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CORRESPONDENCE

Unsupported inferences of high-severity fire in historical dry forests of the western United States: response to Williams and Baker

ABSTRACT

Reconstructions of dry western US forests in the late 19th century in Arizona, Colorado and Oregon based on General Land Office records were used by Williams & Baker (2012; *Global Ecology and Biogeography*, **21**, 1042–1052; hereafter W&B) to infer past fire regimes with substantial moderate and high-severity burning. The authors concluded that present-day large, high-severity fires are not distinguishable from historical patterns. We present evidence of important errors in their study. First, the use of tree size distributions to reconstruct past fire severity and extent is not supported by empirical age–size relationships nor by studies that directly quantified disturbance history in these forests. Second, the fire severity classification of W&B is qualitatively different from most modern classification schemes, and is based on different types of data, leading to an inappropriate comparison. Third, we note that while W&B asserted ‘surprising’ heterogeneity in their reconstructions of stand density and species composition, their data are not substantially different from many previous studies which reached very different conclusions about subsequent forest and fire behaviour changes. Contrary to the conclusions of W&B, the preponderance of scientific evidence indicates that conservation of dry forest ecosystems in the western United States and their ecological, social and economic value is not consistent with a present-day disturbance regime of large, high-severity fires, especially under changing climate.

Keywords

Fire regime, fire severity, General Land Office survey, historical range of variability, ponderosa pine, wildfire.

INTRODUCTION

A recent study in *Global Ecology and Biogeography* (Williams & Baker, 2012, hereafter W&B) applied historical data from General Land Office (GLO) surveys *c.* 1880 to reconstruct historical dry forests on four large landscapes in Arizona, Colorado and Oregon (USA). W&B described forest composition as characterized by ‘abundant ponderosa pine (*Pinus ponderosa* C. Lawson), with lesser amounts of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), juniper (*Juniperus* L.), western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*Pinus contorta* Douglas ex Louden)’. W&B infer that the presence of a certain proportion of trees below a site-specific diameter threshold is evidence of ‘higher’-severity fire, a term they use to indicate a combination of ‘mixed- plus high-severity fire’. They then compare the proportion of plots with evidence of ‘higher’-severity fire to the distribution of fire severities estimated from satellite imagery of recent large wildfires in the western United States, concluding that modern fires are within the historical range of variability (HRV) of fire severity. They also found it ‘surprising’ that dry forests ‘commonly thought to have been open and park-like’ were heterogeneous and relatively dense. W&B conclude that current management practices of thinning small trees and ‘other fuel modifications’ such as low-severity prescribed burning, will move forests outside the HRV rather than restore them.

We appreciate the contribution in W&B of data sets from GLO data (Williams & Baker, 2011). While all historical ecological techniques have strengths and limitations, new data can enrich ecological insights. However, W&B contains substantial errors of method and interpretation. First, the use of tree size distributions to reconstruct past fire severity and extent is not supported by age–size relationship data nor by studies that quantified disturbance history in these forests. Second, the fire severity classification of W&B is qualitatively different from the accepted modern classification, and is based on different types of data. Thus, it is inappropriate to compare these categories in support of the argument that modern fires are unchanged in severity from historical burning. Third, we note that reconstructions of late 19th-century forest structure (stand density, species composition) by W&B are not substantially different from many previous studies, which reached very different conclusions about subsequent forest and fire behaviour changes. The objectives of this response are to identify unsupported scientific inferences in W&B, and to demonstrate how using these erroneous conclusions as a basis for forest management would be inappropriate and potentially damaging to native ecosystems.

INFERENCES ABOUT FIRE SEVERITY

W&B make a major leap from reconstructions of forest structure to infer details of the historical fire regime. W&B assert (p. 1044) that ‘. . . forest-structure parameters (e.g. tree sizes) can be used to reconstruct the severity of disturbances that likely led to the forest structure. . . . Structural reconstruction requires an assumption that tree size is generally related to tree age, and size-class structure and disturbance severity are linked’. However, determining the strength of an age–size relationship in a tree species would require site-specific empirical data (Bowman *et al.*, 2013), and complex natural regeneration dynamics confound simplified interpretations of past regeneration events.

The assumption that tree diameter distributions can be used to reliably reconstruct past fire regimes at patch to landscape scales

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in relatively dry conifer forests is not supported by the scientific literature on these forests and fire regimes. Tree size and age are poorly correlated in ponderosa pine (e.g. Ehle & Baker, 2003), with variability from site to site and among age classes even at the same site, requiring site-specific empirical data from cored trees to develop a relationship (Youngblood *et al.*, 2004). Age and size are even less correlated in more shade-tolerant taxa such as Douglas-fir (*Pseudotsuga menziesii*) and true fir species (e.g. Veblen, 1986; Swetnam & Brown, 2010). Hence, the fundamental inference on which their fire regime interpretations must stand – namely that tree size is a proxy for tree age, which they use to infer fire frequency – is based on an unreliable assumption that tree diameters and ages can be equated.

W&B correctly noted in their section titled ‘Limitations of structural-based reconstructions’ that other confounding factors, such as delayed regeneration or non-fire disturbances, would affect the inferences about past fire severity made from tree size data. However, they concluded that factors other than severe fire did not provide a ‘satisfactory explanation’ so they proceeded to analyse their data as if small tree size = young tree age = evidence of severe fire. In the following text, we present evidence that the confounding factors are in fact important limitations. Post-wildfire tree regeneration is often inconsistent and delayed in dry western forests, unlike many mesic, higher-elevation forests where post-fire establishment of tree cohorts is rapid, consistent and extensive [e.g. quaking aspen (*Populus tremuloides*) or lodgepole pine; Romme *et al.* 2005; Margolis *et al.* 2007, 2011]. Studies of modern (post-1900) wildfires in ponderosa pine-dominant or dry mixed conifer forests have shown highly variable post-fire responses, ranging from no tree regeneration (up to 60 or more years after fire), establishment of shrub-dominated vegetation with minimal tree regeneration or, in a few cases, regeneration of dense patches of pines (Nagel & Taylor, 2005; Savage & Mast, 2005; Goforth & Minnich, 2008; Haire & McGarigal, 2010; Roccaforte *et al.*, 2010).

Regeneration cohorts often appear in the absence of fire disturbance, contradicting W&B’s assumption that all stands with small-diameter trees represent cohort regeneration events following lethal fire. Even if tree sizes were reliably well-correlated with age, this assumption ignores biotic and abiotic disturbances that could have been the cause of synchronized recruitment, such as bark beetles, wind or climatic synchronization of episodic mortality or establishment events (e.g. Brown, 2006; Brown *et al.*, 2008a). Stand-scale studies in Colorado (e.g. Brown & Wu, 2005) and at the regional scale of the whole southwest United States (Swetnam & Brown, 2010) have shown that pulsed ponderosa pine regeneration was associated with past periods of relatively wet climate. The broadest cause of synchronous regeneration in the west has been exclusion of the historic fire regime (Skinner *et al.*, 2006). W&B fail to acknowledge or examine these alternative mechanisms of demographic variation, or the climatic drivers of tree cohort regeneration in dry forest landscapes (Swetnam & Betancourt, 1998).

W&B also fail to acknowledge the lack of contemporary evidence for large, patch-size crown fires in low- and mid-elevation dry forest landscapes, such as primary observation or photographic documentation in the 19th and early 20th centuries. The lack of direct documentary evidence of extensive crown fire in ponderosa pine forests in particular has been noted and reported repeatedly by ecologists and land-use historians for nearly 90 years (e.g. Leopold, 1924; Cooper, 1960). In this error by omission, W&B fail to address a key inconsistency in their fire severity interpretations. If high-severity crown fires in the past burned at frequencies and extents that are indistinguishable from recent fires [e.g. Biscuit Fire (Oregon 2002) 202,000 ha; Hayman Fire (Colorado 2002), 55,900 ha; Las Conchas Fire (New Mexico 2011), 63,000 ha; Rodeo-Chediski Fire (Arizona 2002), 189,000 ha; Wallow Fire (Arizona 2011), 218,000 ha] with total or near-total tree mortality patches of thousands of hectares, why are there no reports of such extensive events from the 18th and 19th centuries at the time of the *c.* 1880 GLO surveys? Early forest inventories carefully noted occurrence of both high- and low-severity fire, as in the Lang & Stewart (1910) survey of the Kaibab Plateau (northern Arizona) in ponderosa pine and lower-elevation mixed conifer forest: ‘. . . evidence indicates light ground fires over practically the whole forest . . .’, whereas high-elevation spruce–fir and aspen forests had ‘vast denuded areas, charred stubs and fallen trunks . . . The old fires extended over large areas at higher altitudes, amounting to several square miles’. In reference to dry mixed conifer forests in California, Sudworth (1900) commented, ‘most likely [the older fires] were similar to those common in the region today. The fires of the present time are peculiarly of a surface nature, and with rare exception there is no reason to believe that any other type of fire has occurred here’. At a mesic mixed conifer site in Colorado with ponderosa pine, aspen, spruce and Douglas-fir, Jack (1900) reported ‘burning here was very complete over many thousands of acres, where barely a conifer has yet started to reforest the ground’. Such reports are lacking in ponderosa pine and dry mixed conifer forests. If W&B’s conclusions that large, severe crown fires were a common occurrence in all dry western forests are correct, then why is there no corroborating evidence in the scientific literature or other reports of the time?

COMPARISON OF HISTORICAL AND CURRENT FIRE SEVERITY

Comparing their reconstructions of fire severity from the GLO data to percentages of area burned at different severities in modern western fires, W&B conclude that the modern occurrence of large, severe wildfires is ‘not unprecedented, and has not increased, relative to the historical record’. This conclusion is not supported by the evidence provided. First, the reconstruction of fire severity from the GLO forest structure and composition data is not reliable or convincing, for the multiple reasons described in the preceding section. Second, even if the data were reliable and the past fires were detected and reconstructed accurately, there are fundamental differences between indices of fire severity used by W&B compared with the techniques of modern fire severity mapping to which they compare their results.

Although fire severity is the central concept of W&B, the term is not defined until the Discussion, where they state that a high-severity fire is one in which ‘70% or more of the trees or basal area are killed or removed,’ which W&B modified for their calculations to be 70% of tree density. Basal area and tree density are not equivalent measures. For example, killing large numbers of small-diameter trees will have a minimal effect on basal area or canopy cover if enough large trees survive.

Much of W&B’s analysis rests on the lumping of moderate (which they refer to as ‘mixed’) and high-severity fire into their ‘higher severity’ category. By arbitrarily combining moderate and high-severity fire areas, W&B bias their results toward interpretations of higher fire severity. Reconstructed percentages from GLO data of low-, mixed- and high-severity fire are presented in W&B’s Table 2. Because a ‘high-severity’ fire as defined by W&B kills at least 70% of trees, the ‘severe’ fires in their Table 2 may have left up to 30% of all trees intact at every section corner and quarter corner; their 'mixed' category would have left even more. Red and orange polygons mapped in Fig. 3 of W&B, supposedly the result of 'higher' severity fires in the 100–140 years prior to the GLO survey (the time depth of fire detectability varied according to their assumptions), could represent places where 30% or more of pre-fire overstorey trees survived. Modern fire severity reported by W&B in their Table 2, obtained from the Monitoring Trends in Burn Severity (MTBS) project (mtbs.gov), was calculated in an entirely different manner from historical reconstruction. The MTBS follows a standard definition of fire severity from the National Wildfire Coordinating Group: the 'degree to which a site has been altered or disrupted by fire, loosely, a product of fire intensity and residence time' (Eidenshink *et al.*, 2007). The purpose of such a broad definition, rather than one calculated from tree mortality, is that it is more useful for representing effects on multiple vegetation types and resources at risk from fire, such as soil, hydrology, wildlife habitat and plants. Quantitatively, fire severity is calculated by categorizing the continuous distribution of differenced normalized burn ratios calculated from spectral reflectance captured in repeated satellite images (Key, 2006; Miller & Thode, 2007). In practice, the process is influenced by site characteristics, seasonality, focus of the analysis (e.g. post-fire response often prioritizes the hazard of soil erosion, not tree mortality *per se*) and field calibration data such as composite burn index (CBI) plots. Numerous caveats about comparability of MTBS map products are given at mtbs.gov, and current research is focused on developing relativized map products more suitable for direct comparison (Miller *et al.*, 2009). Thus, the 'high-severity' reconstruction of W&B, based on an inference from forest structure and composition, is not comparable in any meaningful sense to the quantitative, reflectance-based severity categories created in the MTBS models.

W&B also fail to address differences in the spatial scale and pattern of historic fires compared with recent large fires. Despite W&B's assertions to the contrary, we are unaware of any fire ecologists who claim that dry western forests were uniform in composition, structure or fire regime. For example, in the southwest, historical patches of high-severity fire in ponderosa pine have been documented at scales of 1–100 ha (Swetnam *et al.*, 2011) and in South Dakota at scales of < 5% of the landscape (Brown *et al.*, 2008b). But the spatial pattern of burning in modern wildfires is orders of magnitude higher, with large (10^3–10^4 ha) *contiguous* fire-killed patches. The spatial scale of high-severity patches is an ecologically important property that influences post-fire erosion, soil loss and recovery of the plant community (Haire & McGarigal, 2010). Finally, W&B make a basic typological error by conflating their metrics of typical fire *regime* severity with modern reflectance-based measures of the outcomes of *individual* fires. These are not subtle differences of interpretation, but errors with significant ecological and social consequences.

COMPARISONS WITH OTHER STUDIES

W&B grouped relatively xeric ponderosa pine and pine–oak forests with relatively mesic mixed conifer forests, then expressed surprise at finding denser structure than 'open, park-like forests'. If the GLO data demonstrated higher heterogeneity and density than earlier work, the finding would be novel and supportive of their arguments for a substantial historical role for high-severity fire. However, their Table S1, which is used for comparison with the GLO reconstruction, includes structural data only from selected pine–oak and pine sites, averaging < 100 trees ha^{-1}. W&B cite, but do not critically assess, the results of a large number of existing studies, including some that encompassed extensive spatial scales (e.g. Brown *et al.*, 1999; Fulé *et al.*, 2003; Roccaforte *et al.*, 2010; see Stoddard, 2011, for a comparison of all studies over an entire region), in asserting that their study is uniquely suited to cover large landscapes and that their results show unprecedented heterogeneity in terms of 'high' forest density. W&B state that there is '. . . substantial spatial heterogeneity in historical dry-forest landscapes that were commonly thought to have been rather uniform'. In fact, previously published reconstructed and historical data from mixed conifer forests include higher densities than the studies in their Table S1. For example, dendrochronological reconstructions of South Dakota ponderosa pine landscapes averaged > 127 trees ha^{-1} in 1900 (Brown & Cook, 2006), and reconstructed mixed conifer forests at Grand Canyon National Park (Arizona) averaged > 200 trees ha^{-1} in *c.* 1880 (Fulé *et al.*, 2003).

Current tree densities are much higher than reconstructed densities in these relatively dry forest types, refuting the claim by W&B that modern forests are not outside their HRV. For example, W&B report average densities from the GLO data of < 145 trees ha^{-1} at the two Arizona study sites. Current ponderosa pine density for Arizona averages 300 trees ha^{-1}, double the GLO reconstruction value (O'Brien, 2002). Many ponderosa pine landscapes in the west support stand densities of many hundreds to thousands of trees per hectare (Cooper, 1960; Youngblood *et al.*, 2004; Ritchie *et al.*, 2007). Although the present paper is not focused on the accuracy of W&B's forest reconstructions, it is worth noting that recently published empirical data from Oregon showed that the GLO-based estimates of historical forest density were 2.5 times higher than historical plot measurements on the former Klamath Indian Reservation (Hagmann *et al.*, 2013).

WHY IS THIS IMPORTANT?

W&B (2011, 2012) provide a large-scale and potentially valuable data set of forest composition and diameter distribution reconstructions for the late 19th century. We do not take issue with the reconstruction of forest composition and structure from GLO data (but see Hagmann *et al.*, 2013), and note that W&B's findings are in fact similar to those reported previously. However, W&B make a huge leap, unsupported by modern observation and understanding of post-fire responses of dry forest ecosystems, to infer past fire occurrence and severity from structural data. In so doing, they omit key observations by early surveyors regarding fire in these landscapes, and decades of subsequent scientific findings drawing on multiple lines of evidence on forest dynamics, fire history and silviculture that are not consistent with their interpretations. Their methods are consistently biased toward interpretations of higher fire severity, culminating in the unsupported conclusion that large modern fire events in ponderosa pine and dry mixed-conifer forests are essentially unchanged from the HRV of fire regimes.

In rejecting the unsupported inferences of W&B, we are not making an assertion that past fire regimes in dry western forests were uniformly of low severity. Evidence of past high-severity fire during the Holocene exists in some drier, low- to mid-elevation forest systems (Frechette *et al.*, 2003; Pierce & Meyer, 2008; Jenkins *et al.*, 2011), as well as within the tree-ring record (Brown *et al.*, 1999; Iniguez *et al.*, 2009). Patch size distributions of past high-severity events are largely unknown, however, for virtually all forest types that do not regenerate consistently as even-aged cohorts within large fire-generated openings (i.e. patches *c.* 250 ha). As with any fire regime, historical fires in relatively dry forests dominated by ponderosa pine included a range of fire severities (Agee, 1993). However, the overwhelming weight of scientific evidence from historical records and photos, tree-ring data and the evolutionary history of dominant species (e.g. Keeley & Zedler, 1998) stands in contradiction to the interpretations of spatially extensive high-severity fire reported by W&B.

W&B conclude that current attempts to reduce forest fuels and fire severity, grounded in US federal policy and demonstrably effective (Stephens *et al*., 2012), are misguided because they 'will move most forests outside their historical range of variability, rather than restore them, probably with negative consequences for biological diversity'. We disagree strongly with this assessment. First, as we have shown, the interpretation of HRV presented by W&B is not scientifically supported. Second, dry western forests are documented to be two to ten or more times *more* dense than at the time of fire exclusion, forming more continuous flammable fuel structures than in the past. Third, except for unusual circumstances such as the Gila Wilderness (New Mexico) where historic fire regimes have been reinstated, most dry western forests are increasingly vulnerable to the potential effects of climate change on severe disturbance (e.g. Allen *et al*., 2010; Williams *et al*., 2013). Extreme fire behaviour has affected increasingly large areas in recent major fires, a result of multiyear drought and many decades of fuel accumulation (Miller & Safford, 2012). In addition to tree mortality and erosion potential on severely burned steep slopes, recruitment failure under current and projected climatic conditions may represent a threshold process that will create novel ecosystem configurations (Falk, in press). The weight of scientific evidence indicates that conservation of native dry western forest ecosystems and their ecological, social and economic values is not consistent with the modern pattern of large, high-severity fires. Indeed, uncharacteristic large, high-severity fires pose one of the greatest risks to ecosystem integrity in the 21st century. W&B pose an experiment we cannot afford to conduct.

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