BULLETIN

Climate Change and Extreme Weather

PART II: FOREST IMPACTS

JANUARY 29, 2016 / BY JENNIFER HUSHAW

In Part I of this bulletin, we described why and how we expect to see an increase in the *frequency* and *intensity* of some extreme weather and climate events as the planet warms. We examined the observed and projected trends in extreme heat, heavy precipitation, drought, and flooding. These ***extremes are likely to have a more immediate and drastic impact on our forests than long-term change in average conditions*** because they can trigger disturbance events that affect the health and composition of natural communities.

Extremes Shape Plant Communities

Long-term, gradual changes in average conditions are important for driving vegetation change, as we have discussed, but research also suggests that extremes play an equal or greater role in shaping the distribution, survival, productivity, and diversity of plant communities (Reyer et al. 2012). For example, a 2012 study found that growth in European forests for the past 500 years (based on extensive tree-ring data) responded synchronously to extreme climatic events during that period (Babst et al. 2012). This linkage between forest growth and extremes is likely to become even more important going forward, as we experience the increase in extremes discussed in Part I.

On a smaller scale, individual plant processes are also affected differently by extremes than by changing average conditions. For example, an increase in average temperature can affect phenology by lengthening the growing season and causing earlier leaf unfolding, but a change in variability in the form of early and late frosts can increase the risk of (possibly lethal) frost damage. Likewise, plant water relations can be disproportionately affected by extremes—an increase in night-time warming and average temperature can cause a slight increase in stomatal conductance, whereas an extreme event like drought can actually lead to mortality via stomatal closure and carbon starvation or hydraulic failure (Reyer et al. 2012). In this way, extremes are likely to play an outsized role in inducing the vegetation shifts researchers have been predicting.

Impact of Extremes on Forests

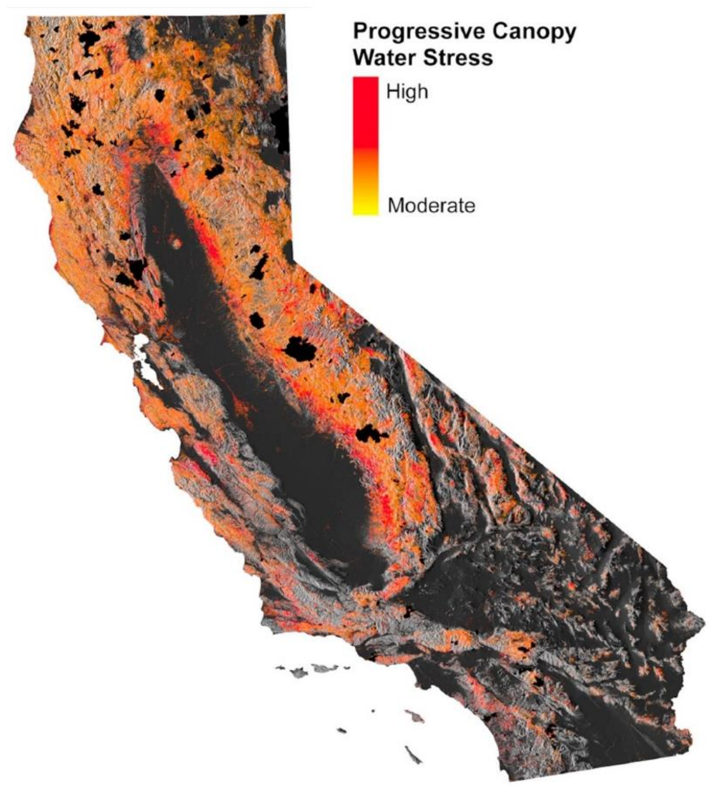
DROUGHT

Of all the climate and weather extremes discussed here, drought receives the overwhelming amount of concern, attention, and research focus. There have been many studies conducted in southern Europe and southwestern United States in particular—both regions where climate models consistently project an increase in the frequency and intensity of future drought. In Europe, for example, researchers have found evidence of a widespread increase in crown defoliation between 1987 and 2007 due to drought, with long-term chronic effects that were most pronounced on drier sites (Carnicer et al. 2011).

U.S. Drought Impacts

In the US, much of the research on drought-related mortality has taken place in the semi-arid forests of the southwest, which provide a useful natural experiment because they are "highly vulnerable to climate-warming-induced drought" (Kolb 2015). These forests have already experienced drought-induced mortality in the form of large-scale die-off of piñyon-juniper woodlands, with an estimated 2.5 million acres affected (Peterman et al. 2013). A number of studies in this region have attempted to identify moisture thresholds (in terms of precipitation-evapotranspiration index, precipitation, vapor pressure deficit, tree-ring-based index of forest drought stress, pre-dawn leaf water potential, and others) that successfully predict tree mortality due to drought (Huang et al. 2015; Clifford et al. 2013; Williams et al. 2012; McDowell et al. 2015). When these thresholds are applied to future climate projections, the results generally point to massive forest mortality later in the century, e.g. McDowell et al. (2015) averaged a number of different modelling approaches and found that 72% of the needleleaf evergreen tree forests in the southwest US will experience mortality by 2050, with nearly 100% forest mortality by 2100.

California has also been in the spotlight for drought impacts in recent years, including a new study that found 10.6 million hectares of forest experienced measurable loss in canopy water content during the recent drought, with 1 million of those hectares experiencing severe water losses of greater than 30% (Asner et al. 2015). The California drought is illustrative of the types of droughts (and related impacts) we are likely to see more of in the future, as recent research has shown that anthropogenic warming contributed to the severity of the current drought and is increasing the probability of these co-occurring warm-dry conditions (Diffenbaugh et al. 2015). The drought impacts in California are also a great example of the worrisome 'layering of stressors' that can occur under these conditions, i.e. drought stresses trees, making them more vulnerable to insect attack, which ultimately increases mortality and the fuel loads to support massive wildfires.



Progressive forest canopy water stress in California for the years 2011–2015 (calculated as the total percentage canopy water content loss for the study period). Black areas indicate fire extents reported by the US Forest Service during this time. Source: Asner et al. 2015, Figure 6

The Real Risk of Climate Change-Type Drought

Despite the obvious risk from hotter drought, there are some natural processes that help stabilize plant populations after these types of disturbance events, such as self-thinning that reduces competition from neighbors, competition release through better adult reproductive performance, or phenotypic variability that helps mitigate mortality. These promote resilience by helping to balance the mortality caused by the event with better survival or increased recruitment (Lloret et al. 2012). These kinds of processes can be harnessed for adaptation purposes or used to help identify forests that are inherently more resilient. Given that not every extreme event leads to a shift in vegetation and these counterbalancing processes are often at work, there is some reason to be optimistic.

However, a recent comprehensive review of the literature suggests that the global outlook is generally negative—Allen et al. (2015) examined all the evidence suggesting that forests are *more* vulnerable to drought, e.g. trees die faster under warmer drought conditions, evolution is too slow relative to projected change, models are over-optimistic because mortality processes are not sufficiently represented, as well as all the evidence that forests are *less* vulnerable, e.g. physiological acclimation and adaptation capacities are large, species diversity and microsite variation can buffer mortality, CO_2 fertilization and water-use efficiency can compensate for drought and heat stress. When all the pertinent issues were examined, they concluded we are most likely *under*estimating global vulnerability to hotter drought. Their conclusion was based, in part, on the fact that a number of drivers that are known with high confidence all point toward greater vulnerability, in particular:

(1) Droughts eventually occur everywhere.
(2) Warming produces hotter droughts.
(3) Atmospheric moisture demand increases nonlinearly with temperature during drought.
(4) Mortality can occur faster in hotter drought, consistent with fundamental physiology.
(5) Shorter droughts occur more frequently than longer droughts and can become lethal under warming, increasing the frequency of lethal drought nonlinearly.
(6) Mortality happens rapidly relative to growth intervals needed for forest recovery.

As we have discussed previously, drought risk actually varies with location, site characteristics, and forest type—see our previous bulletin for more detail on evaluating drought risk.

EXTREME HEAT

In an earlier bulletin, we explored how extreme heat affects plants at the cellular, leaf, and whole plant level, showing that trees have a variety of physiological and morphological responses that help them cope with extreme heat stress. While many species can behave plastically or increase their heat-tolerance by acclimating to warmer temperatures, there are, of course, limits to how adaptable trees can be in the face of these extremes.

Drought-induced forest die-off receives more attention in the scientific literature, but it is recognized that the trend of increasing hot temperature extremes will also pose problems for forests worldwide. As stated by Teskey et al. (2014): “Mortality from drought is far more likely than mortality from heat stress, but the severity of drought stress, and the speed of its onset, is greatly increased under high temperatures.” This is primarily because of the effect of temperature on vapour pressure deficit (VPD)—a key variable in plant water stress. VPD is essentially a combination of temperature and relative humidity that represents the ‘drying power’ of the air (technically, it is the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated, or the vapour pressure in the air compared to the vapour pressure in the leaves). Generally, the higher the VPD the more water plants lose through transpiration. A number of studies have highlighted the critical role of VPD in determining the level of forest drought stress (Breshears et al. 2013; McDowell et al. 2015; Williams et al. 2012) and they suggest that rising VPD is "potentially the largest threat to survival" (McDowell et al. 2015) because climate models consistently predict that VPD and temperature will increase and we have confidence in those projections.

FLOODS/HEAVY PRECIPTIATION

While excess water (due to flooding or water-logged soils) is on the other end of the spectrum from severe drought, it can have similar negative consequences, especially for species that are not well-adapted to those conditions. This includes (paradoxically) decreased water absorption, stomatal closure that reduces CO_2 uptake and growth, and low oxygen conditions in the soil that inhibit root respiration (Reyer et al. 2013). This kind of forest stress is likely to increase in many places during the next century, as we experience large flood events, especially in the Northeast and Midwest regions highlighted in Part I of this bulletin, and more heavy precipitation. Although, in the U.S., the effects are likely to be greatest in those regions with the least flood tolerant species mix.

Note: We recommend referencing Russell et al. 2014 for maps of average flood tolerance and diversity of flood tolerance among tree species in the eastern U.S.

Extremes Can Have Big Implications for the Global Carbon Budget

Most coupled carbon-climate models (e.g. CMIP5 used in the most recent IPCC Assessment Report) show vegetation productivity and carbon sinks increasing in temperate and boreal regions. Although, new research is suggesting that extreme events and associated disturbances can offset or reverse that trend—"even a small shift in the frequency or severity of climate extremes could substantially reduce carbon sinks and may result in sizeable positive feedbacks to climate warming" (Reichstein et al. 2013).

Extremes can increase the risk of accelerated climate change if large-scale changes in terrestrial ecosystems, such as forest die-off or extensive wildfires, create feedbacks with the climate system. For a sense of the scale, view this map from Reichstein et al. 2013, which shows areas where extreme events caused a large decrease in gross primary productivity between 1982 and 2011 (color indicates the cause: water scarcity = blue, extreme high temperatures = red, both = pink, neither = grey, and darker colors indicate greater losses).

Conclusion

Extremes are likely to have an outsized influence on vegetation communities and are likely to be the source of the most immediate climate change impacts in our forests. In particular, the risk of more impactful drought due to the combination of warmer temperatures and reduced precipitation (or changes in seasonality) will make certain regions, such as the southwest U.S., particularly vulnerable to large-scale forest die-off events. In other regions, extreme events may contribute to an increase in forest stress that can reduce productivity or increase vulnerability to other stressors, including insect outbreaks. Critically, the risk of these extreme heat and precipitation events will increase rapidly as average temperatures continue to rise.

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