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More than Drought: Precipitation Variance, Excessive Wetness, Pathogens and the Future of the Western Edge of the Eastern Deciduous Forest

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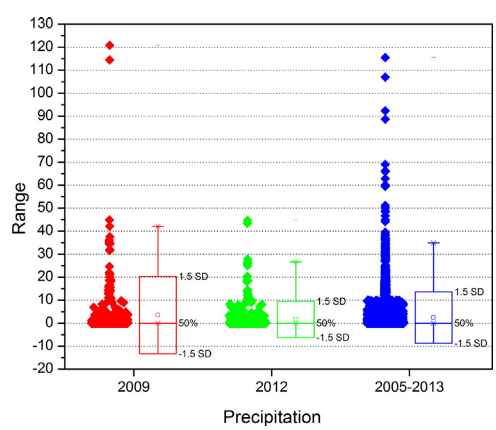
HIGHLIGHTS

- Increasing climate variance requires consideration for ecosystem productivity.
- Extreme wetness may be creating the potential for forest health crises.
- Excessive precipitation may be as detrimental as drought to ecosystem health.
- Evidence suggests that certain regions are susceptible to extreme wetness.
- Research is urgently needed elucidating impacts of drought and wetness.

GRAPHICAL ABSTRACT



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ABSTRACT

For many regions of the Earth, anthropogenic climate change is expected to result in increasingly divergent climate extremes. However, little is known about how increasing climate variance may affect ecosystem productivity. Forest ecosystems may be particularly susceptible to this problem considering the complex organizational structure of specialized species niche adaptations. Forest decline is often attributable to multiple stressors including prolonged heat, wildfire and insect outbreaks. These disturbances, often categorized as megadisturbances, can push temperate forests beyond sustainability thresholds. Absent from much of the contemporary forest health literature, however, is the discussion of excessive precipitation that may affect other disturbances synergistically or that might represent a principal stressor. Here, specific points of evidence are provided including historic climatology, variance predictions from global change modeling, Midwestern paleo climate data, local climate influences on net ecosystem exchange and productivity, and pathogen influences on oak mortality. Data sources reveal potential trends, deserving further investigation, indicating that the western edge of the Eastern Deciduous forest may be impacted by ongoing increased precipitation, precipitation variance and excessive wetness. Data presented, in conjunction with recent regional forest health concerns, suggest that climate variance including drought and excessive wetness should be equally considered for forest ecosystem resilience

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against increasingly dynamic climate. This communication serves as an alert to the need for studies on potential impacts of increasing climate variance and excessive wetness in forest ecosystem health and productivity in the Midwest US and similar forest ecosystems globally.

1. Introduction

Global forest health concerns have attained increased attention recently (e.g. Trumbore et al., 2015). Unlike the single causal relationships that have prevailed as explanations for impacts to forest sustainability and productivity in the past (despite warnings against such approaches) research is increasingly focused on multiple causal factors (i.e. stressors) and integrating forest health with climate change. This cultural shift is not unlike the theory of forest decline that considers predisposing, inciting and contributing factors (Manion, 1981). Recently, however, there is a renewed appreciation and acceptance of the prominent role of climate and that extreme weather events and disease causing agents (e.g. insects, pathogens) synergistically and somewhat unpredictably affect ecosystem function and resilience (McEwan et al., 2011, Millar and Stephenson, 2015, Pautasso et al., 2014).

Despite the recognition that synergistic factors may be creating the potential for forest health crises, many combined effects have been omitted in research and literature. For example, the effects of year-to-year climate variance on forest productivity and dynamics have been greatly overlooked. This is important because climate variance includes drought (i.e. excessive dryness) and excessive wetness. Further, ecosystem responses to climate variables and variability are generally nonlinear and stochastic. While, it is indeed the variability (i.e. drought and wetness) of climate that creates the conditions for biological and ecological complexity (Burkett et al., 2005), the precipitation regime and often overlooked associated plant physiological stressors related to periods of excessive wetness are deserving of equivalent concern as drought in a dynamic and changing anthropogenic climate. It is arguable that increasing variability of climate conditions (both drought and wetness) is among a suite of characteristics requiring a changing perspective in terms of plant and ecosystem productivity, and forest health (Pautasso et al., 2014).

Ensemble global circulation models indicate future changes in precipitation throughout the central US ranging from −2.5% to 19.6%, with a mean increase of 12.4% under the A1B emissions scenario (Girvetz et al., 2009). These changes are supported by studies that show that since the 1950′s larger precipitation events have a higher return interval in the central US (Groisman et al., 2012; Villarini et al., 2013). These observations, coupled with changing temperature regimes are likely to affect the timing of snow melt, evaporative demand, quantity and quality of water, and vegetation productivity. Obviously, considerations of such variance, and particularly excessive wetness in an increasingly wet environment, is of critical importance for forest management. Thus, understanding forest response to increasingly variable climates particularly the precipitation regime and identifying needed research to provide science-based management solutions are essential to manage legacy forests in new climates.

The effects of wetness and climate variance on forests of the western edge of the Eastern Deciduous Forest (EDF) of the United States at long and short time scales are the focus of this short communication. In particular, this urgent problem is exacerbated by recent increased mortality of a dominant forest species, white oak (*Quercus alba*), in the lower Midwest. This rapid mortality has occurred during periods of ample, if not excessive precipitation (NOAA, 2015). The coincidence of tree mortality and excessive soil moisture might suggest a biotic factor that is aggravated by climate effects. On this basis, it is probable that increasingly extreme wet weather systems have contributed to the development of biotic agents, including pathogens and fungal-like oomycetes (water molds) such as *Phytophtora* and *Pythium* that often flourish with combined and prolonged soil and plant moisture (Sturrock et al., 2011). These organisms have been shown to develop in forest soils and cause root death and eventually tree death ultimately affecting plant species distribution and diversity (Augspurger and Wilkinson, 2007, Reinhart et al., 2005). In the following sections, specific points of supporting evidence are provided including climate data, geographic climatology, variance predictions from global change modeling, Midwestern paleo climate data, local climate influences on net ecosystem exchange and productivity, and pathogen influences on oak mortality and decline. Evidence indicates that the western edge of the Eastern Deciduous Forest (EDF) has the potential for increased year to year variance in climate, particularly excessive wetness, perhaps to the detriment of regional forest ecosystem productivity.

2. A changing climate and precipitation variance

There is currently a great deal of uncertainty in predictions of climate change impacts, and in particular precipitation regimes, and how ongoing human activities may continue to affect spatio-temporal precipitation variability. In general projections of global circulation models, under various emissions scenarios, indicate that a continuing warming atmosphere will result in more intense and also less frequent precipitation characterized by greater risk of droughts and floods (Trenberth et al., 2014; Meehl and Tebaldi, 2004; Cook et al., 2015). In fact, recent and sudden (i.e. in the past 50 years or less) shifts in the precipitation regime may already be dramatically altering terrestrial vegetation communities that adapted to a more stable climate that exhibited less climate variance over the last millennia. These recent and dramatic shifts in drought and excessive wetness (the overabundance of precipitation) are likely to alter the dynamics of the terrestrial ecosystems and carbon and water cycles (Knapp et al., 2008).

Climatological variance is a key characteristic of the definition of a 'continental climate'. In mid-continental North America (location of the western edge of the EDF) the climate has varied over the Holocene from Humid Continental, to Humid Sub-tropical continental, to Dry Steppe depending on climate era (Delcourt and Delcourt, 1987). Recent model predictions place the western edge of the EDF in the center of a region of potential increased precipitation and temperature variance (Cook et al., 2015), thereby pointing to the importance of future investigations of forest productivity and excessive wetness in that region.

Precipitation data from St. Louis, Missouri (1873 to 2014) encompasses much of the period of accelerated global change (NOAA, 2015, Mann et al., 1999). Annual precipitation data were analyzed with the a priori hypothesis that short periods of temporal variance in climate would promote stress and possible mortality of forest tree species. For ease of interpretation and graphical representation, a moving seven year standard deviation was used to quantify climate variance. Although somewhat arbitrary, the seven year period is arguably long enough for a climate variance estimate, and short enough to induce rapid biological consequences. A significant ($r = 0.42$, $p < 0.05$) correlation between time (i.e. the years of 1873 to 2013) and precipitation variance (a positive trend) indicates that climate variance exists and may therefore be a novel parameter to consider to quantify the influence of climate on forests on the western edge of the EDF (Fig. 1). Of additional interest, recent periods from 1981 to 2011 exceeded the 95% prediction interval for the seven year variance indicating acceleration of change in recent decades. This finding is strengthened by an examination of drought and extreme wet years and forest productivity in the geographically associated Western edge of the EDF.