Environmental Research Letters

PERSPECTIVE

A new drought tipping point for conifer mortality

Thomas E Kolb

School of Forestry Northern Arizona University Flagstaff, AZ 86001, USA

E-mail: tom.kolb@nau.edu

Keywords: drought, tree mortality, climate change

OPEN ACCESS

RECEIVED
3 February 2015

REVISED
25 February 2015

ACCEPTED FOR PUBLICATION
26 February 2015

PUBLISHED
18 March 2015

Abstract

(Huang *et al* 2015 *Environ. Res. Lett.* **10** 024011) present a method for predicting mortality of ponderosa pine (*Pinus ponderosa*) and pinyon pine (*Pinus edulis*) in the Southwestern US during severe drought based on the relationship between the standardized precipitation–evapotranspiration index (SPEI) and annual tree ring growth. Ring growth was zero when SPEI for September to July was −1.64. The threshold SPEI of −1.64 was successful in distinguishing areas with high tree mortality during recent severe drought from areas with low mortality, and is proposed to be a tipping point of drought severity leading to tree mortality. Below, I discuss this work in more detail.

Predicting future changes of forest vegetation in response to warming over the next century is important for understanding future ecosystem and economic services and for planning approaches to mitigate negative impacts of climate change. A first step in such prediction is identifying meteorological drivers of tree mortality in current forests. Semi-arid forests of the Southwestern US are a model system for research about tree mortality because they are highly vulnerable to climate-warming-induced drought. Unusually high amounts of tree mortality have already occurred in these forests during recent droughts (van Mantgem *et al* 2009, Allen *et al* 2010). In the Southwestern US, the extreme drought of 2002 is an example of the warm 'global climate-change drought' that is expected to increase in frequency in the next century in many global forests (Breshears *et al* 2005). Consequently, many investigations of approaches for predicting drought-induced tree mortality focus on forests of the Southwestern US (McDowell *et al* 2013, Williams *et al* 2013). Huang *et al* advance these investigations by developing a new approach to predicting tree mortality during drought.

The central premise of Huang *et al*'s approach is that tree death is likely when drought is so severe that no annual radial growth occurs. It is well known in dendrochronology that water availability is a strong control on annual ring width of trees in semi-arid forests (Fritts 1976). Trees experiencing extreme drought stress often do not form rings near the base of the bole where rings are typically sampled ('missing rings'). Ring width is the end product of numerous physiological processes which are sensitive to drought, and is an index of tree carbon balance because carbon allocation to radial growth is a lower priority within the tree than allocation to other carbon sinks, such as growth of leaves and fine roots, stem elongation, and tissue respiration (Waring 1987). Conifer trees with frequent narrow or missing rings typically have lower quantitative resin defenses against bark beetles (McDowell *et al* 2007, Kane and Kolb 2010), which are strong agents of tree mortality during severe drought. Trees that eventually die during drought typically have more frequent narrow or missing rings before their death than trees of the same species that survive drought (Kane and Kolb 2014, Macalady and Bugmann 2014). Thus, quantification of drought characteristics associated with zero radial growth of trees has potential for predicting tree death.

Huang *et al* take advantage of the large amount of tree-ring data available from the International Tree-Ring Data Bank for two dominant tree species of the Southwestern US, ponderosa pine and pinyon pine, and data for the standardized precipitation–evapotranspiration index (SPEI), which is precipitation minus potential evapotranspiration (Vicente-Serrano *et al* 2010). They show that average annual radial growth of ponderosa and pinyon pines is zero when SPEI is −1.64 between the previous September and July of the subject year. They hypothesize that this threshold value of −1.64 for SPEI describes the tipping point of meteorological drought that leads to tree mortality. They test this hypothesis by using the SPEI threshold to predict locations of high mortality of ponderosa and pinyon pines in the Southwestern US during the 2002 global-climate-change drought. Locations of tree death during 2002 were based on satellite-measured light spectral data (normalized difference vegetation index), a well-established approach for detecting large amounts of tree mortality over landscapes. Locations of tree mortality predicted with the SPEI threshold were generally consistent with locations shown by the satellite-measured light spectral data. This result indicates potential for using the SPEI tipping point approach to predict future drought-induced tree mortality in the Southwestern US and other regions. The approach's simplicity is a strength, as calculation of the SPEI tipping point requires only tree-ring chronology and meteorological data for a region.

The approach developed by Huang *et al* is a step forward in predicting tree mortality during drought, yet the approach has potential limitations that should be addressed in future investigations. First, the value of SPEI for a specific location can be uncertain because of limited availability of climatic data, and because values of SPEI in semi-arid regions often vary over different approaches for calculating potential evapotranspiration (Begueria *et al* 2014). Second, regionally gridded SPEI does not account for dissimilarities in tree response to water stress caused by local variations in soil properties (Looney *et al* 2012, Peterman *et al* 2012), rooting depth, access to ground water, and microclimate. Third, the approach does not fully encompass all drought-related causes of tree mortality. For example, intense forest fires kill many trees during drought when dry fuels, high winds, and ignition coincide. Tree death during wildfire is determined by numerous factors beyond annual radial growth, such as fuel loads, fire intensity, bark thickness, and tree size (McHugh and Kolb 2003). Fourth, tree mortality processes and the importance of low radial growth as an early warning signal of drought-induced mortality can be species specific in forest types that include multiple tree species (Kane and Kolb 2014, Camarero *et al* 2015). Because no single prediction model of the process of tree mortality during drought is perfect, efforts at predicting future tree mortality should continue to move towards multi-model simulations (McDowell *et al* 2013), following the lead of climate modelers who composite results from many models (IPCC 2013). The tipping point approach described by Huang *et al* has much potential to contribute to these efforts.

References

Allen C D *et al* 2010 A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests *Forest Ecol. Manage.* **259** 660–84

Begueria S, Vicente-Serrano S M, Reig F and Latorre B 2014 Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring *Int. J. Climatol.* **34** 3001–23

Breshears D D *et al* 2005 Regional vegetation die-off in response to global-change type drought *Proc. Natl Acad. Sci. USA* **102** 15144–8

Camarero J *et al* 2015 To die or not to die: early warnings of tree dieback in response to a severe drought *J. Ecol.* **103** 44–57

Fritts H C 1976 *Tree rings and climate* (London: Academic)

Huang K *et al* 2015 Tipping point of a conifer forest ecosystem under severe drought *Environ. Res. Lett.* **10** 024011

IPCC 2013 *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ed T F Stocker *et al* (Cambridge: Cambridge University Press)

Kane J M and Kolb T E 2010 Importance of resin ducts in reducing ponderosa pine mortality following bark beetle attack *Oecologia* **164** 601–9

Kane J M and Kolb T E 2014 Short- and long-term growth characteristics associated with tree mortality in Southwestern mixed-conifer forests *Can. J. Forest Res.* **44** 1227–35

Looney C E *et al* 2012 Pinyon pine (*Pinus edulis*) mortality and response to water addition across a three million year substrate age gradient in Northern Arizona *USA Plant Soil* **357** 89–102

Macalady A and Bugmann H 2014 Growth-mortality relationships in pinon pine (*Pinus edulis*) during severe droughts of the past century: shifting processes in space and time *PLoS One* **9** e92770

Van Mantgem P J *et al* 2009 Widespread increase of tree mortality rates in the Western United States *Science* **323** 521–4

McDowell N G *et al* 2013 Evaluating theories of drought-induced vegetation mortality using a multimodel-experiment framework *New Phytol.* **200** 304–21

McDowell N G, Adams H D, Bailey J D and Kolb T E 2007 The role of stand density on growth efficiency, leaf area index and resin flow in Southwestern ponderosa pine forests *Can. J. Forest Res.* **37** 343–55

McHugh C W and Kolb T E 2003 Ponderosa pine mortality following fire in Northern Arizona *Int. J. Wildland Fire* **12** 7–22

Peterman W, Waring R H, Seager T and Pollock W L 2012 Soil properties affect pinyon pine—juniper response to drought *Ecohydrology* **6** 455–63

Vicente-Serrano S M, Begueria S and Lopez-Moreno J I 2010 A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index *J. Clim.* **23** 1696–718

Waring R H 1987 Characteristics of trees predisposed to die *Bioscience* **37** 569–74

Williams A P *et al* 2013 Temperature as a potent driver of regional forest drought stress and tree mortality *Nat. Clim. Change* **3** 292–7