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CORRESPONDENCE

# High-severity fire corroborated in historical dry forests of the western United States: response to Fulé *et al.*


## ABSTRACT

Accurate assessment of changing fire regimes is important, since climatic change and people may be promoting more wildfires. Government wildland fire policies and restoration programmes in dry western US forests are based on the hypothesis that high-severity fire was rare in historical fire regimes, modern fire severity is unnaturally high and restoration efforts should focus primarily on thinning forests to eliminate high-severity fire. Using General Land Office (GLO) survey data over large dry-forest landscapes, we showed that the proportion of historical forest affected by high-severity fire was not insignificant, fire severity has not increased as a proportion of total fire area and large areas of dense forest were present historically (Williams & Baker, *Global Ecology and Biogeography*, **21**, 1042–1052, 2012; W&B). In response, Fulé *et al.* (*Global Ecology and Biogeography*, 2013, doi: 10.1111/geb.12136; FE) suggest that our inferences are unsupported and land management based on our research could be damaging to native ecosystems. Here, we show that the concerns of FE are unfounded. Their criticism comes from misquoting W&B, mistaking W&B's methods, misusing evidence (e.g. from Aldo Leopold) and missing substantial available evidence. We also update corroboration for the extensive historical high-severity fire shown by W&B. We suggest that restoration programmes are misdirected in seeking to reduce all high-severity fire in dry forests, given findings from spatially extensive GLO data and other sources.



### Keywords

**Fire regime, fire severity, General Land Office survey, historical range of variability, mixed-conifer forests, ponderosa pine, wildfire.**


## INTRODUCTION

Recent rapidly spreading, high-intensity fires have led to global concern about 'megafires' (Adams, 2013). In the United States, the dry forests that are widespread in the western states are a focus for concern (Keane *et al.*, 2008). Dry forests are mid-elevation forests that include ponderosa pine and dry mixed-conifer forests (Hann *et al.*, 1997). Improved fire-severity monitoring (Eidenshink *et al.*, 2007) suggests that there has been a significant increase in fire severity since 1984 in parts of the south-western United States (Dillon *et al.*, 2011). However, prior to 1984, comprehensive fire-severity data are lacking, and it is unknown whether the trend is a departure from historical fire severity or a return to it. An earlier, pre-industrial baseline for historical forests that would answer this question, help separate causes of change and guide restoration programmes is possible in the western United States, as Euro-American settlement often did not expand until the mid-to-late 1800s.

The importance of the pre-industrial historical baseline in the western United States is the backdrop for the critique by Fulé *et al.* (2013; hereafter FE) of our evidence from the US General Land Office (GLO) surveys (Williams & Baker, 2012a; hereafter W&B). In general, the authors of FE support the hypothesis that historical dry forests were maintained primarily by low-severity fire. In many cases, the evidence in W&B supports their previous work. However, we also found that high-severity fire and dense forests were significant aspects of historical dry forests. It is the friction between these competing hypotheses that kindles this exchange. Unfortunately, in their critique, FE extensively misquote our article, mistake our methods and say it addressed topics and made conclusions that were not made, hampering a useful scientific exchange. Thus, FE substantially misleads readers about W&B's findings. To avoid just restating what W&B did find and FE's criticism, we place the details in Table S1 in Supporting Information and focus on the most significant concerns. We first address FE's critiques of our fire-severity reconstructions by reviewing validation and updated corroboration for W&B's findings, then address three false narratives that FE create in their response. Science-based efforts to assess changing fire regimes and forest structure need a firm foundation in accurate evidence, and we use this exchange to suggest how this might be better achieved.

## STRUCTURE-BASED MODELS OF FIRE SEVERITY ARE VALIDATED

FE argue that structure-based models used to reconstruct fire severity are invalid: 'W&B make a major leap from reconstructions of forest structure to infer details of the historical fire regime' (p. 1). FE also say: (1) tree size is invalid as a proxy for tree age, (2) W&B is biased by lumping mixed- and high-severity fire, and (3) W&B did not analyse alternatives.

Structure-based models are not a major leap, as they have long been used to reconstruct fire, and have been critically examined and validated using tree rings (e.g. Lorimer & Frelich, 1998). Structure-based models are based on observed changes in forest structure (e.g. tree density, tree size, tree regeneration) that occur as distinguishable structural stages following disturbance. Using multiple attributes of forest structure, the structural stage and/or severity of past disturbance can be reconstructed. In W&B we cited seven examples of prior scientific use of structure-based models to reconstruct fire. Indeed, three authors of FE have used structure-based models to reconstruct fire severity and understand fire effects (Taylor & Skinner, 1998; Stephens & Gill, 2005), so we do not know why FE critique the similar use of these models by W&B.

However, unlike the applications by Taylor, Skinner and Stephens, we did not simply apply our model but calibrated and then validated it, as explained in detail in W&B (pp. 1044–1046 and Tables S1, S2 & S4). These models are validated because tree size, as a proxy for tree age, is sufficient to distinguish broad, predominant age classes. FE suggested that local data are needed to support this. In our study areas, the local relationships of diameter, age and height are well documented (Woolsey, 1911; Bright, 1912; Munger, 1917). All show that older trees are larger and taller. Significant local linear regressions of diameter and age are also available (e.g. Abella, 2008). However, our model only requires the rough separation of two classes: older and younger trees. For example, in Arizona, W&B used the criterion that large trees (> 40 cm diameter) were ≥ 120 years old, using previous dating. To validate this, we used data from 588 trees cross-dated in a study nearby (Dugan, 2012). The criterion was correct 84% of the time and thus is quite accurate.

FE implied that small trees alone or diameters alone were used in our structure-based model. W&B is clear that small trees, large trees and tree density were used together. W&B did show that areas of reconstructed high-severity fire were dominated (73%) by small trees and few large trees (10.8%, 21.3 trees ha$^{-1}$), representing a forest recovering from a high-severity event.

FE suggest our methods for interpreting fire severity are biased by lumping (FE, p. 2). This claim has no merit; our main results (e.g. Table 2 and Fig. 3 in W&B) and discussion do not lump fire severities. We lumped moderate and high-severity fire just to contrast with low-severity fire, often considered to be the historical fire severity in dry forests. There is no bias in a comparison. Readers can combine data from Table 2 of W&B in any combination for comparisons.

FE say we did not consider alternative explanations (delayed regeneration, other causes of recruitment) of reconstructed forest structure. These were the exact alternative explanations that were analysed and rejected in W&B (p. 1050, left column), so we are baffled by this criticism.

## HISTORICALLY DENSE DRY FORESTS SUPPORTED HIGH-SEVERITY FIRE

FE say: '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' (p. 3). W&B's mean (141–145 trees ha$^{-1}$) and range (0–740 trees ha$^{-1}$) for tree density on Arizona landscapes were about 10–20% higher than in earlier work.

However, what also sets our reconstructions apart is the large amount of high-density forest. In combined Arizona landscapes, dense (> 200 trees ha$^{-1}$) patches covered 17.3% of the area, with one contiguous dense patch of > 17,000 ha. Very dense (> 300 trees ha$^{-1}$) patches covered 4.2% of the area. High-density patches were also scattered across lower-density areas. Forests outside Arizona were even denser and more heterogeneous (Front Range, mean 217, range 0–1223 trees ha$^{-1}$; Blue Mountains, mean 167, range 0–683 trees ha$^{-1}$; Eastern Oregon Cascades, mean 249, range 0–1606 trees ha$^{-1}$; Baker, 2012). Dense patches occupied 44.8 and 28.7%, and very dense patches occupied 20.1 and 8.3% of the Front Range and Blue Mountains, respectively. Very dense patches occupied ≥ 25% of the Eastern Cascades (Baker, 2012). These large areas of high density do support 'the argument for a substantial role for high-severity fire'. These findings also suggest that restoration can leave large areas of dense and very dense forest already known to be important habitat for some ponderosa pine forest obligates (e.g. Abert's squirrel; Patton, 1984).

## EXTENSIVE HIGH-SEVERITY FIRE CORROBORATED IN GLO STUDY AREAS

FE say: 'W&B fail to acknowledge the lack of contemporary evidence of 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' (p. 2). In W&B, we summarized (W&B, Appendix S1) corroborating evidence from early scientific reports, primary observations, photographs, palaeoecological reconstructions and others that support the proportion of high-severity fire reconstructed from survey records. The synopsis was missed by FE. More corroboration is now published or forthcoming. We update three cases.

The most complete corroboration is in the Eastern Cascades of Oregon (Baker, 2012). There, the GLO fire-severity reconstruction matched rougher direct observations made later by early US government scientists in a forest reserve report (report overlapped 84% of GLO reconstruction). Also, a reconstruction of historical fire severity from early aerial photography in an overlapping area found similar proportions of historical fire severity: 18% low, 59% mixed, 23% high in Baker (2012) and 19% low, 52% mixed, and 30% high in Hessburg *et al.* (2007). FE suggest primary observation of high-severity fire is lacking, but both reconstructions are corroborated by 76 quotes from early direct, primary observations (Baker, 2012). The rate of major fires, probably including high-severity fire, is validated by palaeoecological reconstruction (Long *et al.*, 2011).

Similar corroboration for the Mogollon Plateau fire-severity reconstruction comes from Leiberg *et al.* (1904). That report is based on 2 years of timber cruising and systematic scientific observations across every section (259 ha) of a 785,279 ha forest reserve, about 317,000 ha of which overlap our Mogollon Plateau study area. We compared our high-severity fire reconstruction with timber stands that Leiberg *et al.* (1904) said indicated past high-severity fires: 'The light stands in many cases represent tracts which were burned clear, or nearly so, one hundred or one hundred and twenty years ago, and now are chiefly stocked with sapling growths, ranging in age from 35 to 90 years' (Leiberg *et al.* 1904, p. 23).

Their data suggest that light stands covered about 17% of the forest reserve's ponderosa pine area (Table S2), representing a historical high-severity fire rotation of about 600–700 years (100–120 years/0.17). These are similar to W&B's estimates of 14.5% of area burned at high severity in the same period, and a historical high-severity fire rotation of 828 years. Palaeoecological reconstruction also corroborates the rate of high-severity fire (Jenkins *et al.*, 2011). Extensive historical high-severity fire is spatially and temporally corroborated for the Mogollon Plateau.

Corroboration also exists now for the Colorado Front Range fire-severity reconstruction. W&B used a GLO structure-based model with surveyor tree data to reconstruct fire severity over 65,525 ha. Williams & Baker (2012b) used a separate GLO dataset of direct observations by surveyors along section lines to reconstruct higher-severity fire for 624,000 ha. The observations by surveyors specifically identify areas that burned in high-severity fire. Estimated fire rotations were similar at 249 and 271 years, respectively. Further corroboration, in the form of early historical scientific records, photographs, tree-ring studies and other documents, which FE said is lacking, has been available for some time, as it was extensively reviewed in Baker *et al*. (2007) and Baker (2009). W&B's Colorado reconstructions also are spatially and temporally validated.

## FE'S THREE NEW FALSE NARRATIVES

### Are high-severity patch sizes now orders of magnitude larger?

FE's first false narrative is their conclusion that patch size and fire size have increased. FE's hypothesis is that disruption of dry forests by logging and exclusion of low-severity fire led to increased fire severity and larger high-severity patches than occurred historically. A recent policy forum, including three authors of FE, also implies that high-severity patch sizes are unnaturally large in dry forests, hampering tree regeneration after fires (Stephens *et al*., 2013). Neither cites data.

W&B did not study patch size or fire size and made no conclusion about them, so we do not know why FE address them, but at first they say: 'Patch size distributions of past high-severity events are largely unknown' (p. 3). This is consistent with the fact that no old or new evidence is presented by FE substantiating either historical or modern patch sizes. Thus, any conclusion about fire size or patch size presumably lacks a scientific basis for FE. Remarkably, FE still conclude: 'But the spatial pattern of burning in contemporary wildfires is orders of magnitude higher, with large ($10^3$ to $10^4$ ha) *contiguous* fire-killed patches' (p. 3).

Published evidence was actually available and the largest sample does not support FE. Inference has been made about historical high-severity patch and fire sizes from limited samples or modern landscapes thought to have recent fires similar to historical ones (e.g. Collins & Stephens, 2012; Miller *et al*., 2012). That evidence was not cited, although it includes an author of FE, but it does suggest increased fire/patch size in managed landscapes, as opposed to wilder landscapes with more natural fire regimes. However, so far as we know, evidence from a large sample of actual historical patch sizes in dry forests is limited to Williams & Baker (2012b). We showed, using primary observations by GLO surveyors (i.e. descriptions of forest burned in high severity), that recent ($n = 112$ patches) higher-severity patch-size distributions in dry forests of the Colorado Front Range are similar to historical ones ($n = 301$ patches), except for recent deficiency in the largest patch sizes. FE's first false narrative uses no data, not even their own, and has no weighing of available evidence.

### Are comparisons of historical and recent fire severity valid?

FE reject our comparison of fire-severity reconstructions with modern estimates of fire severity from remote-sensing data, but then create their second, related false narrative. They begin with: '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' (p. 3). W&B of course used different types of data to compare historical and modern high-severity fire. No comparison could be made at all if historical data had to be reflectance-based, as FE suggest.

We think that comparison of historical and modern fire severity, using data, has value, but of course recognize that historical and modern data are not fully compatible. Modern comparisons between reflectance-based and ground-based estimates of fire severity provide some support (Eidenshink *et al*., 2007). Most works have found plot-based and remotely sensed assessment of fire severity to be highly correlated and yield similar fire-severity estimates (van Wagtendonk *et al*., 2004; Cocke *et al*., 2005). In a study in ponderosa pine, the largest error was between unburned and low fire severity; high fire severity had the highest accuracy (Cocke *et al*., 2005). Surveyors did not use plot-based estimates of fire severity, but their tree data can be used to accurately estimate fire severity.

However, if FE think our comparison is invalid, then FE themselves could not possibly make the conclusion they made for their first false narrative, that fire-killed patches are larger in modern fires (p. 3). By applying an impossible data standard for W&B, or any study, then creating an illusion of truth with no data at all, FE generate a second false narrative.

### Do early scientific reports demonstrate a lack of extensive high-severity fire?

FE's third false narrative is that early scientific reports do not describe extensive high-severity fire in historical dry forests, an idea central to their low-severity hypothesis. We cited early evidence, above, corroborating extensive historical high-severity fire in GLO study areas. Apparently, it is the extensive aspect of high-severity fire found by W&B that is the issue for FE; the occurrence of high-severity fire in dry forests is not contested. In fact, historical high-severity fire in dry forests is documented by five authors of FE (Taylor & Skinner, 1998; Brown *et al*., 1999; Swetnam *et al*., 2001, Fulé *et al*., 2003, 2009; Iniguez *et al*., 2009; Bekker & Taylor, 2010). Two authors of FE (Brown *et al*., 1999; Bekker & Taylor, 2010) actually document, by reconstructions, extensive historical high-severity fires in dry forests. We are puzzled as to why FE do not mention this finding from these two studies.

FE begin by misusing two studies they believe support their narrative: '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)' (p. 2). It is surprising that FE did not know that Leopold (1924) is not about ponderosa pine forests but instead the next vegetation zone lower in elevation. Leopold documented this zone had historically open, grassy vegetation with scattered junipers maintained by severe fires. He said historical wildfires 'kept the juniper and other woodland species decimated' (Leopold, 1924, p. 3), indicating severe wildfires. Also, although he thought them rare, Cooper (1960) reported structure-based evidence of extensive high-severity fire in ponderosa pine in the Prescott National Forest: 'With the possible exception of a part of the Prescott National Forest, there appears to be no area in Arizona where extensive even-aged pole stands indicate that a major fire destroyed most of the mature timber and permitted extensive even-aged regeneration' (Cooper, 1960, p. 137). Leopold and Cooper actually support extensive historical high-severity fire and its ecological role in maintaining vegetation and encouraging tree regeneration.

But the problem with FE's conclusion is larger, because FE would have to review all early scientific studies, not a selected few, and show that none of them found evidence of extensive historical high-severity fire in dry forests. FE support their third false narrative by citing only two reports for California and the Kaibab. At least 23 others, that do document extensive high-severity fire, are missed by FE. In northern California, FE miss Leiberg (1902), who mapped and described extensive area of high-severity fire in dry forests. FE also miss early scientific reports of high-severity fire in dry forests of the Eastern Oregon Cascades (five forest-reserve reports from 1900–03 reviewed in Baker, 2012), in the Blue Mountains of Oregon (Langille, 1906) in the Colorado Front Range and across the Rocky Mountains (15 forest-reserve reports, near 1900, reviewed in Baker *et al*., 2007), in northern Arizona (Leiberg *et al*., 1904) and in the Black Hills (forest-reserve report from 1899 reviewed in Shinneman & Baker, 1997).

FE's third false narrative misuses evidence and fails to use abundant available evidence. FE may restate lack of evidence three more times (p. 2) for emphasis, but their 'lack of evidence' idea is FE's third false narrative.

## ALDO LEOPOLD, FALSE NARRATIVES AND MISDIRECTED RESTORATION

FE employed some false narratives, repeated for emphasis. Here is a different narrative. FE used Aldo Leopold, a conservation hero, as a powerful authority to support their hypothesis that high-severity fire was historically lacking in dry forests. However, FE not only got the vegetation wrong, but also Leopold's findings, which do not support FE's idea that historical high-severity fire was lacking in dry forests. Leopold (1924) also showed that a popular idea at the time, using intense grazing to lower fuel loads to prevent severe wildfires, was misdirected and damaging to watersheds, and incompatible with the ecological role of severe wildfires. Leopold studied and then articulated the ecological roles of severe wildfires, then to counter prevailing fears about severe fires he also showed that these fires were infrequent. Ironically, FE show the same fear of high-severity fire today, and endorse lowering fuel loads, that Leopold countered in 1924.

Historical baselines, in part from sources like Leopold (1924) and Leiberg *et al*. (1904), are commonly used to help guide restoration programmes, which can be misdirected if evidence is misused, incomplete or based on false narratives. A publically funded programme is in place, for example, on the Mogollon Plateau (4fri.org, http://www.fs.usda.gov/main/4fri/planning). This key document for 4fri lists but does not review Leiberg *et al*. (1904), and mistakenly treats high-severity fire as generally uncharacteristic in these forests. Similarly, the US Omnibus Public Land Management Act of 2009 established a Collaborative Forest Landscape Restoration Program. Restoration proposals must 'reduce hazardous fuels . . . to modify fire behavior, as measured by the projected reduction of uncharacteristically severe wildfire . . .'. This law presumes that uncharacteristically severe wildfire is common and requires reduction, rather than requiring proposals to compile and review all available scientific evidence to guide restoration. If scientific evidence had been systematically reviewed, it would not have supported these programmes. We cited above the many early scientific studies, direct observations and other evidence, in addition to W&B, that do not support the idea that high-severity fire was uncharacteristic in dry forests nor the goal of these programmes to reduce all high-severity fire.

## COMBINE EVIDENCE TO CREATE A MORE RELIABLE HISTORICAL BASELINE

The best possible historical baseline for dry forests is likely to come from systematically combining all sources. Past studies that supported the past incomplete historical baseline, which suggested that low-severity fire primarily maintained historical dry forests, were often spatially limited, incomplete samples of larger landscapes. Tree-ring methods can reconstruct to fine scales back to the late 1800s, but are difficult to complete across large landscapes (but see Heyerdahl *et al*., 2001). Palaeoecological reconstructions can provide key temporal evidence, but are also difficult to replicate across large landscapes. GLO data, in contrast, can be used to develop reconstructions across hundred of thousands to millions of hectares. New findings from GLO data have challenged past findings about the nature of the historical baseline in dry forests, but it is the role of science to continually test past findings. Refining the historical baseline should help avoid misuse of evidence, false narratives, and misdirected restoration and provide a sound scientific foundation for predicting the effects of climatic change on wildfire and forests.

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

**Table S1** Misquotes and misrepresentation of results and conclusions of Williams & Baker (2012a) by Fulé *et al.* (2013).

**Table S2** Timbered area of ponderosa pine and dry mixed-conifer forests in the San Francisco Mountains Forest Reserve, Arizona in AD 1904 that may represent 'light stands' associated with high-severity fires in the 1700s and 1800s.

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