much as 2000 years (Swetnam et al. 1999 & 2011, Swetnam and Betancourt 1998, Allen et al. 1998 & 2008, Brown and Wu 2005, Fule et al. 2012, Falk et al. 2011, Margolis et al. 2011, Roos and Swetnam 2012, Touchan et al. 2010, Woodhouse et al. 2010). Even older evidence can go back many thousands of years in the form of plant pollen, other plant remains, and charcoal deposited in layers of sediment at the bottoms of lakes and bogs (e.g., Weng and Jackson 1999, Anderson et al. 2008a). These sediment records reveal how today's high mountain tree species like spruce and fir were growing at much lower elevations during the colder climate of the last ice age, before moving upslope as the world's climate moved into the current warmer interglacial period about 11,000 years ago (Anderson et al. 2008a,b). Similarly, plant macrofossils preserved in the middens of ancient packrat nests directly show how much, and how fast, the ranges of plant species have expanded and contracted geographically, moving north and south, and locally upslope and downslope, in response to climate variations (Betancourt et al. 1990). These pollen and macrofossil records also show that past vegetation communities often consisted of combinations of plant species unknown today (Betancourt et al. 1990, Weng and Jackson 1999, Anderson et al. 2008a). For example, midden and pollen evidence of ponderosa pine is almost non-existent in the Southwest during the last ice age, but with the early post-glacial warming and the associated development of our summer monsoon climate after about 10,000 years ago this pine expanded across the region to eventually become a dominant forest species (Betancourt et al. 1990, Allen et al. 1998, Weng and Jackson 1999).

During this same time period, the abundance of charcoal deposited in lakes and bogs increased markedly across the region (Anderson et al. 2008a,b, Allen et al. 2008), reflecting increased frequency and extent of fire activity on Southwestern landscapes, which likely also favored the expansion of fire-dependant species, like ponderosa pine (Weng and Jackson 1999). Charcoal records over the past 1,000 years in the West and Southwest generally show the modulating effects of climate on fire activity, with modest increases in charcoal concentrations during the Medieval Warm Period, and also some significant decline during the Little Ice Age. Both charcoal and tree-ring fire scar records from ancient giant sequoia groves in the Sierra Nevada of California (Swetnam

et al. 2009) and from across the West (Marlon et al. 2009 & 2012, Power et al. 2012) show similar patterns. Overall, the world's greatest concentration of tree-ring studies of tens of thousands of precisely dated fire scars from hundreds of forest sites across the Southwest reconstruct high-resolution spatial and temporal patterns of fire extending back about 500 years, showing high levels of frequent and widespread fire activity that were closely tied to climate patterns (Swetnam et al. 1999 & 2011, Falk et al. 2011).

These pre-1900 fire-climate relationships are consistent with those that we see today (Swetnam and Betancourt 1998, Swetnam et al. 1999), with much higher levels of fire activity in warm dry years. For about two-thirds of the fire scars we can even date the season that the fire scar formed, allowing us to demonstrate that most pre-1900 fire spread occurred in the dry spring and early summer period, just as today, before the July onset of summer rains. Tree-ring reconstructions demonstrate that frequent, low-severity surface fires dominated the pre-1900 fire activity in the widespread ponderosa pine and drier mixed-conifer forests that predominate in much of the Southwest (Swetnam et al. 2009). Climate synchronized fire activity across the region, with large portions of most Southwestern mountain ranges burning in some extreme fire years (1748, for example, is the biggest fire year known in the Southwest [Swetnam et al. 1999]).

It is important to note that there is a great diversity of forest and fire patterns across the Southwest. For example, high-severity stand-replacing fires also occurred in the less extensive wetter mixed-conifer and high-elevation spruce-fir forests in the region (e.g., Margolis et al. 2011), although not as much research has been done on such fire regimes in the Southwest. Tree-ring studies also show that major climate relationships with tree establishment, growth, and death have been rather consistent for the past 1,000 and more years. That is to say, forest trees in the Southwest grow better and reproduce in pulses during wetter periods, whereas during periods of extended warm drought trees experience high levels of drought stress and mortality (Swetnam and Betancourt 1998, Allen and Breshears 1998, Swetnam et al. 1999, Brown and Wu 2005, Falk et al. 2011). Finally, the charcoal sediment records show relatively high levels of fire activity in the Southwest for most of the past 9,000 years. Charcoal sediment records for the last century, however, show an anomalous deficit of fire activity across both the Southwest (Anderson et al. 2008a, Allen et al. 2008) and West as a whole (Marlon et al. 2012, Power et al. 2012). Similarly, the abundant tree-ring reconstructions of Southwest fire histories clearly demonstrate that previously frequent and widespread surface fire activity ceased across the region between 1880 and 1900. This reduced fire activity occurred because of man-made rather than climatic reasons.

Land Management Practices

Over approximately the past 150 years regional forest landscapes and fire regimes have responded both to changes in human land use and land management and to patterns of climate variability. The prehistoric pattern of widespread, high-frequency surface fire regimes across the Southwest initially collapsed in the late 1800's, because with the entry of railroads to this region there was a buildup of herds of domestic livestock that interrupted the former continuity of the grassy surface fuels by widespread overgrazing, trampling, and trailing (Swetnam et al. 1999). The suppression of surface fires by overgrazing then morphed into active fire suppression and exclusion efforts by land management agencies in the early 1900's, which has continued with ever-increasing effort and expenditure to the present (Pyne 1982).

With the circa-1900 change in surface fire regimes in many Southwestern forests, the multitude of young trees that established were thinned out by frequent surface fires which had favored relatively open, grassy forest conditions. As a result, woody plant establishment exploded into the

1900s, particularly during several favorable wet climate windows for tree regeneration and growth. Twentieth century fire suppression resulted in a general pattern of forest and woodland expansion into grasslands and meadows, along with increases in the densities of many (although not all) Southwestern forests and woodlands. For example, in some common forest types, like various types of ponderosa pine and dry mixed-conifer forest, tree densities commonly increased ten-fold or more, often from less than 100 trees per acre to over 1,000 trees per acre.

In the absence of frequent surface fires, such increases in forest density also were accompanied by huge increases in surface fuel loads and the widespread development of understory thickets of small, suppressed trees. These “ladder fuels,” as they are known, allow surface fires to easily spread upward into tree canopies. Thus with active fire suppression over the past century the former fire-maintained mosaic of open forests across diverse Southwest landscapes became a uniform blanket of dense forests with fuel structures that could support the initiation and spread of explosive high-severity canopy fires. Generally wet conditions in the Southwest from 1978 through 1995 fostered rapid tree growth and further forest “woodification,” but the wet conditions also helped keep wildfires in check. Thus by the mid-1990s many southwestern forests likely were near their maximum possible densities and levels of biomass accumulation at both landscape and stand scales.

The last 20 years have seen more severe fires and drought-induced tree mortality, with associated bark beetle outbreaks, in Southwestern forests and woodlands, with 18% of Southwestern forests affected by significant tree mortality from combinations of drought stress, bark beetles, and high-severity wildfire between 1984 and 2008 (Fig.4, Williams et al. 2010). (And this does not take into account the record wildfire years in 2011 and 2012.) The scale of these forest disturbances certainly is unprecedented in this region since historic record keeping began around 1900, almost certainly is unprecedented since the megadrought of late 1500’s (Swetnam and Betancourt 1998), and in the case of high severity fire patches in southwestern ponderosa pine forests quite possibly is unprecedented since before modern climate, vegetation, and fire regime patterns established 6,000 years ago. Similar patterns of increasingly extensive high-severity fires and drought-induced tree mortality also have emerged elsewhere across the intermountain West (Westerling et al. 2006, Raffa et al. 2008).

Despite these recent disturbance trends and emerging risks for forests in the Southwest, there are a variety of forest management approaches available to buy time for our forests through increasing their resistance and resilience to growing climate stress to restore and maintain historically sustainable patterns of forest structural conditions, species compositions, landscape-scale patterns of fire hazard, and ecological processes (Sisk et al. 2006, Fulé 2008, Finney et al. 2005 & 2007, Ager et al. 2010, Stephens et al. 2012). For example, by using combinations of mechanical tree harvesting and managed fire treatments to reduce forest stand densities and hazardous fuel loadings, foresters can reduce excessive between-tree competition for water and other resources, thereby concurrently reducing overall forest drought stress and risk of high-severity fires, and at the same time restore historical forest ecological conditions that we know were sustainable for at least many centuries prior to 1900 (Swetnam et al. 1999, Allen et al. 2002, Fulé 2008, Stephens et al. 2012).

In summary, forests as we know them today in the Southwest are at risk from amplified tree mortality and high-severity fire due to increasing drought and heat stress. The recent increases in regional forest drought stress, the greater extent and severity of forest disturbance, and the lack of post-disturbance tree regeneration on some sites all suggest that if modeled climate projections of a warmer and drier Southwest come to pass we can expect to see regional forest ecosystems change

beyond the observed patterns of the last few centuries. Nevertheless, forest management practices can improve forest resistance and resilience to climate stressors and associated disturbances.

Thank you again for the opportunity to testify here today. I would be happy to answer any questions you may have.

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Additional Information

Interactive drought monitoring maps: <http://vegdiri.cr.usgs.gov/>

USGS water information: <http://waterwatch.usgs.gov/>

Figures



