TESTIMONY OF
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SENEATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

HEARING ON
CURRENT AND FUTURE IMPACTS OF CLIMATE CHANGE ON THE INTERMOUNTAIN WEST; FOCUSING ON DROUGHT, WILDFIRE FREQUENCY AND SEVERITY, AND ECOSYSTEMS

August 17, 2012

Introduction: Good morning Chairman Bingaman, Ranking Member Murkowski, and members of the committee. I am honored to speak to you today regarding current and future impacts of climate change on the intermountain west. I am Nate McDowell, staff scientist within the Earth and Environmental Sciences Division at Los Alamos National Laboratory, and director of the Los Alamos National Environmental Research Park. My team has published approximately 20 papers on vegetation mortality in relation to climate change. We are the global leaders in the study of how vegetation dies in relation to drought, both currently and in the future (Figure 1). We also have a strong research focus on how vegetation mortality feeds back to accelerate warming of the earth. Our research is aided by the massive mortality our local forests have experienced in the last decade (Figure 2). Bark beetle-associated mortality during and after drought kills approximately double the amount of forests as fire in the intermountain west (J. Hicke *unpublished results*, Williams et al. *in revision*). With the exception of management implications, I will leave the discussion of drought and fire in this hearing to Dr. Craig Allen and the other invited speakers. The focus of my testimony today will be on the impacts of climate change on vegetation mortality and the associated carbon and climate consequences of vegetation death.

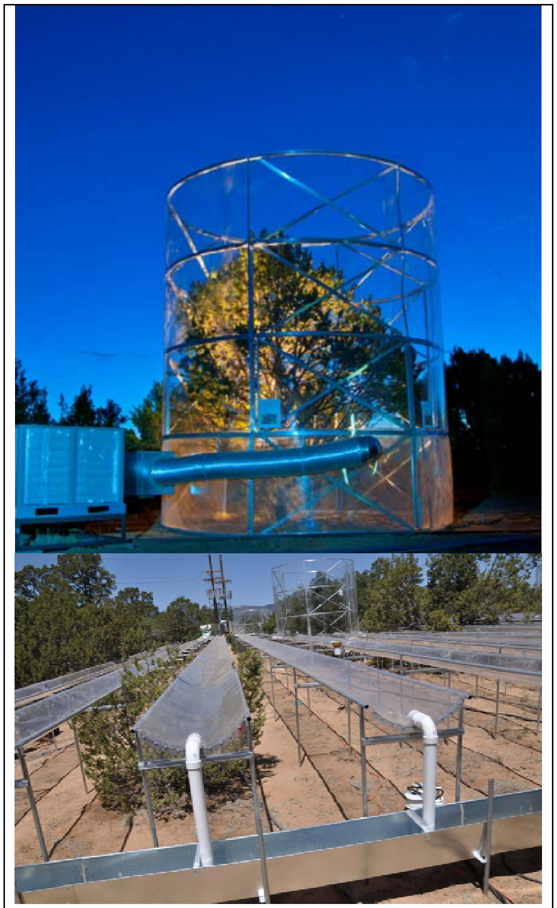


Figure 1. LANL's elevated temperature (top) and drought experiments (bottom) are providing insight into how current and future droughts kill forests (photo's Josh Smith/LANL)

My main message today is that there is strong scientific evidence for 1) rising rates of vegetation mortality during drought at the global scale and

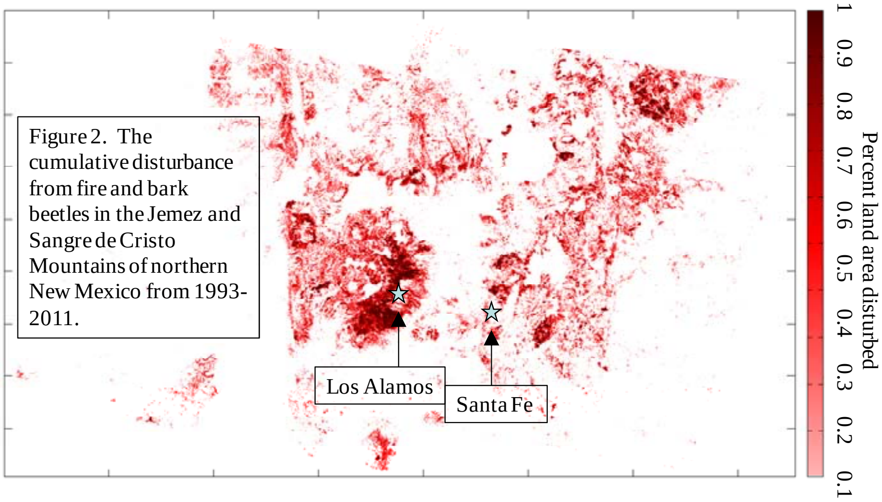


Figure 2. The cumulative disturbance from fire and bark beetles in the Jemez and Sangre de Cristo Mountains of northern New Mexico from 1993-2011.

within the intermountain west, 2) forest mortality will continue to accelerate, despite CO_2 fertilization, and 3) the consequences of forest loss to drought-associated mortality include but are not limited to a strong positive feedback on climate warming due to the transfer of carbon stored in forests to the atmosphere. There are multiple research and mitigation options that should be pursued in the very near future if we are to stem the tide of forest mortality and associated carbon release to the atmosphere.

Vegetation mortality is rising in northern New Mexico, throughout the intermountain west, and globally (Figure 2-3, Raffa et al. 2008, van Mantgem et al. 2009, Allen et al. 2010, Peng et al. 2011, Hicke et al. 2012, Williams et al. *in revision*)**.** The bulk of the evidence suggests this rise is a result of climate warming and in some ecosystems, forest management. It is most strongly correlated with rising air temperature (van Mantgem et al. 2009, Allen et al. 2010, Peng et al. 2011). There is a wide range of evidence to explain why rising temperature has, and will continue, to accelerate mortality of vegetation.

Forest mortality will continue to accelerate. Everyone can understand the general idea that drought kills plants because of a lack of water. The details of the process of drought-induced mortality are relevant to expand upon within this testimony, however, because combining the current climate forecasts with the mechanisms by which climate causes plant stress paints an ominous picture for the future of forests in the intermountain west.

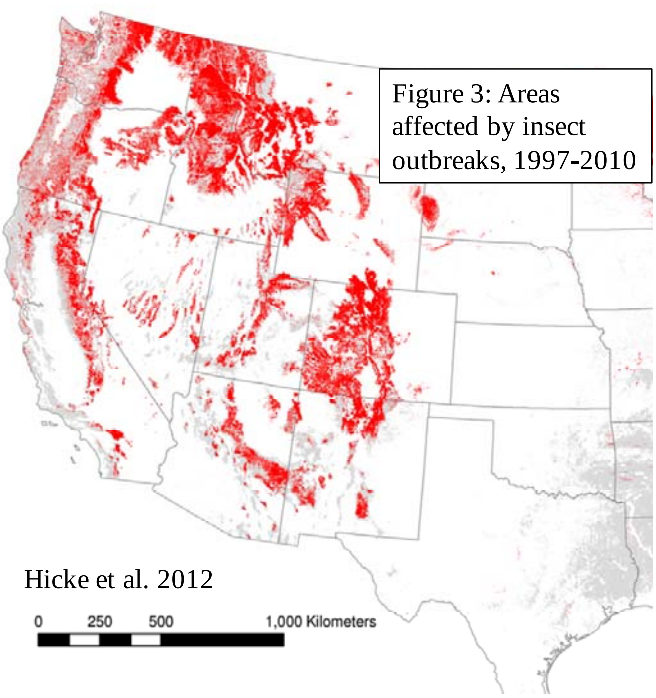


Figure 3: Areas affected by insect outbreaks, 1997-2010

Hicke et al. 2012

Large-scale vegetation mortality events have occurred throughout the history of the earth. These events were typically associated with rapid changes in climate, in particular, rapid increases in temperature or decreases in moisture (McElwain and Punyasena 2007, McDowell et al. 2011). The term “rapid” is important in this context, because the change in climate we are currently experiencing is more rapid than any in the geologic record.

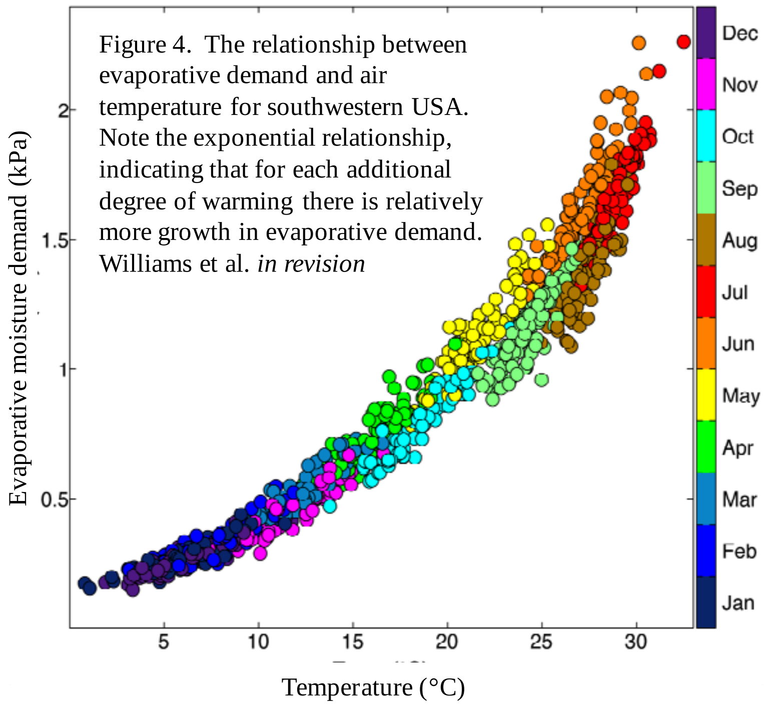


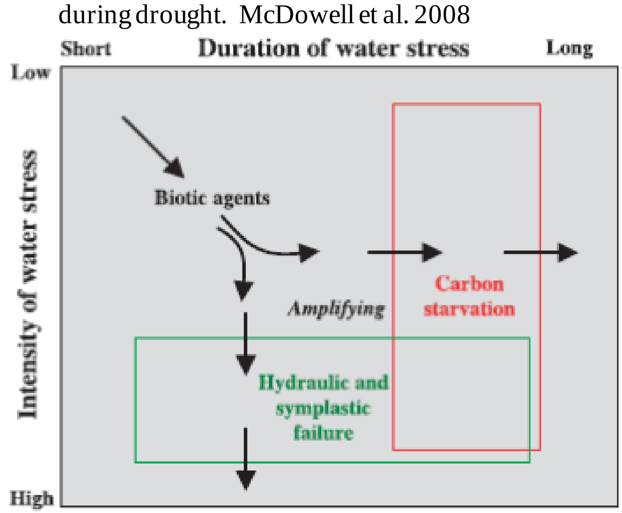
Figure 4. The relationship between evaporative demand and air temperature for southwestern USA. Note the exponential relationship, indicating that for each additional degree of warming there is relatively more growth in evaporative demand. Williams et al. *in revision*

The rise in temperature from 1900 to 2000AD was approximately twice that of any other century going back to 750AD, and the forecasted temperature growth will four- to ten-fold more rapid by 2100 AD (IPCC AR4).

Warmer air holds more moisture, thus increasing temperature raises evaporative demand (Figure 4) and drives greater movement of water from forests to the air; this is called evapotranspiration. Evapotranspiration exacerbates the impact of droughts because for every inch of precipitation, a larger fraction of that water in the soil and plants is extracted by the moisture-hungry air, thus causing current droughts to induce greater stress upon plants than past droughts have caused (McDowell et al. 2008). This has been referred to as climate-change-type drought (Breshears et al. 2005).

The primary determinant of plant survival in the intermountain west is the supply and demand of water because in this region the supply is low relative to the demand. Plants move water to their leaves through a process similar to the movement of water in a straw: tension is placed upon the top of the straw by the dry air, thus pulling the water upwards from the soil and through the plants. Insufficient soil water or a large pull on the top of the straw can cause cavitation, or the formation of air bubbles in the straw. This blocks further water flow and if un-repaired, results in further decreases in water flow, a process we call **hydraulic failure** (Figure 5, McDowell et al. 2008, 2011). Plants avoid this problem through closure of their stomata, or the tiny pores on their leaves that allow release of water and uptake of CO_2 into the leaf (i.e. photosynthesis), and thus they reduce the risk of hydraulic failure. However, stomatal closure means that no photosynthesis occurs. During this period of minimal photosynthesis they must rely on stored carbohydrates, akin to the fat stores of mammals, to stay alive and defend themselves against pathogens such as bark beetles. If drought is prolonged, this can result in **carbon starvation**, or the loss of carbohydrate stores, so that life cannot be maintained and defense against attack

Figure 5. Carbon starvation and hydraulic failure during drought. McDowell et al. 2008



agents, such as beetles, may fail (Figure 5, McDowell et al. 2008, 2011). There is strong evidence that both hydraulic failure and carbon starvation are occurring throughout the intermountain west during the prolonged drought that has extended from 1996 through 2012.

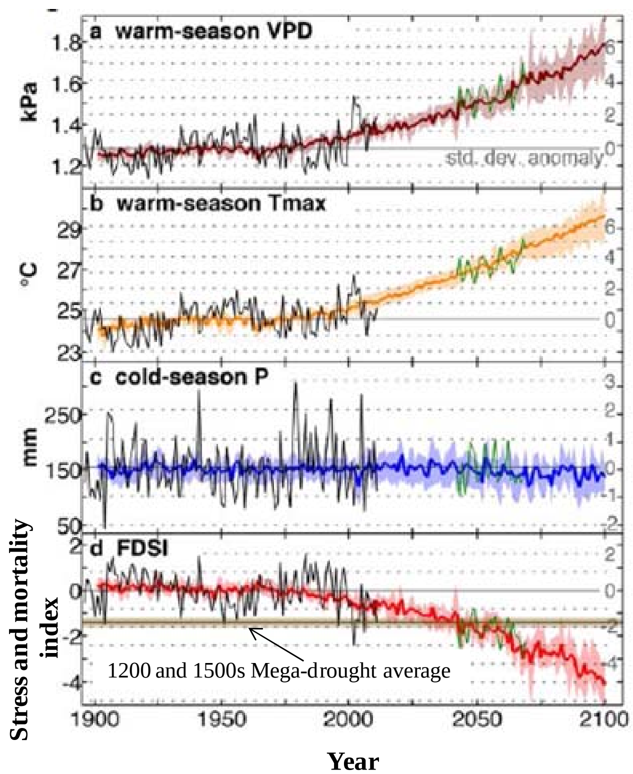


Figure 6. a) evaporative demand, b) maximum temperature, c) precipitation, and d) forest drought severity (an index of mortality) from 1900 to 2100AD. Williams et al. *in revision*

Increasing temperature has three additional impacts on vegetation survival. First, temperature is exponentially related to the loss of carbon through metabolism, so temperature rises can drive elevated loss of the carbohydrate stores needed to support life and fight off biotic agents such as bark beetles (Amthor 1994, Atkin et al. 2007, McDowell 2011). Second, biotic agents such as bark beetles grow faster and achieve more generations per year with rising temperature. Thus attacks on trees by bark beetles increase with rising temperature both due to increasing tree stress and increasing beetle population size (Raffa et al. 2008). The net effect is that rising temperature increases the risk of vegetation mortality. Third, as described by Dr. Craig Allen, rising atmospheric demand due to temperature increase the rate of spread of fire.

Forest mortality will continue to accelerate because evaporative moisture demand by the year 2100 will have increased approximately 34% from the 1950-2000 due to rising temperature (Figure 6a,b, Williams et al. *in revision*, CMIP3). This is extremely likely to force widespread vegetation mortality throughout western USA even if precipitation remains fairly steady (Figure 6c, d, Williams et al. *in revision*) with a simulated carbon loss by 2100 equal to six years of the United States fossil fuel emissions (Figure 7, Jiang et al. *in review*). There is very strong evidence that we are already witnessing the consequences of increased evaporative demand on widespread bark beetle outbreaks and forest fires since the late 1990s (Williams et al. 2010, *in revision*). Future projections suggest that *the average climate* in Southwestern USA will be a stronger drought than any of the last 1000 years, including the mega-droughts of the 1200's and 1500's that caused the mass-migration of ancestral Puebloans and the widespread forest mortality throughout Southwestern USA (Figure 6). Thus, even if precipitation were to remain unchanged, the increasing evaporative demand due to rising temperature will cause the forests to experience future drought conditions that are nearly guaranteed to cause widespread mortality. In other words, increasing forest mortality over the next century is almost certainly going to occur in some regions of the world, including the intermountain west.

Recent forest growth in response to CO_2 fertilization does not provide significant benefit to vegetation survival during severe drought (Franks et al. *in revision*). This is because the elevated CO_2 only benefits plants whose stomata are open to allow photosynthesis to occur; both low precipitation and high evaporative demand force stomatal closure, thus preventing photosynthesis. This has been shown in numerous observations and experiments (reviewed in Franks et al. *in revision*). Therefore, rising CO_2 does not prevent mortality during drought.

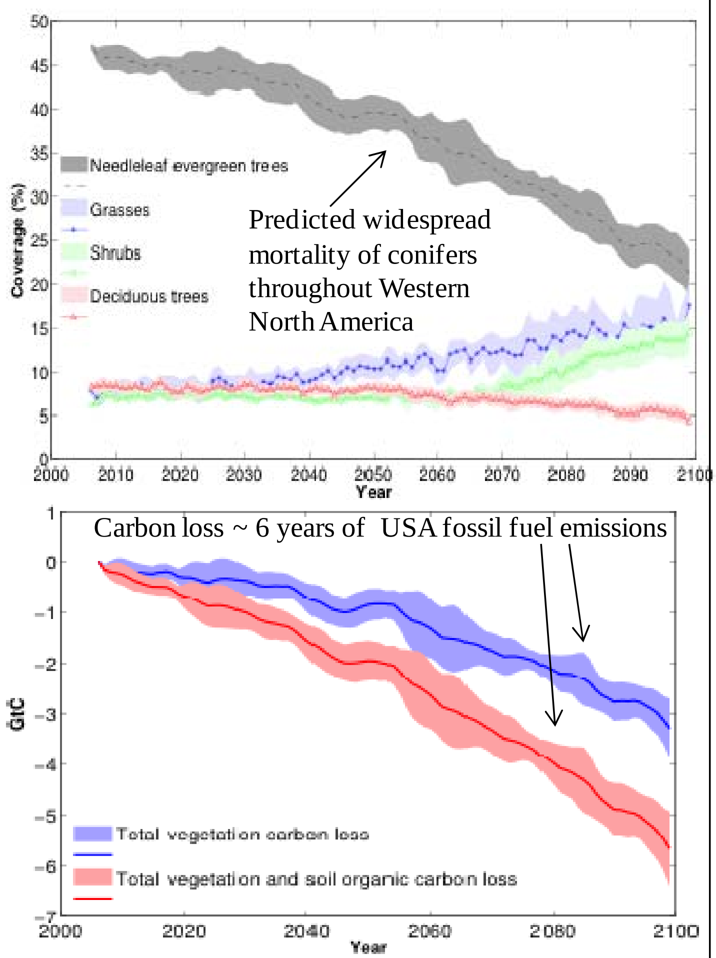


Figure 7. Modeled future vegetation changes and associated carbon loss in Western North America. Jiang et al. *in revision*

Mortality from both fire and bark beetle/drought has numerous consequences on ecosystems including a strong feedback by which forest death leads to accelerated climate warming. Live forests store approximately 33% of anthropogenic CO_2 emissions annually and contain approximately 55% of carbon stored in terrestrial ecosystems (Bonan 2008). The loss of these forests to mortality and replacement vegetation with lower carbon storage such as shrubs (as described in Dr. Allen's testimony) reduces the ecosystems ability to extract CO_2 from the atmosphere, and furthermore, the mortality results in the release of large amounts of CO_2 from the decomposition of dead trees (Harmon et al. 1990, Hicke et al. 2012). For example, British Columbia's carbon loss from drought/insect attack in the early 2000's was equivalent to six years of Canada's transportation sector CO_2 emissions and influenced national carbon policy (Kurz et al. 2008a, b). Similarly, the loss of forests in Western North America due to non-fire mortality alone is projected to equal six years of United States fossil fuel emissions (Figure 7, Jiang et al. *in revision*). In northern New Mexico, the loss of forest carbon in northern New Mexico over the last decade was equivalent to 25% of New Mexico's fossil fuel emissions. Thus, the continued growth of forest mortality from both fire and drought will drive a positive forcing on climate warming. The impacts of mortality on climate warming via CO_2 release are mirrored with similar impacts on hydrology and energy budgets, not to mention aesthetics, timber production, tourism and other ecosystem services provided by forests (Adams et al. 2010).

Many people, scientists included, have assumed that primarily forests in drier systems, such as lower elevations or lower latitudes, are vulnerable to climate-change-type drought. We now know this assumption is incorrect. Recent work in my lab has observed two key results across elevation gradients within New Mexico's Jemez and Sangre de Cristo Mountains *and* up the spine of the Rockies from Mexico to Canada. In both studies, the more arid low elevation or low latitude forests die first, but wetter forests at higher elevations and latitudes followed suit a few years later with mortality of equal spatial magnitude. Perhaps more importantly, these wetter forests store far more carbon than more arid forests, thus the loss of the wetter forests causes a much greater release of CO_2 to the atmosphere (Jiang et al. *in revision*). Thus, no forest appears safe from rising temperature and more intense droughts, and thus we can expect widespread mortality and significant feedbacks to accelerate future climate warming.

Recommendations: drought and insect mortality, along with wildfire induced mortality, have common drivers and common possible solutions. Rising rates of both of these forms of mortality are due in part to the declining moisture content of the forest that results from rising air temperature. The most effective, but most difficult solution is to curb the release of anthropogenic CO_2 to the atmosphere. The exclusion of fire since the arrival of livestock and the Smoky the Bear policy has caused the forests to become far denser than the historical average, allowing far more fuel to build up in the forests and thus promoting more fires and greater competition for scarce water. Sustainable forestry that lowers the fuel load and promotes more old-growth characteristics is the only management option I can see that will mitigate the threat of continued growth of massive wildfires and insect outbreaks. Such thinning should emphasize removal of smaller trees to promote survival of tall trees that are more resistant to fire damage and to reduce competition for water and nutrients.

In addition, I feel valuable **long-term solution** to this rising threat of forest loss due to climate change is education of society. Without knowledge of the current and potential future impacts, the common public can become unaware of the magnitude of what is occurring and will occur in the future. Lastly, we urgently need **more research** to understand why and where some trees die while others do not. This information is essential so that we can inform management and policy options to maximize the likelihood of forest survival, carbon storage, and the other ecosystem services our society values.

In conclusion, there is strong scientific certainty that future droughts will promote the loss of forests in the Western United States. This will occur through both increased severity of drought stress upon forests and subsequent insect and pathogen attack, and through wildfire. Without significant changes in the global energy portfolio and increased investment into sustainable forest management, the loss of forests in the Western US is inevitable.

Thank you for the opportunity to appear before the Committee

Much of our work was made possible by the Laboratory Directed Research and Development Program, which makes it possible for the Laboratories to invest in cutting edge R&D that anticipates emerging national needs. Details of the LDRD program can be found at tri-lab.lanl.gov.

Some relevant websites

McDowell Lab at Los Alamos National Laboratory
http://climateresearch.lanl.gov/

DOE-Office of Science-Climate and Environmental Science Division
http://science.energy.gov/ber/research/cesd/

Community Climate System Model
http://www.ccsm.ucar.edu/

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