fire

Review

Countering Omitted Evidence of Variable Historical Forests and Fire Regime in Western USA Dry Forests: The Low-Severity-Fire Model Rejected

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Abstract: The structure and fire regime of pre-industrial (historical) dry forests over ~26 million ha of the western USA is of growing importance because wildfires are increasing and spilling over into communities. Management is guided by current conditions relative to the historical range of variability (HRV). Two models of HRV, with different implications, have been debated since the 1990s in a complex series of papers, replies, and rebuttals. The "low-severity" model is that dry forests were relatively uniform, low in tree density, and dominated by low- to moderate-severity fires; the "mixed-severity" model is that dry forests were heterogeneous, with both low and high tree densities and a mixture of fire severities. Here, we simply rebut evidence in the low-severity model's latest review, including its 37 critiques of the mixed-severity model. A central finding of high-severity fire recently exceeding its historical rates was not supported by evidence in the review itself. A large body of published evidence supporting the mixed-severity model was omitted. These included numerous direct observations by early scientists, early forest atlases, early newspaper accounts, early oblique and aerial photographs, seven paleo-charcoal reconstructions, ≥18 tree-ring reconstructions, 15 land survey reconstructions, and analysis of forest inventory data. Our rebuttal shows that evidence omitted in the review left a falsification of the scientific record, with significant land management implications. The low-severity model is rejected and mixed-severity model is supported by the corrected body of scientific evidence.

Keywords: ponderosa pine; mixed conifer; dry forests; historical range of variability; fire regime; low-severity fire; mixed-severity fire; high-severity fire; forest structure

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1. Introduction

1.1. The Issue of Historical Forest Structure and Fire in Dry Forests

Wildfires are increasing in dry forests of the western USA, particularly from climate change [1], with dire concerns for the nearby built environments facing serious fire risk to lives and property [2]. The scientific basis for this difficult nature–people wildfire problem has recently been compounded by omitted and false evidence in a review by Hagmann et al. [3] of historical forest structure and fire in western USA forests, including dry forests, the subject of rebuttal in this paper. Dry forests cover ~25.5 million ha of the western USA [4] and include ponderosa pine (*Pinus ponderosa*) forests (Figure 1) and dry mixed-conifer forests (ponderosa with several associated trees). Dry forests often begin at the lower limit of tall trees and extend upward, forming the lower part of the montane zone, covering plateaus and mesas as well as mountain slopes, often bordered below by woodlands (*Pinus-Juniperus*) or semiarid sagebrush (*Artemisia* spp.) shrublands and grasslands.

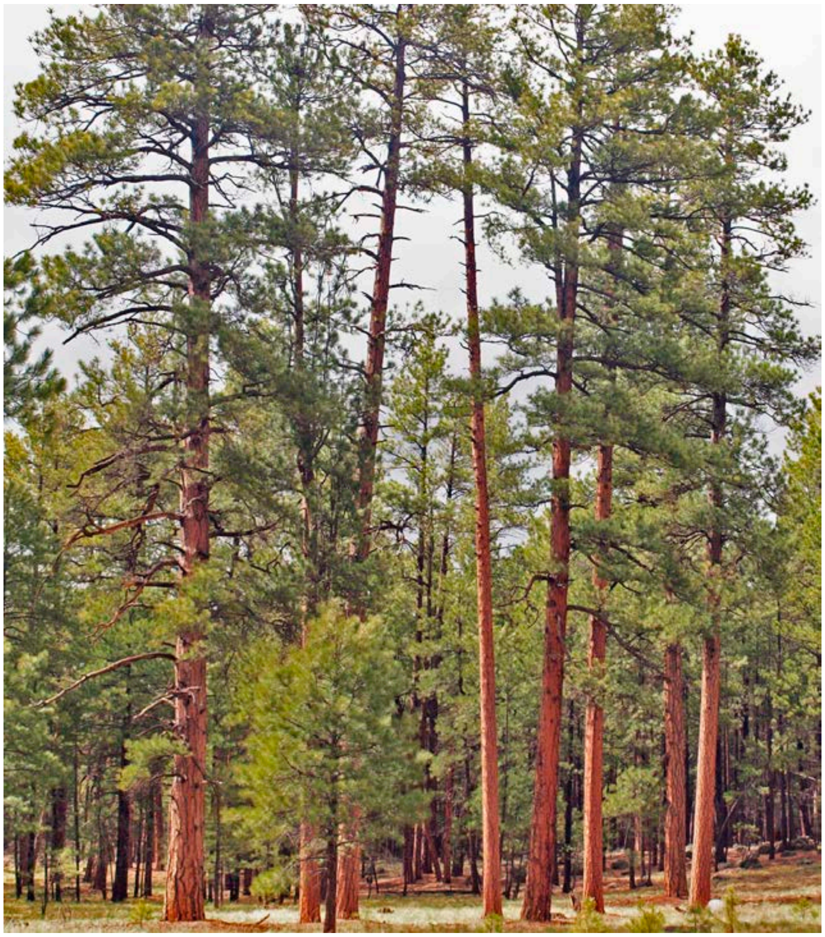

Figure 1. A typical older ponderosa pine forest. Photo by W.L. Baker.

The fire problem in dry forests is a wicked problem [5], as much is at stake for people and nature, and the issues are difficult. Dry forests have become favored but dangerous locations for development, which is continuing expansion in the wildland–urban interface (WUI) [6]. Increasing wildfires ignited in wildland vegetation, including dry forests, spill over into expanding WUI-built environments [2]. There are significant concerns about ecological effects (e.g., [7]) and cost and effectiveness [8] of fire management.

This difficult situation is also the setting for what has been a lengthy scientific debate about historical forest structure and fire in dry forests. Since the 1990s, there has been competing evidence that dry forests historically were either (1) open, low-density forests maintained by frequent low-severity fires (e.g., [9]), called here the "low-severity fire" model, although limited moderate-severity fire is included, or (2) had both low- and high-density forests with a mixture of fire severities, including high-severity fires (e.g., [10–12]), the "mixed-severity fire" model. Evidence in this debate has become extensive and was reviewed previously by Odion et al. [12] and Hanson et al. [13]. A large body of evidence for both models has developed from local [14,15] and landscape-scale studies [11,16]. Findings have been challenged and rebutted in a complex series of papers, comments, and rebuttals (e.g., [17–19]). Hagmann et al. [3] do not call it the low-severity-fire model, but they explain that "high-severity fire is overrepresented in forests historically characterized by frequent low- to moderate-severity fire regimes" [3] (p. 13).

In general, sound evidence about the historical structure of dry forests and the ecosystem processes shaping them remains important today in understanding and managing dry forests, especially as climates change. Evidence about the historical range of variability

(HRV) of ecosystems provides an essential frame of reference for restoring and adapting ecosystems to maintain biological diversity and ecosystem services as climates change [20]. By historical, we mean prior to the expansion of industrial development and displacement of Indians, usually in the late 1800s in the eleven western states where dry forests occur. Biological diversity has embedded genetic composition from long-term response to HRV where organisms live, which constrains their ability to rapidly adapt to a changing climate, forest structure, and fire [21]. This makes departures from HRV undesirable for biological diversity, including dominant dry-forest trees, and heightens the importance of HRV as a major basis for sound forest management.

The fire regime is particularly a focus of HRV research in western North America because this area retains substantial original, if modified, vegetation that developed under the influence of wildfires and other natural disturbances. Wildfires have been modified by fire management (including logging), human-set fires, livestock, and climate change.

1.2. Rationale and Methodology of This Paper

Here, we rebut evidence in a recent review (Hagmann et al. [3], "H" hereafter) of HRV for forest structure and fire, focused on dry forests in North America. H extensively critiqued the mixed-severity-fire model and was a major basis for associated policy proposals [22,23] that are now disputed [7]. Here, we critically examine and rebut evidence against the mixed-severity model. This makes H a logical focus as they support only the low-severity model. We are authors of many papers critiqued in H, including its focus on the Williams and Baker [24] method ("WB" hereafter) of reconstructing historical forest structure and fire from US General Land Office (GLO) land survey data from the late 1800s; thus, we think it is appropriate to take this critical approach to evidence in H. The WB method is a new method using design-based statistical theory and Voronoi polygons to reconstruct forest structures from GLO bearing-tree data [24]. Science can benefit from a detailed examination of evidence about methods and models. We think it will be easier for readers to compare evidence and arguments if we follow H's structure, including the tables they used to present evidence. The result is not a systematic or full review but instead a focused rebuttal of evidence. The result is a review of the substantial evidence that supports the mixed-severity model and rejects the low-severity model of HRV for forest structure and fire in dry forests of western North America.

Our method, which is generally replicable, given the focus in H on WB methods, was to seek key published rebuttals and original evidence relevant to each item in Tables 3–6 in H, as well as other evidence and critiques of the WB method in H's text. Since our authorship includes the two original authors of the WB method and authors of other rebuttals of published studies by authors of H, we know all our original and rebuttal evidence. Evidence from other sources was primarily cited in these papers.

We found that evidence in H omitted major bodies of published evidence that do not support the low-severity model. H said our publications misrepresented the state of the science. Here, we refute this and show that it is the evidence in H where falsification occurred. Unfortunately, omissions and false evidence in H became a theme because these are so numerous and significant. H claimed the WB method should be evaluated with independent evidence, not WB's evidence, but the validity of the WB method is not scientifically evaluated if original validations and rebuttals of critiques of the WB method are omitted, as H did. As we show, H not only omitted key original and rebuttal evidence about the WB method but also large bodies of independent evidence by other authors, including authors of H, that do not support the low-severity model.

We present three sections (Sections 2–4 below) to make the case about false evidence and omitted evidence in H. In Section 2, we show that an expansion of evidence about HRV for forest structure and fire in dry forests since the 1990s was omitted in H. In Section 3, we show that the evidence that H presented to argue that high-severity fire has been burning recently at rates that exceed historical rates shows the opposite. In Section 4, we refute evidence that H presented to argue that the WB method of reconstructing historical forest structure and fire from land survey data is flawed. We show that all the evidence that shows that the WB method is valid and accurate was omitted in H. These sections together show the substantial evidence that rejects the low-severity model and supports the mixed-severity model.

2. Expanding Sources of Evidence about Dry-Forest HRV since the 1990s Omitted in H

H was rooted in earlier and now-disputed evidence about historical fire and forest structure in dry forests. Up to about the middle 1990s, fires in dry forests were often thought to have historically burned frequently and mostly at low to moderate severity in low-density dry forests dominated by large trees (Figure 1), as found in parts of the southwestern United States (e.g., [9]) (Table 1, Group 1). Fire histories in these forests often assumed low-severity fire dominated and did not reconstruct fire severity, as they were targeted at old park-like forests with long fire-scar records, which inherently lacked much higher-severity fire for long periods [25]. Dominance by low- to moderate-severity fire and low tree density were also found in some parts of land survey reconstructions, but other parts of these landscapes were found to have higher-severity fire and denser forests (Figure 2), so low- to moderate-severity fires were 85–98% of fires (Table 1, Group 1). Tree-ring [26] and land survey reconstructions agree that tree density was typically low, with ~140 trees/ha overall in these areas (Table 1, Group 1). These forests were in the driest areas, mostly in New Mexico and Arizona, but scattered in other states [25]. Thus, it is not in dispute that substantial area in historical dry forests, particularly in the driest areas of the southwest, had low- to moderate-severity fire and open, low-density forests. The issue is that evidence now shows that even these seemingly stable areas with low-severity fires, and other parts of these landscapes, at times also had infrequent high-severity fires and denser forests [27], as shown in Figure 2.

Table 1. The 15 dry-forest landscapes with reconstructions from US General Land Office survey data based on WB methods.

Study Area	Source	Area (ha)	Historical Fire Severity					Historical Tree Density (Trees/ha)		
			Low (%)	Mixed (%)	Low + Mixed (%)	High (%)	High Rotat. (yrs)	Mean	Median	C.V. (%)
Group 1—Mostly low- to moderate-severity fires and low tree density										
Mogollon Plateau, AZ	Williams and Baker [24]	405,214	62.4	23.1	85.5	14.5	828	141	124	54
Coconino Plateau, AZ	Williams and Baker [27]	41,214	58.8	38.7	97.5	2.5	2000 [1]	142	121	46
Group 2—Mostly moderate- to high-severity fires and intermediate to high tree density										
W Sierra, CA-North	Baker [28]	133,482	12.6	48.2	60.8	39.2	281	318	229	106
W Sierra, CA-South	Baker [28]	196,461	26.4	42.5	68.9	31.1	354	275	191	203
W. Sierra, CA–Greenhorn Mts. [2]	Baker and Hanson [17]	49,050	-	-	-	26.9 [3]	-	280 [4]	-	-
Blue Mts., OR	Williams and Baker [24]	304,709	40.3	43.2	83.5	16.5	849	167	146	54
E Cascades, OR-N	Baker [29]	146,555	32.5	44.2	76.7	23.3	515	246	211	-
E Cascades, OR-C	Baker [29]	147,502	10.4	48.2	58.6	41.4	278	262	215	-
E Cascades, OR-S	Baker [29]	104,160	29.4	61.7	91.1	8.9	1180	233	224	-
Siskiyou Mts., OR [2]	Baker [30]	46,445	-	-		-	-	272	253	
Group 3—More high-severity fires and intermediate tree density										
Black Mesa, AZ	Williams and Baker [24]	151,080	12.0	32.8	44.8	55.2	217	144	137	47
Front Range, CO	Williams and Baker [24]	65,525	2.5	32.9	35.4	64.6	271	217	162	100
Front Range, CO–Section-line area	Williams and Baker [31]	624,156	-	-		-	249 [5]	-	-	-
Uncompahgre Plateau, CO [4]	Baker [32]	227,036	0.0	28.7	28.7	71.3	175	182	183	86
San Juan Mts., CO [2]	Baker [33]	235,787	29.2	32.5	61.7	38.3	240	191	118	99

[1] This estimate was not reported in Williams and Baker [27] because so few (about 2.5%) high-severity fires were found. In order to have complete data, a rough estimate of 2000 years was used here. [2] This study area is new since Baker and Williams [34] classified the other 11 landscapes, but it appears to best fit this group. [3] This is not from GLO survey data but instead a count of early timber inventory transects recording evidence of high-severity fire. [4] All estimates are the mean between the ponderosa pine and dry mixed-conifer estimates. [5] This estimate, the only one based on section-line data, is for “higher” severity fires, meaning pooled moderate- to high-severity fires, so the number is shown under each category but applies to them jointly.

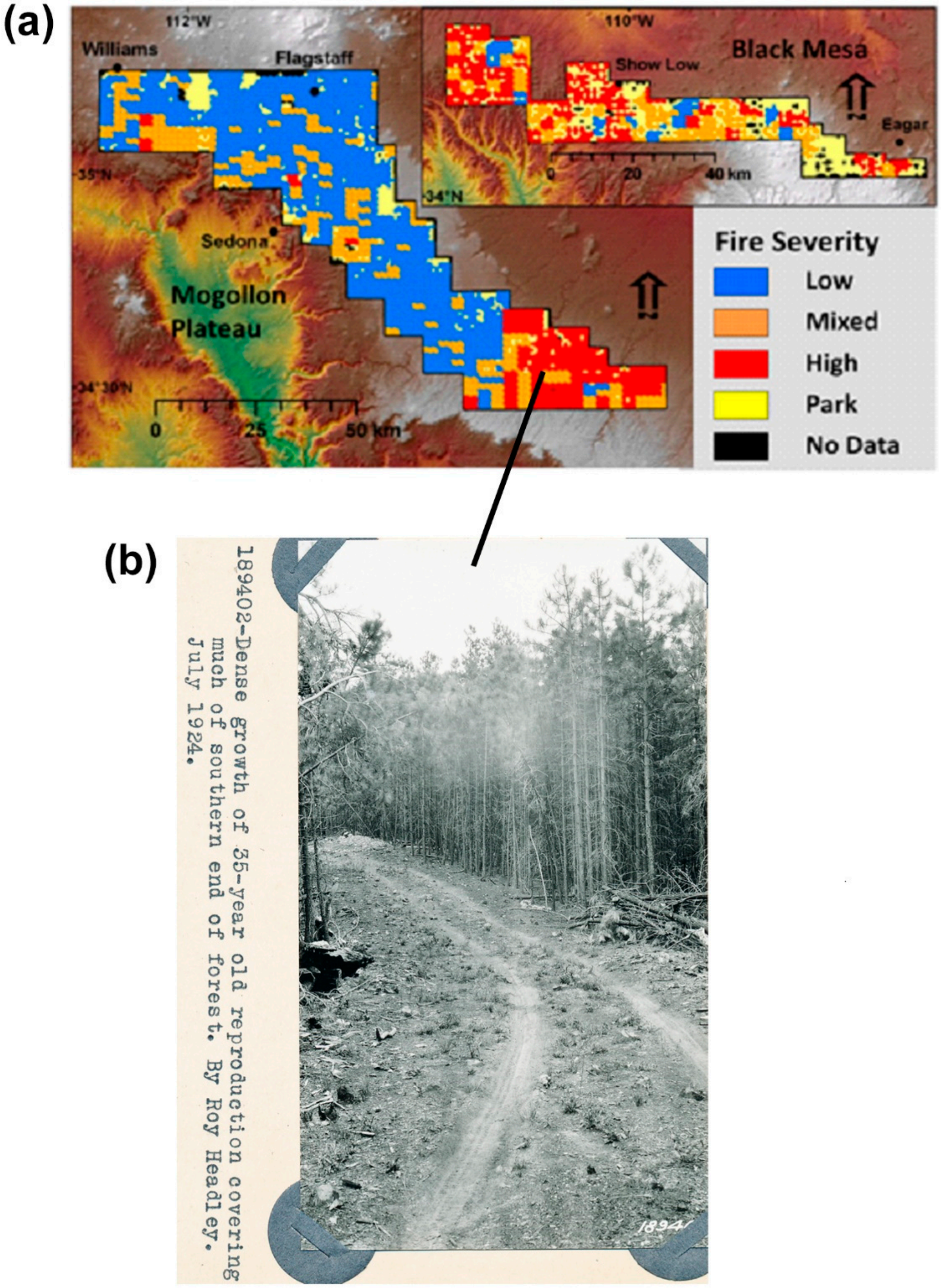

Figure 2. (**a**) "Fire severity evidence from forest structure, based on survey reconstructions on the Mogollon Plateau and nearby Black Mesa, Arizona". Note the extensive mixed- to high-severity fire on Black Mesa compared to the more extensive low- to mixed-severity fire on the Mogollon Plateau. Reprinted from [24] with permission from John Wiley and Sons, and (**b**) a photograph taken in 1924 by Roy Headley, Historical Photo Collection, Region 3, U.S. Forest Service, Albuquerque, New Mexico.

This was discovered because fire histories expanded, between the late 1990s and the 2010s, from just fire scars in small plots, the primary basis for H's review and the low-severity model, to the landscape scale and due to the use of multiple sources of evidence (Table 2). This research found more severe historical fires, including moderate- (20–70% tree mortality) and high-severity (>70% tree mortality) fires and denser and more heterogeneous dry forests, even within Southwest landscapes but especially outside driest areas (Table 1, Group 2 and 3 landscapes). These findings were extensive enough to generally support the mixed-severity model. Sources included early photographs (Figure 3a), maps, and reports, including forest reserve reports [10,35], age structures showing trees likely killed by fire and regenerating abundantly after fire (Figures 2b and 3b), paleo-charcoal reconstructions [36,37], and early aerial photos (Figure 4). Where combinations of sources were available (Figures 2 and 5), validation is enhanced, as H mentioned. For example, Figure 2 shows that where a land survey reconstruction found that the southern end of the Mogollon Plateau had mixed- and high-severity fire in the late 1800s, an old oblique photograph shows dense tree regeneration, without large surviving trees, several decades later. In another example, Figure 5 shows that dry forests mapped as "severely burned" timber [38] ca 1900 were recorded by land surveyors in preceding decades as mature timber. This is independent multi-proxy evidence that the low-severity model is not supported, since mature forests historically burned with high severity at times.

Since historical fires in dry forests were previously considered nearly all low severity, it was surprising at this time to discover this was not the case over large areas. Hessburg et al. [11] used early aerial photography to reconstruct historical fires from forest structures across 178,902 ha of ponderosa pine and Douglas-fir cover types in eastern Washington and Oregon mixed-conifer forests (Figure 4). They explained their findings:

Table 2. Sources of evidence about historical forest structure and fires in dry forests, and selected methods papers and examples.

Historical Forest Structure	
Tree-ring reconstructions from remnant evidence	Fulé et al. [39]
Land survey reconstructions from bearing-tree data	Williams and Baker [24,40,41]
Early forest reserve reports	Baker et al. [35]
Early records from forest inventories	Baker and Williams [34]
Early aerial photographs	Hessburg et al. [11]
Early oblique photographs	Veblen and Lorenz [42]
Historical Fires	
Tree-ring reconstructions from fire scars—small plots	Baisan and Swetnam [43]
Tree-ring reconstructions from landscape-level data	Farris et al. [15]
Land survey reconstructions from bearing-tree data	Williams and Baker [24,40,41]
Land survey reconstructions from section-line data	Williams and Baker [31]
Forest Inventory and Analysis reconstructions	Odion et al. [12]
Paleo-charcoal reconstructions	Pierce et al. [36]
Early records from newspaper accounts	Baker [44]
Early scientific publications	Baker [44]
Early forest reserve reports	Baker et al. [35]
Early forest atlases	Baker [44]
Early oblique photographs	Baker [45]
Early aerial photographs	Hessburg et al. [11]

"The structure of mixed conifer patches, in particular, was formed by a mix of disturbance severities . . . evidence for low-severity fires as the primary influence, or of abundant old park-like patches, was lacking in both the dry and moist mixed conifer forests. The relatively low abundance of old, park-like or similar forest patches, high abundance of young and intermediate-aged patches, and widespread evidence of partial stand and stand-replacing fire suggested that variable fire severity and non-equilibrium patch dynamics were primarily at work" [11] (p. 5) and also: " . . . before any extensive management had occurred, the influence of fire in the dry forest was of a frequency and severity that intermittently regenerated rather than maintained large areas of old, fire tolerant forest" [11] (p. 19).

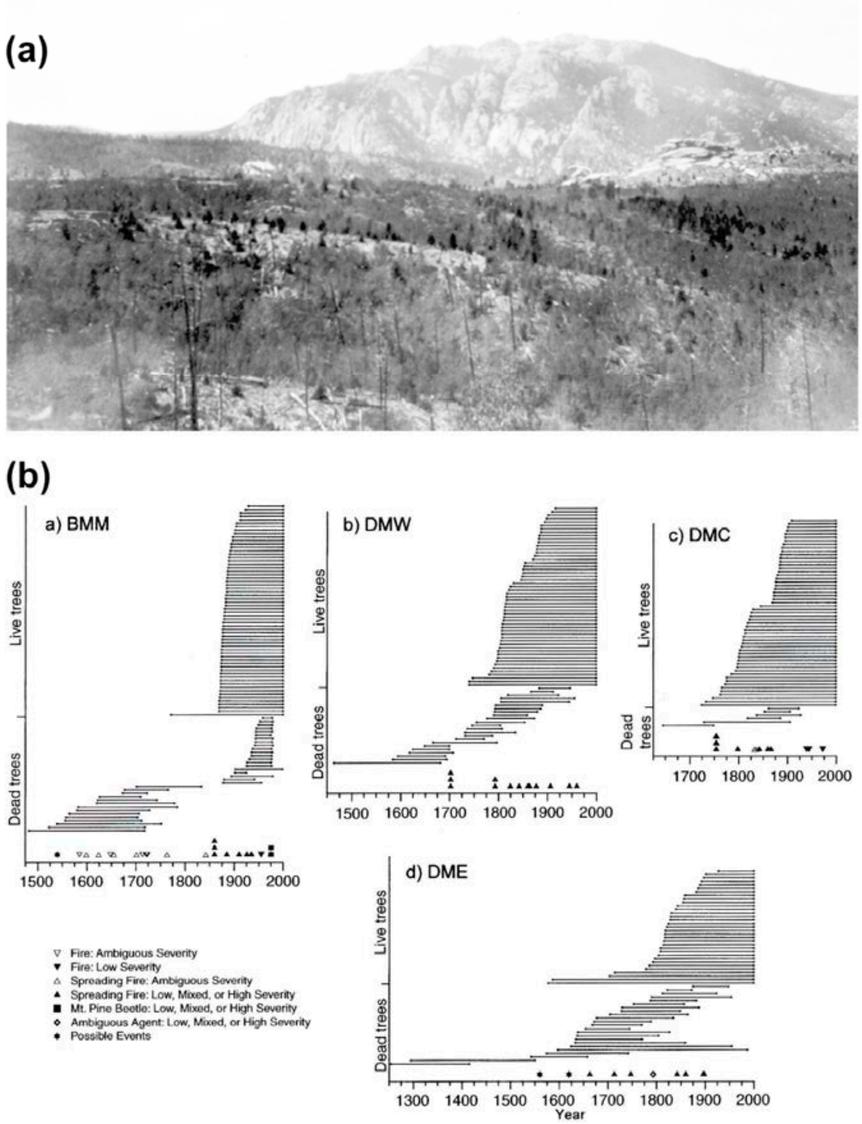

Figure 3. Two sources of evidence, early oblique photographs, and tree-ring reconstructions of age structure and fire scar dating of high-severity fires in dry forests in the Colorado Front Range: (**a**) high-severity fire identified by Jack [46] as in ponderosa pine and subsequent ponderosa pine (dark black) and quaking aspen regeneration in central Colorado in the Plum Creek Reserve; original photo, taken 18 August 1889, probably by John Jack, labeled "Looking north at Devils Head (Platte) Mt. from east side". Original photo in the National Archives, FRA no. 008, (**b**) event diagram for four sample plots in which a tree-ring reconstruction of age structure of live and dead trees was completed in dry forests in Rocky Mountain National Park, Colorado. The severity of an event is indicated by the number of symbols stacked vertically: 1, low severity; 2, mixed severity; and 3, high severity. For example, in plot BMM, a high-severity fire was identified in the 1870s by a fire scar, extensive regeneration after the fire, and dead trees before the fire. Each line shows the lifespan of one tree. Reprinted from ([14] Figure 2) with permission from John Wiley and Sons.

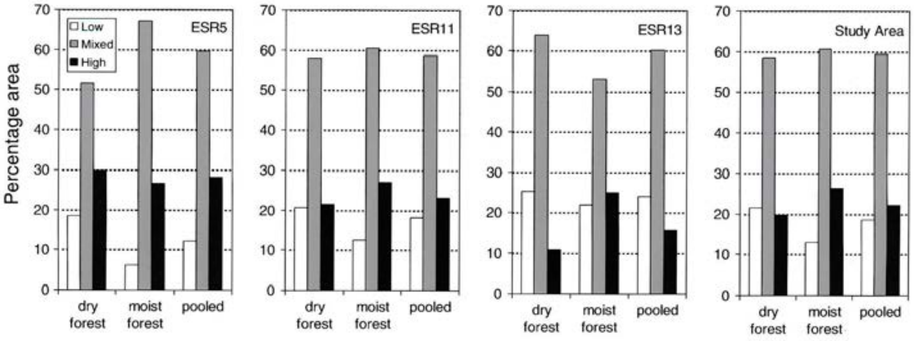

Figure 4. The proportions of the pre-management-era forest area (ha) by forest potential vegetation type in low-, mixed-, and high-severity fire (corresponding with percent canopy mortality values of ≤20%, 20.1–69.9%, and ≥70%, respectively) of Ecological Subregions 5, 11, and 13 and the study area. Comparisons are shown for the dry and moist forest potential vegetation types and pooled (sum of dry and moist). Note the dry-forest columns in each subregion and in the study area as a whole. Reprinted from Hessburg et al. ([11] Figure 5 part) with permission from Springer Nature.

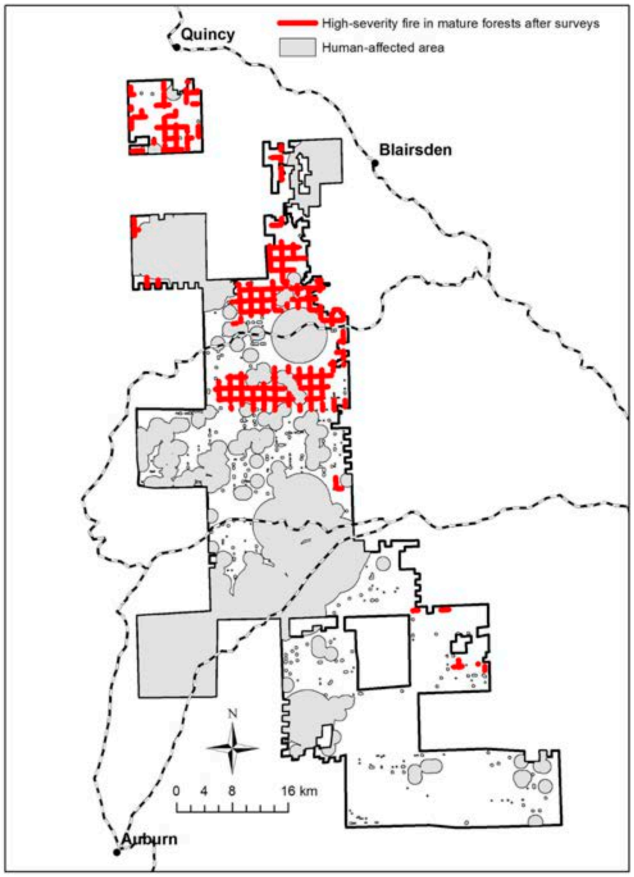

Figure 5. Areas of mature Sierran mixed-conifer forest burned at high severity after the surveys and before Leiberg's mapping ca 1900 [38]. The Leiberg 75–100% burned category from 1900 was overlain on the survey section-line data from 1865 to 1890. Section lines shown in red were described by surveyors as "heavily timbered", "good timber", or "excellent timber", and thus as mature forest in 1865–1890 before Leiberg mapped these areas in 1900 as severely burned. Reprinted from Baker ([28] Figure 8) with permission from John Wiley and Sons.

In the 2010s, Williams and Baker [24,40,41] developed new methods to use General Land Office (GLO) surveys from the late 1800s to systematically reconstruct historical forest structures (e.g., tree density and basal area) and fire rates and severities from bearing-tree records across large landscapes (Figure 2a). They also validated that historical fire rotations and patch sizes could be reconstructed from GLO section-line data [31]. GLO survey reconstructions have been completed for 15 landscapes across > 2.5 million ha of dry forests of the western USA (Table 1, Figure 6). In eastern Oregon, GLO data were shown to be consistent with the findings of Hessburg et al. [11], corroborating both [29].

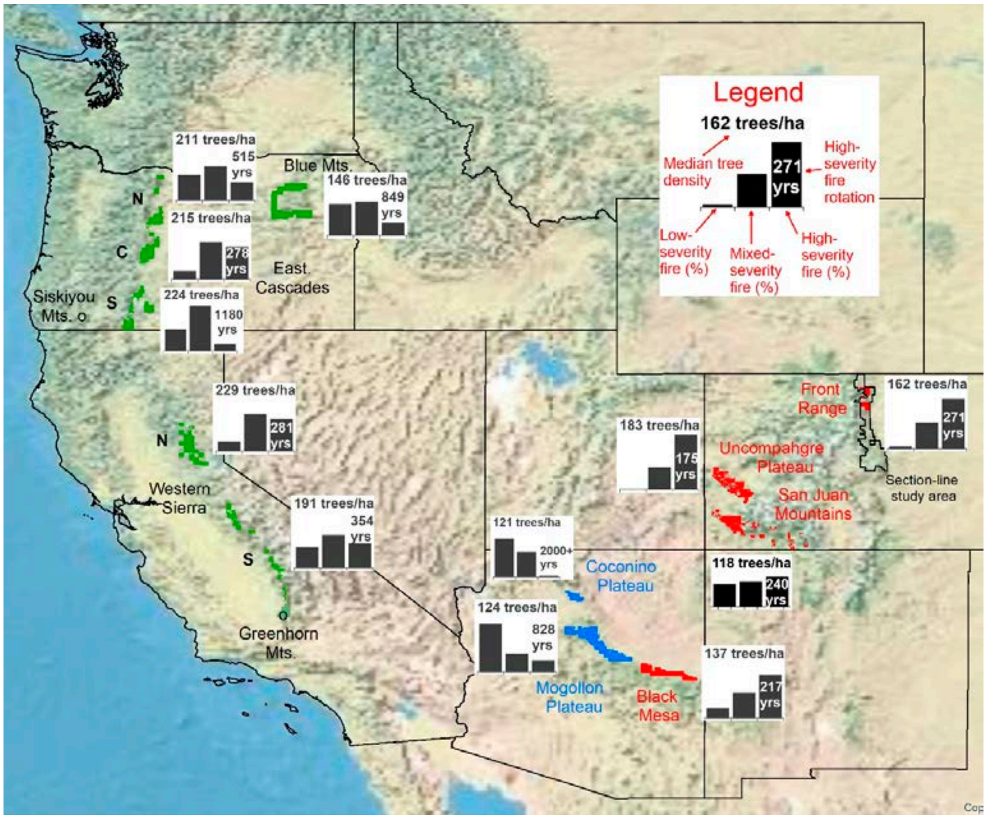

Figure 6. The 15 dry-forest landscapes with reconstructions from U.S. General Land Office survey data based on WB methods. The Greenhorn Mts., CA, and Siskiyou Mts., OR, study areas are small and do not have full reconstructions. The Front Range section-line study area, used in the [31] analysis, is shown by an outline.

During this same period, extensive research on methods of fire history reconstruction from fire scars and tree age structures led to improvements that enabled accurate estimation of fire rotation, the essential spatial measure of fire rates [47,48]. Earlier small-plot "composite fire interval" (CFI) methods, a primary basis for the low-severity model, created a pooled list of fire years from scars and then calculated mean, median, and other statistics from the list (e.g., [43]). However, these early CFI estimates, often called mean fire-return intervals (MFRIs), were further tested, found to overestimate rates of fires, and new, more accurate methods for small plots were derived [49–51].

Even more important, landscape-scale methods were also developed that do not depend on calculating intervals between fires in small plots. They instead use plots to simply detect and map fire-year occurrence, enabling the creation of landscape-scale fire-year maps (Figure 7) from which fire rotations can be directly estimated [15,52]. Inaccurate CFI methods were no longer needed. It also became possible to correct inaccurate CFI estimates to fire rotations via regression. This enabled historical fire rotations for low-severity fires to be estimated and shown across dry forests (Figure 8). This evidence alone, omitted in H, showed that frequent low-severity fire (rotations < 25 years) was found across only ~14% of historical dry forests [25]. Forest atlases, mapped in the early 1900s, provided another source of landscape-scale maps [44], showing historical moderate- to high-severity fires in the 1800s (Figure 9). These also validated GLO methods of fire-history reconstruction [33]. Artificial intelligence methods [16,53] also have made it feasible to expand fire history evidence from plots across large land areas (Figure 10).

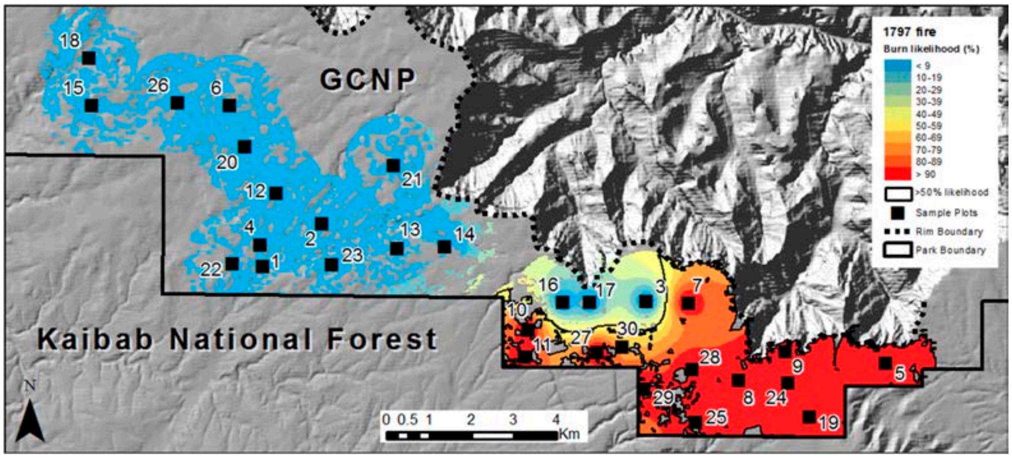

Figure 7. An example fire-year map for an 1829 fire on the south rim of Grand Canyon, Arizona. The reconstructed fire area was derived using inverse distance weighting based on plot records that showed where the fire did and did not burn. Reprinted from ([52] Figure S1) with permission from John Wiley and Sons.

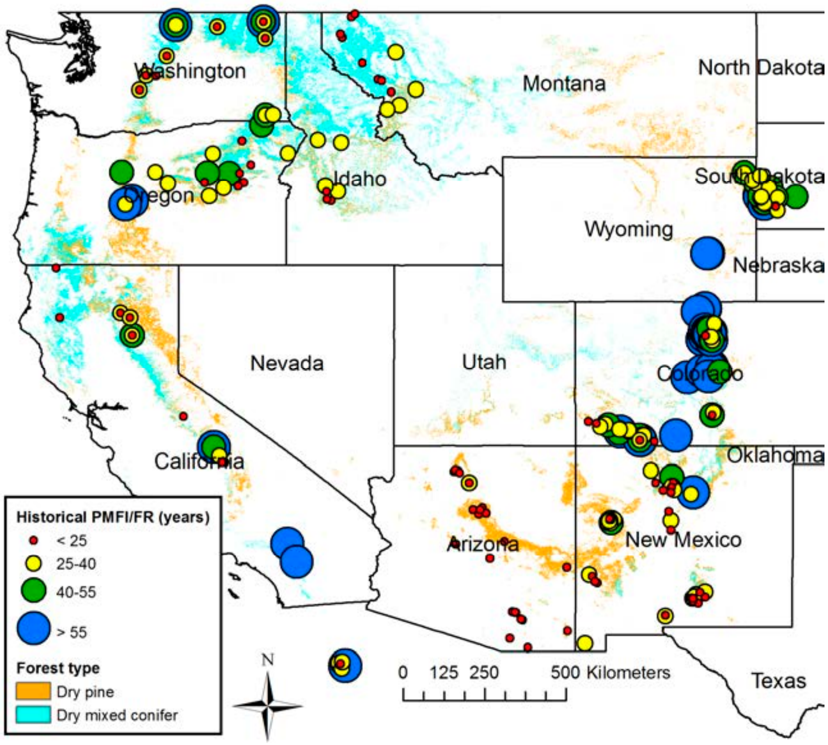

Figure 8. "Estimated historical low-severity population mean fire interval/fire rotation (PMFI/FR) for the combined set (n = 342) of calibration cases and prediction sites in dry forests of the western USA". Reprinted from [25] with permission from PLoS ONE.

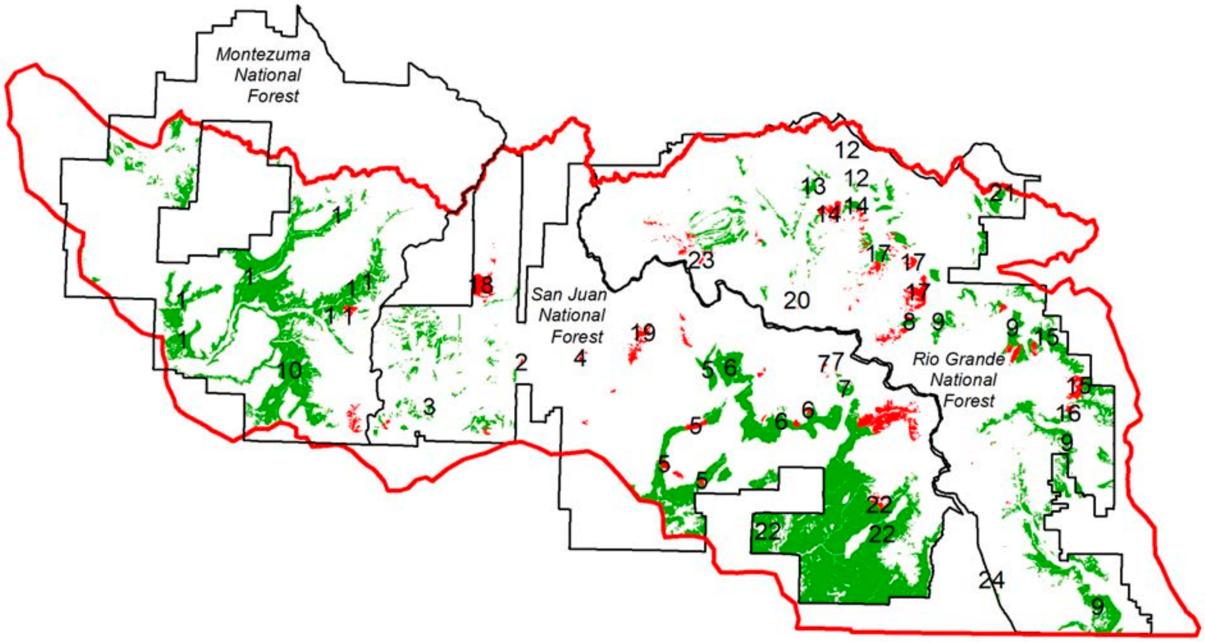

Figure 9. "The three atlas boundaries (black lines) and the fires (red) and woodlands (green) shown on the atlases with the area of ponderosa pine and mixed-conifer forests. Fires were likely mostly stand-replacing, and woodlands likely moderate- to high-severity fires, 1850–1909. Fire and woodland numbers are used in tables and text". The red boundary is the study area in the southwestern San Juan Mountains, Colorado. Reprinted from ([44] Figure 1b) with permission of MDPI.

H omitted this history of development of new fire history and forest structure reconstruction methods, correction of old fire history methods, and addition of new sources (Table 2), including findings of limited areas (14%) of frequent low-severity fire and extensive evidence of widespread mixed-severity fire with infrequent moderate- to high-severity fire and denser dry forests. H instead used (1) only the early inaccurate CFI estimates of fire rates, which are documented to overestimate rates of fire unless corrected [25,47], and (2) just two sources, tree-ring reconstructions and modeling, when there are multiple sources of evidence (Table 2). We show here that H omitted most evidence since the mid-1990s that improved fire history methods and understanding of historical dry forest structure and fire, showing more evidence of mixed-severity fires. Evidence in H omitted even their own authors' use of these new methods and their own findings of historically moderate- to high-severity fires and denser forests.

Given the large body of research and multiple methods (Tables 1 and 2) since the mid-1990s, evidence for the mixed-severity model of historically heterogeneous dry forests and mixed-severity fire has a sufficiently compelling evidence basis to qualify as an established model. Before the advances since the 1990s, there was also evidence in support of the low-severity model that historical dry forests were more uniform, low-density forests with predominantly low- to moderate-severity fire. H, for the first time, synthesized evidence against the mixed-severity and in support of the low-severity model.

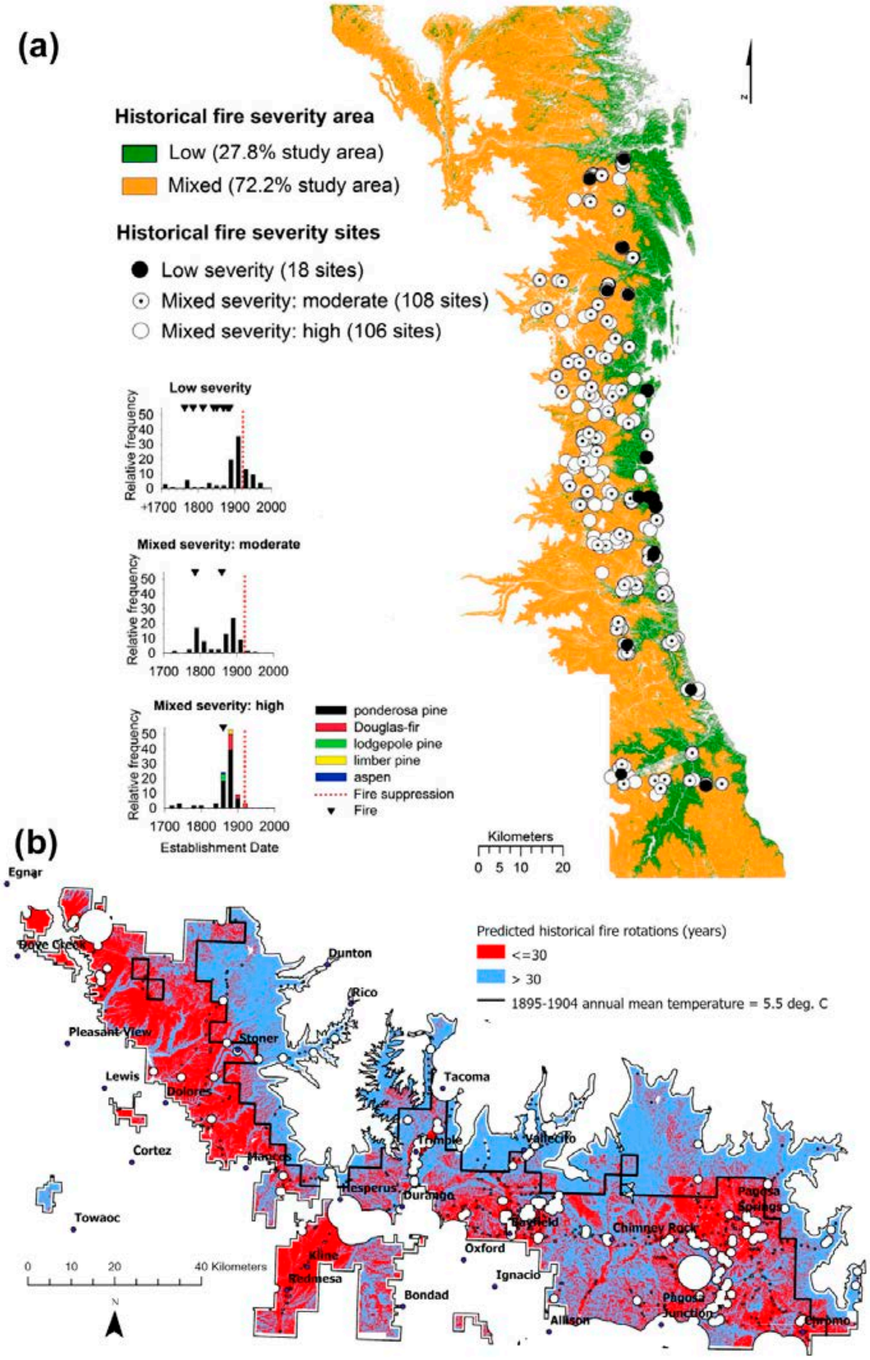

Figure 10. (**a**) "Distribution of 232 sites with historical (pre-1920) evidence of low-severity and mixed-severity fires." This is a map of the montane zone in the Colorado Front Range, showing on the left the evidence used to classify the fire regime into low or mixed severity at three example sites. The map shows the result of using classification and regression trees (CARTs) to extrapolate from classified sites to map the two fire regimes across the whole landscape using physical predictors (e.g., elevation and slope). Reprinted from ([16] Figure 5) with permission of PLoS ONE, (**b**) "Relatively frequent fire (all-severity fire rotations ≤30 years) versus longer-rotation fire in historical montane forests overlain by the contour for 5.5 °C annual mean temperature between 1895 and 1904, which roughly corresponds with the upper limit of relatively frequent fire". This map was derived by using random forest modeling of 28 tree-ring-based fire history sampling sites versus 14 topographic, soils, and climate predictors. Reprinted from ([53] Figure 5a) with permission of John Wiley and Sons.

3. Debunking H's: "Fire Regimes Are Significantly Departed"

H presented in their Table 2 [3] (pp. 14–15) a list of 14 publications they claimed show that "high-severity fire effects in recent fires exceed the pre-fire exclusion range of historical variation in landscapes historically dominated by frequent low- and moderate-severity fires." If this were true, it would imply that recent wildfires are too severe and warrant substantial active management via fuel reduction as claimed, but this is not the case, as all but 3 of the 14 publications were inadequate in area or data. The three adequate ones found the opposite: high-severity fire was occurring at or below historical rates.

To have an adequate sample area for this question, study areas need to be several times larger than the largest recent fires, which means generally on the order of 250,000 ha or more [4], because if only one or a few fires nearly fully burned an area, then $n = 1$ or a small number, and the sample is inadequate. Of the 14 cited studies, 1 was just a review, 8 had inadequate sampling areas <25,000 ha, and another [54] contained no evidence about historical fires. Nigro and Molinari [55] did not even report the area burned at high severity, so their finding was unusable. A total of 11 of 14 studies (79%) cited in H had an inadequate area or lacked necessary area-burned data. The remaining 3 studies [56–58] had study areas ≥250,000 ha and reported area burned, meaning ample sample area and data.

These three studies found that high-severity fire was recently burning at similar or lower rates than historically, not at higher rates recently, as reported in H: (1) Reilly et al. [56] found that the 1985–2010 high-severity fire rotation in ponderosa pine forests was 1693 years vs. historical 705–849-year rotations, so the recent high-severity fire rate was deficient relative to historical rates; (2) Haugo et al. [57] did not calculate fire rotations, but area-burned data in their Table 4 (32 years/(337,000 ha Obs./6,400,000 ha Extent)) show that the 1984–2015 high-severity fire rotation was 608 years in Group 1 forests, which include ponderosa pine, relative to a historical 226-year mean return estimate for the ten forest types in Group 1. Haugo et al. [57] (p. 9) summarized these results as follows: "We also found smaller, and in some instances no, deficits of moderate and high-severity fire in FRG1 forests . . . ". This indicates that high-severity fire rates were near or low relative to rates under the HRV; (3) Mallek et al. [58] also did not calculate fire rotations, but their data show that the 1984–2009 high-severity fire rotation was 413 years in yellow (ponderosa) pine (their Tables 1 and 3: 1/(3727 ha AAHS/1,540,923 ha Extent)) and 695 years in dry mixed conifer (1/(1061 ha AAHS/737,759 ha Extent)). They also reported these rates to be "within the range of the corresponding pre-settlement estimates" [58] (p. 9) and stated that "Modern regional rates of burning at high severity exhibited comparatively little or no departure from their pre-settlement levels in lower and middle-elevation forests" [58] (p. 11). In conclusion, only 3 of 14 publications cited in H had adequate sampling area and data; all 3 showed that high-severity fires in dry forests had burned recently at long rotations (413, 608, 695, and 1693 years) directly reported by 2 of 3 authors to have burned at rates longer than or within the range of high-severity fire rates under the HRV.

Evidence in H omitted findings from the largest study (25.5 million ha) of recent vs. historical rates of high-severity fires, covering nearly all dry forests of the western USA [4]. H included this study in their "Literature Cited", but there was no citation or use of this study in H's text, just a listing in their tables. This largest study showed that high-severity fires had burned between 1984 and 2012 in western USA dry pine forests at rotations from 470 to 15,043 years (mean = 1045 years) in 23 analysis regions averaging 547,982 ha in area and totaling 12.6 million ha. Additionally, high-severity fires in this period had burned in dry mixed-conifer forests at rotations from 212 to 7909 years (mean = 875 years) in 20 analysis regions averaging 645,960 ha and totaling 12.9 million ha. These means and ranges of recent fire rotations were similar to, or longer than, historical high-severity fire rotations, which ranged from 217 to 849 years, in 42 of 43 the analysis regions, except 1 region in southern California dry mixed conifer. The 217- to 849-year historical range is based on reconstructions from paleo-charcoal, land-survey, and aerial-photo reconstructions for 18 study areas covering millions of hectares. Conclusions from all four studies with adequate samples [4,56–58] were the same: recent high-severity fire rates are not higher than under the HRV.

It is important to mention that one measure, high-severity fire area as a percentage of total burned area, does not provide a valid estimate to judge whether "high-severity effects" . . . "exceed the pre-fire exclusion range of variation" in H's title for their Table 2. It is widely known, and shown by data in the studies H cited, that suppression of fires, since the end of the pre-industrial period, reduced low- to moderate-severity fires in dry forests. Mallek et al. [58] (p. 16) explained:

> " . . . nearly the only fires that reach any size are those that escape control under severe climatological conditions, in heavy fuels, and/or in inaccessible topography . . . Since almost all fires occurring under moderate conditions are put out, areas burned by wildfire in the contemporary study area suffer a statistical predisposition to burn at higher severity. This is especially evident in lower and middle elevation forests like yellow pine and mixed conifer . . . "

The four studies show that more area is not burning annually at high severity in recent periods than burned annually at high severity in historical periods in dry forests. Suppressing low- to moderate-severity fires thus did not increase high-severity fires in dry forests. Adequate evidence in H's Table 2 and the omitted study [4] shows the opposite of the table heading, as there are no "high-severity effects" that "exceed the pre-fire exclusion range of variation".

In conclusion, the assertion in H that "high-severity fire effects in recent fires exceed the pre-fire exclusion range of variation" (H Table 2 title) is rejected. Evidence from the three studies with adequate sample areas and data [56–58] agrees with evidence from the larger study [4] omitted in H. Recent rates of high-severity fires are too low or within HRV. Evidence from the four studies shows that what is needed to restore historical fires in dry forests and adapt forests to climate change is just to increase low- to moderate-severity fires. Expanding fuel-reduction treatments, proposed in accompanying policy proposals [22,23] that are based on H, aim to reduce high-severity fires. This would generally be ecologically deleterious, if successful. Reducing fires that are burning at or below historical rates has many effects similar to the effects of intentional fire suppression, which is still occurring but is widely accepted to be ecologically damaging to dry forests.

4. Debunking H's "Evaluating Evidence of Lack of Change"

H presented ~37 critiques in a section on "Evaluating evidence of lack of change" divided into two parts: "Misrepresented historical forest conditions" and "Misrepresented fire regimes." We also divided our text here into these two sections. To facilitate the comparison of evidence in H and evidence reviewed here, we replicated Tables 3–6 in H and added the evidence omitted in H into a new column in each of the four corresponding tables here (Tables 3–6).

H summarized their critique in this section as:

> " . . . publications that suggest the preponderance of evidence misrepresents or overgeneralizes departures from active fire regimes. These publications then suggest that management actions aimed at recapturing the influence of abundant low- and moderate-severity fire lacks [sic] a sound ecological foundation. Over the past two decades, independent research groups have evaluated the methods and inferences proposed by these publications and documented multiple weaknesses. Despite demonstrated methodological biases and errors, new papers employing these methods, or results and conclusions derived from them, continue to pass peer review" H. (p. 16)

H did not cite any specific source that showed "evidence of lack of change", but it would not be our publications. We documented that significant adverse cumulative impacts are widespread in dry forests from logging, livestock grazing, fire exclusion, and fuel-reduction treatments (e.g., [7,45]). In their last section, H presented evidence of change. There (Section 3), we evaluated H's evidence and reported that change has occurred, particularly a reduction in low- to moderate-severity fires since the pre-industrial era, but not, through 2010–2015, increased rates of high-severity fires. It is unclear which publications H is referring to: "these publications then suggest that management actions aimed at recapturing the influence of abundant low- and moderate-severity fire lacks [sic] a sound ecological foundation." The major body of evidence in the 15 land survey reconstructions, omitted in H, in fact showed an average of 76.0% low- to moderate-severity fire across dry forests (Table 1). Furthermore, "Restoring and managing low-severity fire in dry-forest landscapes of the western USA" [25] provides updated rates and guidance on restoring missing low-severity fires.

4.1. H's "Misrepresented Historical Forest Conditions" Section Omitted Evidence

The "Misrepresented historical forest conditions" section in H is largely a critique of an established method (WB method) to reconstruct historical tree density and other forest structure measures from original land survey records [41] and an assertion that early timber inventories provide valid estimates of historical tree density. The WB reconstruction method has been used across 15 large landscapes in >2.5 million ha of dry forests (Table 1). This method provided extensive evidence that dry-forest landscapes were heterogeneous in structure (e.g., tree density and basal area) and included both sparse and dense forests, supporting the mixed-severity model.

As we show below in the next two sections, (Section 4.1.1), evidence showing the validity and accuracy of the WB method, omitted in H, does not support their claim that the WB method overestimates historical tree density, and (Section 4.1.2), rebuttals of critiques of the WB method, omitted in H, includes original and rebuttal evidence that early timber inventories underestimate, also omitted in H. To show details and implications of evidence omitted in H, we replicated Table 3 in H in our Table 3. We then added a column that shows how conclusions in H were incorrect because H omitted all evidence that validates the WB method and omitted evidence that early timber inventories are flawed, which is shown in original papers and rebuttals that H omitted.

4.1.1. Evidence Showing Validity and Accuracy of the WB Method, Omitted in H

With historical reconstruction methods (e.g., WB method), there is a need to evaluate evidence about the development of the method and validations against independent modern and historical sources. Validations are inherently multi-proxy evidence, which H cited as most valuable, yet are omitted in H. Here, we present and discuss key evidence, omitted in H, showing the high accuracy and validity of the WB method and its findings in reconstructing historical tree density: (a) evidence of development of the WB method relative to earlier methods, (b) modern and historical validations showing high accuracy of the WB method, and (c) independent multi-proxy evidence of variable density and dense forests. This entire body of multi-proxy validation evidence, including evidence in original papers, rebuttals, and other publications, was omitted in H.

- Evidence of development of the WB method relative to earlier methods, omitted in H

H suggested that the analysis presented by Cogbill et al. [59] is the correct analysis to use in evaluating the WB method, implying the WB method was not derived and tested properly: " ... valid methods exist for deriving estimates from spatial point patterns, such as GLO bearing trees" (p. 15). However, Cogbill et al. only tested older existing point-pattern measures, with no test of the WB method at all, and they did no testing in western dry forests, only moister forests in the Midwest. The study by Cogbill et al. is thus not relevant to the WB method. Cogbill et al. showed that old point-pattern measures typically have low accuracy, are biased, and require large sample sizes. These are known limitations that spurred the development of improved design-based estimators, including Voronoi-based estimators, that are more robust to a wide range of spatial patterns [60]. Williams and Baker [41] explicitly improved on older methods by developing Voronoi-based estimators for use in western dry forests. For comparison, Williams and Baker also tested older point-pattern measures in modern validations; they did generally perform poorly, were biased, and required larger sample sizes, just as Cogbill et al. [59] found. Williams and Baker [40,41] had already shown by the time of Cogbill et al. that their WB method was well derived, statistically sound [60], and overcame the limitations of methods reviewed by Cogbill et al. These motivations, advances, and published comparisons of the WB method were omitted in H.

Table 3. Hagmann et al. ([3] Table 3) about historical tree density is replicated in the left two columns about counter-evidence, except that citations are changed to match our reference list. Omitted rebuttals and other omitted published evidence omitted by H are added in the right column to show Hagmann et al. omitted published evidence and made incorrect conclusions as a result.

Counter-Evidence		**Evaluation of Counter-Evidence**		**H Omitted Rebuttals and Other Published Evidence also Essential to Evaluation of Counter-Evidence**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Williams and Baker [41] Baker and Williams [34]	Novel methods provide estimates of tree density from point data, i.e., General Land Office (GLO) records of bearing trees	Levine et al. [61,62]	Multiple existing plotless density estimators (PDEs) provided less biased estimates than the PDE developed by Williams and Baker [41], which overestimated known tree densities by 24–667% in contemporary stands	Omitted Rebuttal by Baker and Williams [63]	Levine et al. [61] incorrectly coded and applied the WB method, producing spurious results that had no bearing on the WB method.
				Omitted Rebuttal by Baker and Williams [63], Omitted evidence in Williams and Baker [41]	Levine et al. [62] corrected their flawed 2017 code in [61], but then in [62] used incorrect equations. Baker and Williams [63] used corrected equations with their code at their sites and showed the WB method worked well. Williams and Baker [41] had shown that Voronoi-based estimators work better than existing PDEs and do not overestimate in western dry forests.
		Knight et al. [64]	Methods supported by PDE sampling theory and multiple accuracy assessments further demonstrate the potential for misrepresentation of historical tree density by biased estimators used at resolutions substantially smaller than the minimum recommended for −50% accuracy	Omitted evidence in Williams and Baker [41]	Knight et al. [64] did not use or test the WB method at all. They used old point-pattern measures that Cogbill et al. [59] had already shown were inaccurate, require large samples, and underestimate. The WB method was designed to overcome these known limitations and had already been validated [41] to be able to accurately estimate tree density at the −518 ha scale in western dry forests.
Williams and Baker [24]	Historical forests were denser than previously documented	Johnston et al. [65]	Existing method for estimating tree density from point data [66,67] yielded densities less than half as large as estimates using Williams and Baker [41]	Omitted Rebuttal by Baker and Williams ([63] Appendix S1)	This study roughly estimated Voronoi-based tree density of 89.6 trees/ha for Johnston et al.'s sites, a modest error of 20% if a Johnston et al. estimate of 112 trees/ha is considered truth. This is within expected accuracy for the WB method [41]. Their estimate is not from a random sample and is too small to compare, as they did, with the mean for the whole WB study area, but is within one s.d. of the reconstructed historical mean [24] and so is congruent with historical variability, as found in the reconstruction.

Table 3. *Cont.*

Counter-Evidence		Evaluation of Counter-Evidence		H Omitted Rebuttals and Other Published Evidence also Essential to Evaluation of Counter-Evidence	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Williams and Baker [24] Baker [25,28,29,68]	Historical forests were denser than previously documented	Hagmann et al. [54,69–71], Collins et al. [72], Stephens et al. [73,74], Battaglia et al. [75], Johnston et al. [65]	Consistent with the finding that Williams and Baker [41] methods overestimate tree density (Levine et al. [61,62], Johnston et al. [65], and Knight et al. [64]), early timber inventory records and tree-ring reconstructions for the same study areas documented substantially lower tree densities than those estimated using Williams and Baker [41] methods	New evidence here	See above for why Levine et al. [61,62], Johnston et al. [65], and Knight et al. [64] do not show that the WB method overestimates tree density. Regarding early timber inventories, see the last line below. Battaglia et al.'s [75] study area was ~30 times WB's, a major scale-mismatch, and was based on sampling 97% in logged forests. There has been no validation that the method they used can accurately reconstruct historical tree density in their region, and there especially has been no validation of their method in heavily logged forests where evidence likely has been destroyed by harvesting and associated activities.
Hanson and Odion [76]	Managing for dense, old forest and high-severity fire is consistent with historical conditions	Collins et al. [77]	Fundamental errors compromise assertions about historical conditions including (1) inappropriate use of coarse-scale habitat maps and (2) inaccurate assumption that areas lacking timber volume in early inventories indicate past high-severity fire	Omitted rebuttal in Hanson and Odion [78]	Collins et al. [77] is not about tree density or forest density and did not belong in this table. However, Hanson and Odion [78] showed that (1) Collins et al. thought maps were wrong but missed that areas that were forested by 1992, having recovered from early high-severity fires, had burned again, and (2) Collins et al. had omitted including essential 1911 field survey notes that directly described high-severity fires.
Odion et al. [12], Baker [4,68], Baker and Hanson [17]	Spatially extensive early timber inventories and bias in their use and interpretation misrepresent historical conditions	Stephens et al. [73], Collins et al. [77], Hagmann et al. [18,54,71]	Fundamental errors compromise conclusions, including (1) the use of previously discredited methods (Williams and Baker [24]) to estimate tree density from GLO data as a baseline comparison; (2) incorrect assumptions about the methodological accuracy of early timber inventories; (3) inappropriate comparisons of studies of vastly different spatial scales, forest types, and diameter limits; (4) unsubstantiated assessment of bias in the locations of early timber inventories; and (5) unwarranted assumptions about vegetation patterns as indicators of fire severity	Omitted Rebuttal in Baker et al. [19]	Evidence in H omitted our rebuttal [19], where we showed that Hagmann et al. [18] did not contest Baker and Hanson's [17] key findings: (1) early two-chain-wide timber inventories, documented to underestimate, are unreliable and were abandoned by the 1930s, (2) comparisons between timber-inventory estimates and other sources showed it is timber inventory estimates that underestimate and need correction, (3) one-chain-wide inventories, if available data are used, could be fairly accurate, and (4) omission of immature conifers and non-conifers may lead to additional underestimation. In response, we revised our estimates of needed correction multipliers to 1.6–2.3. Hagmann et al. [18] still contended that inventories do not have biased placement, but we presented more evidence.

H also incorrectly implied that the WB method can only provide an accurate estimate over a very large land area, but this is just a known limitation of earlier methods, not a limitation of the WB method or an inherent property of land survey data. H incorrectly said " . . . the extremely low sampling density of this national land survey limits reliable estimates to the average forest density for a large area" [3] (p. 16). H listed some accuracies for large land areas (3000+ ha), but these are only from using the old, inaccurate, biased, point-pattern methods that require pooling data across large land areas [59]. Using the WB method, modern and historical validations (detailed below) showed that sample areas of

~518 ha in dry forests provide tree-density estimates with weighted mean errors of 19.3%. The WB method had already been well validated [40,41] as an advance over older methods that previously provided just one estimate for very large land areas [59]. Our conclusion from this updated evidence is that Cogbill et al. did not test the WB method, their study was about midwestern forests, and their study had no relevance to the WB method or its findings. All published evidence of higher validity and accuracy, from the development and testing of the WB method [40,41], was omitted in H.

- Modern and historical validations showing high accuracy of WB method, omitted in H

H did not mention or review substantial published evidence on the accuracy and lack of bias of the WB method from both modern and historical validations [24,28,29,31,34,40,41,63,68,79]. These validations documented considerable agreement with independent multi-proxy sources, something H had highlighted as strong evidence, but evidence in H did not include any of these highly relevant published validations.

In modern forests, the WB method's Voronoi estimators and 9 other existing estimators of tree density from land survey data were tested and compared in field validations at 499 section corners in dry forests in 3 states ([34] Appendix Table S1, [41]). The latest summary showed a weighted mean error of 19.3%, relative to plot estimates, using the WB method ([34] Appendix Table S1). As mentioned in the last section, nearly all other estimators, except the two new Voronoi estimators, including some tested by Cogbill et al. [59], were found to be significantly biased and underestimated modern tree density [41]. The WB method's Voronoi estimators are still validated as the most accurate, unbiased estimators of tree density for use with land surveys in modern dry forests in the western USA, but all this evidence was omitted in H.

In historical forests, evidence in H also did not cite or review published evidence ([34] Appendix Table S4) that the WB method is quite accurate in reconstructing historical tree density, based on specific and general cross-validations with multiple sources that also show high independent multi-proxy agreement. Specific cross-validations compare tree density from the six-corner reconstruction polygon, which intersects an alternative source location, with tree density at this source. Specific cross-validations at 18 source locations in Arizona, California, and Oregon had relative mean errors of 10.4–11.2% ([34] Appendix Table S4), much better than the 19.3% from modern validations. Relative mean errors were 9.6–10.7% in comparison with 12 tree-ring reconstructions, 10.0% in comparison with 2 early 1-chain-wide timber inventories, and 13.1% in comparison with 4 early permanent plots or other non-timber inventories. The WB method cross-validated well against multi-proxy historical sources, evidence that H said they especially valued, but all this evidence was omitted in H.

Published general cross-validations compared sets of mean tree densities from independent historical studies (imprecisely located so they cannot be overlaid) in or near reconstruction areas with tree-density reconstructions using the WB method for that area. For example, 19 tree-ring reconstructions across Arizona's Mogollon Plateau had a mean of 122 trees/ha, whereas the land survey reconstruction using the WB method had a mean of 141.5 trees/ha and a relative error of 16.0% ([34] Appendix Table S9). A recent compilation of 15 tree-ring reconstructions, early inventories, and land survey reconstructions for dry mixed conifer in the Southwest found a mean of 144.5 trees/ha [26], nearly identical to the WB method estimate for mixed conifer on the Mogollon Plateau of 144.3 trees/ha [24]. An author of H co-authored this publication showing the WB method works well [26], but this evidence was still omitted in H. Other general cross-validations [34] included Oregon's Blue Mountains (4 early inventories) with a relative error of 27.8%, Oregon's Eastern Cascades (2 early inventories and 2 tree-ring reconstructions) with a relative error of 14.2%, and California's western Sierra (18 early inventories and 1 tree-ring reconstruction) with a relative error of 6.0%. All this evidence was omitted in H.

These comparisons show that the implication in H, that the WB method overestimates historical tree density, is refuted. The WB method showed relative errors of only 6–28%

in validations across large land areas. The WB method's accuracy is also validated by cross-validations with multi-proxy evidence and independent compilations that H said they value. Yet, all this evidence of the accuracy of the WB method was omitted in H.

- Independent multi-proxy evidence of variable density and dense forests, omitted in H

H said they especially valued independent multi-proxy evidence, but again, all of it, supporting the mixed-severity model, was omitted in H. Baker et al. [35] reviewed evidence from 20 tree-ring reconstructions, forest reserve reports, and early scientific reports that dry forests in Rocky Mountain states had highly variable tree densities from 17 to 19,760 trees/ha. Baker ([29] Appendix Table A1) published nine quotes from early forest reserve reports and early scientific reports that historical dry forests in the eastern Cascades of Oregon varied in historical tree density, including some dense forests. Similarly, Baker [28] (Appendix A) published 47 quotes from early forest reserve reports and other scientific reports documenting that Sierran mixed-conifer forests in California were highly variable in density but typically dense. Additionally, Baker and Williams [63] published evidence from 30 independent early estimates of historical tree density in Sierran mixed-conifer forests in California that had a mean of 257 trees/ha and a standard deviation of 100 trees/ha, showing that these historical forests were highly variable in tree density and generally dense. H reported [3] (p. 16) " ... as Fulé et al. (2014) observed, existing research documented even greater heterogeneity in historical forest conditions, including higher densities, than were reconstructed from GLO data." A total of 8 authors of Fulé et al. [80] are also authors of evidence in H, which omitted this highly relevant independent evidence, including their own, from more than half of the 11 western states. Omitted evidence shows that historical dry forests varied in density and included substantial areas that were dense. This omitted independent multi-proxy evidence, alone, without using evidence from land surveys and the WB method, rejects the low-severity model in favor of the mixed-severity model.

4.1.2. Rebuttals of Critiques of the WB-Method, Omitted in H

H said that papers that used the WB method "have suggested that densities and fire severities of dry forests were higher and more variable than previously thought (Table 3) ... " [3] (p. 16), implying that WB-method estimates of tree density are erroneous and too high. H summarized evidence the WB method overestimates tree density, stating that "Density estimates based on Williams and Baker (2011) methods are also inconsistent with tree-ring reconstructions and early 20th-century timber inventory records for areas where the data overlap ... " [3] (p. 16) and also that "Dendrochronological reconstructions and early timber inventories demonstrate consistency with each other and with other independent sources" [3] (p. 16). We reviewed in the last section that published validations show that historical tree density reconstructions from the WB method are very consistent with tree-ring reconstructions where they overlap, also shown in a publication [26] that included an author of H, but all this evidence was omitted in H.

H's evidence (their Table 3) that WB method estimates of historical tree density are too high rests largely on their comments, on publications using the WB method, which were rebutted in publications omitted in H. Here, we review that this omitted evidence shows that (a) Levine et al. modeling and plot tests are incorrectly coded, (b) older point-pattern methods have lower accuracy than the WB method, (c) the WB method has evidence of scale-matched high accuracy, (d) original and rebuttal evidence shows that early timber inventories underestimate, and (e) the fourth entry in H Table 3 is misplaced and belongs in H Table 5.

- Levine et al. modeling and plot tests shown to be incorrectly coded, omitted in H

Evidence from Levine et al. [61,62] simulation modeling that the WB method overestimated tree density actually showed the WB method works well, but the modeling was incorrect. First, Levine et al. [61] incorrectly coded the WB method, an error that invalidated their study, as shown in detail in a section of Baker and Williams [34], omitted in H. Levine et al. [62] next used revised code in permanent plots and again reported overestimation by the WB method. However, our rebuttal, Baker and Williams [63], omitted in H, showed that Levine et al. [62] this time used incorrect equations. For their three sample sites, using their coding of the WB method, Baker and Williams [63] showed that if correct equations were used, relative mean errors were only 6.2%, 7.0%, and 25.9%, well within expected accuracy for the WB method [41]. Levine et al. [61,62] are listed incorrectly in H Table 3 and their text as evidence the WB method is wrong, but both Levine et al. studies are fatally flawed because of the use of incorrect code and equations. Baker and Williams [63] showed that, after correcting Levine et al. errors, the WB method worked correctly and accurately even in highly altered modern forests in tiny plots, well outside their geographical setting and historical landscape-scale design, strong evidence of robust validity. All this published evidence that the WB method works well was omitted in H.

- Older point-pattern methods lower accuracy than WB method, rebuttal omitted in H

H said two studies [64,65] that used land survey data showed that tree densities from the WB method are too low. However, the findings of low tree density in these two studies were from the application of older point-pattern methods [64,65], not the WB method. As noted in Appendix S1 in [63], if Johnston et al. [65] had used the WB method at their sites, we estimated a relative error of ~20%, within the expected error for the WB method. The methods they instead used have known lower accuracy than the WB method [41]. Neither Johnston et al. nor Knight et al. expressed any awareness of the significant limitation of the methods they used. However, these two studies also have no basis for claiming anything about the WB method, since they did not use or test the WB method at their sites. Evidence of the accuracy of the WB method, reviewed in Section 4.1.1, and the rebuttal [63] explaining this matter for the Johnston et al. study area, were both omitted in H. We explain, next, more about misinterpretation by Johnston et al.

- WB method has published evidence of scale-matched high accuracy, omitted in H

Critiques in the past, including several by these same authors, used a double standard on scale mismatches, as they do here again. H was concerned about mismatches in spatial scale in comparisons of a ~518 ha reconstruction polygon with a tree-ring reconstruction. This is just an inherent limitation of tree-ring reconstructions that their typically small plots produce scale mismatches with most other historical sources.

H was concerned about scale mismatches but did not cite, mention, or review evidence from the most closely scale-matched validations of the WB method, which are the modern validations performed in three states [41] that we reviewed in Section 4.1.1. These validations compared tree-density estimates from land-survey section-corner data with tree tallies in small plots placed over these same section corners [41]. These closely scale-matched comparisons showed the WB method has high accuracy. These closely scale-matched validations were omitted in H.

Although H critiqued smaller scale mismatches, they employed much larger scale mismatches as evidence against the WB method. Battaglia et al. [75] and Johnston et al. [65] were presented in H's Table 3 as showing the WB method overestimates tree density. Battaglia et al.'s study area is ~30 times that of the WB study area in the Front Range [24], and Battaglia et al. did not report estimates for just the WB study area portion, so this is a very large scale-mismatch. At most, only 6 of their 28 sampling points (21%) might occur in the WB study area. Johnston et al. [65] compared their tree-ring reconstructions in five small plots with the Williams and Baker [24] overall estimates for their 305,000 ha Blue Mountains study area. As explained in the Baker and Williams ([63] Appendix S1) rebuttal, " . . . Johnston et al. sampled and summarized Blue Mountains forests from only five clustered points covering the equivalent of perhaps 4 six-corner GLO pools, while our study sampled and summarized over a much larger area including over 500 six-corner GLO pools. Johnston et al. cannot validly infer from a small, nonrandom sample to the entire Blue Mountains landscape . . . " These are examples of a double standard in H; neither comparison H used is valid because of very large scale-mismatches.

One small source, such as Johnston et al. [65], does not provide a valid comparison, particularly since its estimate is within reconstructed HRV. Land-survey reconstructions using the WB method show variability was large, based on the coefficient of variation (CV), across historical dry-forest landscapes (Table 1). H cited Johnston et al. as evidence the WB method overestimates tree density. However, the Blue Mountains reconstruction [24] had a mean of 167.3 trees/ha (median 146 trees/ha) and an s.d. of 89.8 trees/ha, so Johnston et al.'s weighted mean of 112 trees/ha [63] is well within the HRV for Blue Mountain forests. Additionally, Johnston et al. used a method biased toward underestimation [41,59] and is not a statistically valid sample of Blue Mountain dry forests.

When comparing other sources, at much finer spatial scales, to the overall study-area estimates from land-survey reconstructions, it is only valid to do a "general cross-validation" [34] with findings from multiple sites in the reconstruction area. The first largest general cross-validation is (1) in California's western Sierra, where Baker and Williams [63] compared means, quartiles, and confidence intervals from 30 independent historical estimates of tree density with similar data from the Baker [28] land survey reconstruction. They found overlapping 95% confidence intervals for historical mean tree density (independent = 257 trees/ha and land surveys = 293 trees/ha), similarity in distributions, and 14% relative error if independent estimates are considered the truth. The second largest general cross-validation is (2) on Arizona's Mogollon Plateau, where the mean study area estimate was 141.5 trees/ha versus the mean from 8 tree-ring reconstructions of 122.0 trees/ha, with a relative error of 16.0%, assuming tree-ring reconstructions represent truth ([34] Appendix Table S9). This is multi-proxy evidence that shows the WB method accurately reconstructs historical tree density across large landscapes, omitted in H.

In summary, the fuller set of evidence reviewed here shows scale mismatches to be inherent limitations of comparisons with some methods of reconstruction (e.g., tree-ring reconstructions). H criticized some WB method validations for scale mismatches, but evidence in H used much larger scale mismatches, which shows that a double standard was used in H. Published evidence of high accuracy from our closely scale-matched modern cross-validations was omitted in H. All our published general cross-validations with multiple independent reconstructions in land-survey study areas, which show compelling independent, multi-proxy evidence that the WB method accurately reconstructs historical tree density across large landscapes, were omitted in H.

- Original and rebuttal evidence early timber inventories underestimate, omitted in H

H implied that tree-density estimates from the WB method are too high. H in their Table 3 said " . . . early timber inventory records and tree-ring reconstructions for the same study areas documented substantially lower tree densities than those estimated using Williams and Baker (2011) methods", implying that estimates from the WB method are in error. This conclusion is incorrect based on evidence in the original paper [17], evidence omitted in H, and evidence in the rebuttal [19], also omitted in H.

Early timber inventories using two-chain-wide strips failed early in modern evaluations and tests and later also in historical validations that found similar errors [17]. These inventories required visual estimation over too large a distance (2 chains or 40 m) to be accurate. Baker et al.'s [19] rebuttal of the Hagmann et al. [18] comment, which was omitted in H, confirmed that Hagmann et al. actually did not contest Baker and Hanson's [17] central findings about these early timber inventories, which we quote again here: (1) "early timber inventory data, particularly from two-chain-wide transects, were documented between 1911 and 1916 to underestimate and be unreliable and were abandoned and replaced by more accurate methods by the 1930s . . . " [17] (p. 2), (2) " . . . comparisons between timber inventory estimates and other sources . . . showed that it is timber inventory estimates, not other sources, that underestimate and need correction" [17] (p. 3), (3) " . . . one-chain-wide inventories, if all available data are used, could be fairly accurate, but further validation is needed . . . " [17] (p. 3), (4) quantitative estimates of immature conifer density and non-conifer trees "were not included in Stephens et al. (2015)" [17] (p. 3), and, if included, historical tree density " . . . was ~17 times higher than the 25 trees/ha reported in ponderosa pine, and ~7 times higher than the 75 trees/ha reported in mixed-conifer forests . . . by Stephens et al. (2015)" [17] (p. 3). This evidence, which Hagmann et al. [18] did not contest, was omitted in H.

Although Hagmann et al. [18] did not dispute the central findings of Baker and Hanson [17] that early timber inventory data substantially underestimate tree density and that 1.6–2.3 correction multipliers need to be used before reporting tree-density estimates, evidence in H omitted any mention of the rebuttal [19] and did not perform the necessary corrections. H still claimed that the study by Baker and Hanson [17] is among several papers where "Fundamental errors compromise conclusions, including . . . (2) incorrect assumptions about the methodological accuracy of early timber inventories" ([3] Table 3).

Regarding other points made by Hagmann et al. [18], (1) the rebuttal [19] showed that early inventory quality control records were not accuracy tests and did not correct erroneous estimates, (2) the rebuttal agreed that [17] had overestimated time available (more likely 15–30 min) for tallying trees in a transect, (3) the rebuttal updated ([17] Table 1) to address concern about matching tree species, sizes, and time periods, and (4) the rebuttal found that the needed correction multipliers for early timber inventory estimates were then 1.6–2.3, not 1.6–3.2, still large errors showing the need for correction multiplication of early timber inventory tree-density estimates, shown here in Table 7. Moreover, Baker and Hanson [17] and Baker et al. [19] did not discuss "assumptions" about the accuracy of early timber inventories as H put it in the above quote; they instead presented evidence, including documents, agency reports, and field tests, that showed that early timber inventories have low accuracy and need correction multipliers of 1.6–2.3 to estimate tree density. These are failures, not "assumptions" as H falsely characterized them, that led to government abandonment and replacement of early timber inventories by the 1930s [17,19].

Large underestimation bias by early two-chain-wide timber inventory estimates can be seen in other validations: (1) in comparing mean tree density from 3 early timber-inventory estimates (48 trees/ha) versus 19 estimates from independent sources (254 trees/ha) in the California western Sierra and (2) in comparing 2 early timber inventory estimates (67 trees/ha) versus estimates from 4 other independent sources (218 trees/ha) in the Oregon E. Cascades ([34] Appendix Table S9). These comparisons also document that it is only early timber inventories that substantially underestimate tree density, and it is only timber inventory estimates that need correction multipliers.

The papers that used two-chain-wide early timber inventories to estimate tree density and did not use correction multipliers, making their conclusions invalid, are in Table 7. Shown are the missing corrected estimates using 1.6–2.3 correction multipliers and corrections for missing non-coniferous trees and small trees in one case. What emerges from this evidence, after these corrections, is that the forests that received timber inventories often had historical tree-density estimates that were near the first quartile to the median tree density reconstructed from land survey data for these areas and thus are within the estimated HRV for tree density but have lower density (Table 1). We made the case [17,19] that areas that received timber inventories likely had concentrations of large trees that typically are less dense than in younger forests with smaller trees. Thus, the full set of available evidence, reviewed again here, shows that early records and reports had documented that timber inventories underestimate tree density, that correction multipliers of 1.6–2.3 must be applied, and that, if applied, these estimates may be congruent with independent estimates from other historical older forests with large trees, although these corrected estimates will be quite imprecise (Table 7). Evidence in H omitted all evidence, which Hagmann et al. [18] did not dispute, in both the original paper [17] and all evidence in the published rebuttal [19].

- The fourth entry in H Table 3 is misplaced and belongs in H Table 5

Collins et al. [77] is not about tree density or forest density and did not belong in this Table but instead in H Table 5. However, this is another case where H cited their own comment [77] on Hanson and Odion [76] but omitted the rebuttal of this comment by Hanson and Odion [78]. Hanson and Odion [78] showed that (1) Collins et al. [77] said maps were wrong, and therefore, the interpretation that forests had burned at high severity was wrong, but Collins et al. [77] just missed areas that were forested by 1992, having recovered from early high-severity fires and burned again after the early high-severity fires, and (2) Collins et al. [77] had omitted including essential 1911 field survey notes that directly described these high-severity fires. Both errors show that Collins et al.'s [77] critiques were incorrect, and Hanson and Odion's [76] remains valid, which is more evidence that does not support the low-severity model.

4.1.3. Conclusion—Historically Heterogeneous Tree Density and Dense Forests

We showed here that what H [3] (p. 16) called "multiple weaknesses" and " ... demonstrated methodological biases and errors" regarding land survey reconstructions of historical tree density using the WB method had already been shown, in original papers and in rebuttals omitted in H, to be false. H could have presented the evidence in these omitted original papers and rebuttals and then offered new counter-evidence, but they did not. H simply summarized their previous comments critical of the WB method and then omitted all evidence in published rebuttals of these comments and nearly all evidence in the original papers.

The WB method of reconstructing historical tree density from land survey data had been well validated, before the H review, to accurately estimate historical tree density, based on many closely scale-matched modern validations at section corners and through many specific and general historical cross-validations with independent multi-proxy evidence (Section 4.1.1). Abundant independent sources (not land-survey reconstructions) in more than half of the 11 western states agreed that historical dry forests were highly variable in tree density and included a substantial area of dense forests (Section 4.1.1). In contrast, early timber inventories, which H said closely match tree-ring reconstructions, were documented very early to produce estimates that were unreliable and far too low (Section 4.1.2), so these inventories were abandoned and replaced by the 1930s. H omitted this evidence that rejects the low-severity model, but supports the mixed-severity model.

4.2. "Misrepresented Fire Regimes" Section in H Omitted More Evidence

H began this section with a somewhat incorrect summary of publications cited in their Tables 4–6: "Counter-evidence publications have also posited that the high-severity component of contemporary wildfires is consistent with historical fire regimes." What was found and reported in publications using the WB method was that the proportion of high-severity effects on historical landscapes was higher than previously thought. Thus, some modern wildfires considered uncharacteristic are more likely within HRV. Subsequent research that used land survey data, paleo-charcoal data, and aerial photo evidence together did find [4], as reviewed earlier, that recent high-severity fire rates were within or below rates under the HRV.

4.2.1. Evidence about Low-Severity Fires Omitted/Misinterpreted in H Table 4

Evidence in the H Table 4 "Counter-premise" list (Table 4) mentions concern about past methods of estimating rates of historical low-severity fires. H said, "Counter-evidence" publications showed that historical rates of low-severity fires were not as frequent (short) as reported using "composite fire interval" (CFI) methods. Yes, as reviewed in the Introduction, this began with Baker and Ehle [47,48], who critiqued the theoretical basis of CFIs and ITFIs (individual tree fire intervals) for estimating the essential fire rate parameters of fire rotation (FR) and population mean fire interval (PMFI), which they showed to be equivalent estimators of historical fire rates across landscapes. They hypothesized that the true fire rate, PMFI/FR, may lie between a CFI estimate, which is too short, and an ITFI estimate, which is too long. Baker and Ehle hypothesized and presented evidence that the omission of origin-to-scar intervals, the inclusion of small fires, targeted sampling, and known decline in mean CFI as samples increase could together explain CFI estimates that are too short. H Table 4 cited studies that presented evidence defending against these concerns with CFI estimates (e.g., Van Horne and Fulé [81], Collins and Stephens [82], Brown et al. [83], and Stephens et al. [84]), but these studies did not analyze why CFI estimates are too short relative to PMFI/FR, as shown in Baker [25].

H Table 4 omitted citing and reviewing the much larger body of evidence in Baker ([25] S1 Text), where there is a detailed analysis, using 342 fire-history sampling sites, of all known hypotheses that could explain why CFI and ITFI estimates of PMFI/FR are inaccurate and biased toward intervals that, this study discovered, are both too short. These explanations included (1) overcompensation from the compositing process, (2) destruction of long fire intervals by compositing, (3) insufficient CFI restriction rules, (4) censoring causing loss of long fire intervals, (5) targeted sampling also causing loss of long fire intervals, and (6) unstudied fire severity inflating low-severity fire rates because some of the fires likely were not low severity.

As mentioned in the Introduction, even more important is that the H Table 4 column entitled "Implications of evaluation" omitted extensive new evidence about how much CFI and ITFI both underestimate PMFI/FR and how both now can be corrected to accurately estimate PMFI/FR [25]. Baker [25] used a 96-case calibration and analysis dataset from 44 fire history studies where both CFI and/or ITFI were calculated, or could be calculated, and could be compared with estimated PMFI/FR. CFI measures all produced estimates that were too short (biases of 38–72%) and were quite inaccurate (errors of 43–70%) in estimating PMFI/FR. ITFI measures also produced estimates that were too short but less so (biases of 3–28%) and also less inaccurate (errors of 16–33%). Most important, linear regression showed that historical PMFI/FR could be very accurately estimated from Weibull mean ITFI (RMSE = 7.52, $R^2_{adj} = 0.972$) and quite accurately ($R^2_{adj} > 0.900$) from eight other CFI/ITFI measures. These linear regressions (1) showed that all the CFI and ITFI measures and methods produced historical estimates that were too short and (2) enabled correction of all CFI/ITFI estimates to provide valid estimates of historical PMFI/FR at 342 sites across the western USA (Figure 8).

Fortunately, a new landscape-scale method has been developed and validated for directly estimating PMFI/FR using random or systematic plots in which all scarred trees are sampled, fire years are cross-dated, and individual fire years are reconstructed spatially from these plot data and then used to directly estimate PMFI/FR [15,51]. Baker [25] was able to find and use many of these spatial reconstructions, showing that the fire-year reconstruction method (e.g., Figure 7) is being used. This new landscape-scale method does not require further use of inaccurate CFI or ITFI estimates from small plots; thus, earlier debates over compositing, targeted sampling, etc., the focus of H's comments, are now of little to no interest, as science has moved on.

Improved plot methods could still be used but have lower accuracy than these newer landscape methods, and, at a minimum, require pooling over several plots, limiting their value. CFI and a new all-tree-fire-interval (ATFI) plot method [49,50] were tested in a modern and historical validation at the Grand Canyon [51], omitted in H. In these tests, ATFI outperformed all CFI measures. ATFI was always correct in modern tests at the plot scale and CFI mostly failed. In historical tests, ATFI had a mean relative error of 14.3%, and the best traditional CFI measure, scar-to-scar 25% filtered CFI, had a mean relative error of 35.3%. ATFI was thus superior to all other plot-scale methods. ATFI at the plot scale can possibly achieve errors <26.6%, but errors <20% require at least 4 plots over 600–1000 ha [51]. H's discussion of their Table 4 claimed that, "Additionally, as acknowledged by Kou and Baker (2006: Accessory Publication), ATFI will always be much longer than any MFI ... " [3] (p. 20). H thought this was a failing of the ATFI method, but this is because CFI estimates are always erroneously too short [25], and ATFI is longer and more correct [49–51].

Estimates from the new landscape-scale methods (e.g., Figure 8) and corrected estimates from regression [25] show (Figure 8) that frequent low-severity fire was less common historically than was thought in the 1990s when the early, inaccurate CFI estimates were all that was available. For 342 sites, the mean low-severity fire rotation was 39 years and the median was 30 years. Only ~14% of the dry-forest area, mostly at lower elevations in drier areas, had frequent fires (PMFI/FR < 25 years), and ~86% of the dry-forest area instead had multidecadal mean PMFI/FRs. In mountainous areas (Figure 8), landscapes often contained a wide range of low-severity fire rates. This is significant because PMFI/FR's ≥25 years will not generally keep fuels at low levels, as fuels can fully recover. This means that the idea that frequent fires kept fuel loads at low levels, and fires low in severity, was actually a condition found primarily only in limited areas, such as the driest areas in the Southwest and dry areas elsewhere at low elevations (Figures 8 and 10a).

Table 4. Hagmann et al.'s table ([3] Table 4) about rates of fire is replicated in the left two columns, with omitted published evidence added in the right column, to show Hagmann et al. omitted published evidence and made incorrect conclusions as a result.

Counter-Evidence		**Evaluation of Counter-Evidence**		**Published Evidence, Essential to Evaluation of Counter-Evidence, That Was Omitted**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Baker and Ehle [47,48], Ehle and Baker [14], Kou and Baker [49,50], Baker [25,85], Dugan and Baker [51]	Tree-ring reconstructions misrepresent historical fire regimes by overestimating fire frequency and extent because (1) unrecorded fires (e.g., fires that did not scar trees) increase uncertainty of mean fire interval (MFI); (2) interval between pith (origin) and first fire scar should be considered a fire-free interval and included in calculations of MFI; (3) targeted sampling of high scar densities biases MFI; and (4) mean point fire interval (mean of intervals between fire scars weighted by the number of fire scars) may more accurately represent historical fire rotation than MFI (mean between all fire scars)	Collins and Stephens [82]	Unrecorded fires (fire did not scar the tree) may contribute to underestimation, not overestimation, of fire frequency and extent in frequent fire systems. Probability of scarring decreased when intervals between successive fires were short in areas burned by up to four late-20th-century fires. Absence of scar does not indicate absence of fire.	Omitted evidence in Baker ([25] S1 Text)	It is generally agreed that each fire only scars some of the trees. However, with typical scarring fractions, only ~50 trees or ~1 ha need sampling to detect all the fires in a plot. In a sample of 262 reconstruction sites in dry forests of the western USA, 88% sampled ∃1.0 ha. Thus, underestimation from unrecorded fires is likely rare, and absence of a scar in a particular year likely does show lack of fire. A key problem with "composite fire intervals", the primary source of evidence about historical low-severity fire rates, is the compositing process itself. Compositing makes a single list of all fire years in the plot. This assumes all fires burned the whole plot, which is not true, based on 11 studies [47]. Putting small fires in a single list with large fires reduces the "mean composite fire interval" to a small value, leading to large overestimation of rates of fire. Small fires can be filtered, but filtering is arbitrary, and compositing still destroys the long intervals that were found.
		Brown and Wu [86], Van Horne and Fulé [81], Brown et al. [83], Stephens et al. [84], Yocum Kent and Fulé [87], Meunier et al. [88]	Including origin-to-first-scar interval erroneously inflates MFI. Not all trees that survive fire are scarred. As an ambiguous indicator of fire-free interval, it should not be included in calculations of MFI. Additionally, tree establishment may not indicate a stand-replacing disturbance in dry forests where regeneration is strongly associated with climate	Omitted evidence in Kou and Baker [49], Polakow and Dunne [89], Moritz et al. [90] Omitted evidence in Dugan and Baker [52]	Fire history data typically have incomplete intervals at the start and end of a period of record. Real but long fire intervals have more chance of appearing at the beginning or end, and getting left out, than do real but short intervals. Thus, censoring the starting or ending incomplete intervals biases the record toward estimates that are too short and have reduced variability [49], as found in two other independent studies [89,90]. There is no citation in the counter-evidence list that assumed tree establishment indicates stand-replacing disturbance in dry forests. Brown and Wu [86] incorrectly assumed that a fire scar before a pulse of tree establishment does not indicate moderate- to high-severity fire [52].

Table 4. *Cont.*

Counter-Evidence		**Evaluation of Counter-Evidence**		**Published Evidence, Essential to Evaluation of Counter-Evidence, That Was Omitted**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
		Fulé et al. [91] Van Horne and Fulé [81], Farris et al. [15,92], O'Connor et al. [93]	Complete, systematic (gridded), and random sampling at stand, watershed, and mountain range scale have repeatedly demonstrated fire frequencies similar to those derived from targeted sampling within forest types and scales. In direct comparison studies, no evidence was found that targeted sampling of fire-scarred trees biased MFI estimates. Targeted sampling reconstructed fire parameters comparable to those derived from systematic sampling of both a subset of the trees and all trees in a study area and from independent 20th-century fire atlases	Omitted evidence in Baker ([25] S1 Text)	Evidence cited in H in Farris et al. [92] and in Van Horne and Fulé [81] is not correct. Farris et al. instead found that using a targeted sample led to CFI estimates that were shorter (80–96%, comparing targeted and probabilistic sample size corrected in their Table 3) than that from a statistical sample. Van Horne and Fulé found that a targeted ITFI estimate was only 83% (inverse of 1.2 from p. 865) of ITFI from a random sample. These studies thus show that targeted samples produce CFI/ITFI estimates that are shorter than estimates from random samples.
		Farris et al. [15] Huffman et al. [94]	Rather than overestimating fire frequency as suggested in counter-premise papers, MFI may underestimate fire frequency, especially where small fires were abundant	Omitted evidence in Baker [25]	MFI as used in H is just composite fire interval (CFI), which has the well-established property of producing estimates that are too short relative to fire rotation, the gold standard, as shown in this monograph on this topic, which was omitted in H
		Van Horne and Fulé [81] Farris et al. [92]	Composite mean fire intervals (CMFI, e.g., fires recorded on 25% of samples) are relatively stable across changes in sample area or size. See the section on "Underestimated historical fire frequency" for a more detailed summary of CMFI and the highly problematic and inherently biased alternatives proposed in counter-evidence publications	Omitted evidence in Baker [25]	CFI estimates do vary with sample size, but they also definitely produce estimates that are too short relative to fire rotation, the gold standard, as shown in this monograph on this topic, which was omitted in H

In summary, H used out-of-date, inaccurate, biased methods of reconstructing historical rates of fire, and mentioned old arguments about these CFI methods that are no longer of interest, but omitted that these dated CFI measures and small-plot methods have been replaced by newer, more accurate PMFI/FR measures and spatial reconstruction methods. Also omitted in H is that 342 dated, inaccurate estimates have been corrected to new PMFI/FR estimates using regression, and corrected estimates show that historically frequent low-severity fires only dominated in ~14% of the dry-forest area [25]. This large, significant body of evidence, which does not support their model, that low-severity fires dominated and were frequent across dry forests, was omitted in H.

4.2.2. Evidence about Historical Fire Severity Omitted/Misinterpreted in H Table 5

In this section, which is about H Table 5, we show that H's low-severity fire model is based on more false and omitted evidence, in this case about historical fire severity: (a) published validations of WB-method fire-severity reconstructions vs. independent multi-proxy sources in both modern and historical forests, (b) abundant independent, multi-proxy evidence of historically severe fires, including tree-ring reconstructions and evidence in H's own publications, (c) incorrect use of fire scars and age structures omits the role of historically severe fires in H, (d) evidence that historical dry forests, in general, lacked high-severity fires falsely based on tree-ring reconstructions of fire targeted in old growth, where high severity is inherently rare, (e) Baker et al.'s [19] rebuttal of Hagmann et al. [18] on high-severity fire, omitted in H, (f) Odion et al.'s [95] rebuttal of Stevens et al. [96], showing FIA data still can reconstruct fire severity, omitted in H, and (g) rebuttal, new evidence of historically large high-severity fire patches, omitted in H.

- Published validations of the WB-method fire-severity reconstructions vs. independent multi-proxy sources in both modern and historical forests, omitted in H

Williams and Baker [24] calibrated and then validated their fire-severity reconstruction method using information directly from tree-ring reconstructions or direct measurements from historical forest plots where fire severity had been assessed. Methods were directly calibrated using 55 estimates from areas where low-severity fire was dominant and from 9 areas where mixed- or high-severity fire was dominant. The calibrated definitions and methods correctly predicted fire severity at all the low-severity sites and all but 1 of the higher-severity sites, which was incorrectly assigned low severity as the high-severity event occurred 300 years ago.

For historical cross-validations with independent sources, Baker and Williams [34] reported that "For historical fire severity, 10 specific cross-validations in six study areas in four states had high mean accuracy of 89.1–90.1%, based on PSC . . . " [34] (p. 288), with the individual cross-validations listed in their Appendix S1 Table S7. PSC is percent similarity in composition. Additionally, Baker and Williams [34] reported that "There is substantial corroborating evidence that moderate/mixed-to-high-severity fires occurred and were extensive in some areas, based on evidence for five study areas in four states . . . These include 99 quotes from early forest reserve and other reports, four tree-ring reconstructions, two paleo studies, and two using early photographs." This evidence was presented in detail in their Appendix S1 Tables S1 and S11 in [34], but was omitted in H.

Furthermore, Williams and Baker [31] validated the use of survey section-line data to characterize the modern moderate- to high-severity fire regime in the Colorado Front Range (Figure 6) and then analyzed 6904 km of historical section-line records and found a historical higher-severity fire rotation of 249 years. This estimate is similar to, and independent of, the WB method estimate (271 years) from Williams and Baker [24] for part of this area, further validating the WB method. Also important is that this is independent, direct surveyor-recorded evidence of historical moderate- to high-severity fires in historical dry forests, which does not use the WB method that H critiqued. All this evidence was omitted in H.

- Abundant independent, multi-proxy evidence of historically severe fires, including tree-ring reconstructions and evidence in H's own publications, omitted in H

The authors of H previously omitted evidence of historically severe fires in dry forests, the start of a pattern of omission of evidence. Fulé et al. [80], among whom were eight authors of H, said:

> "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 . . . ". [80] (p. 826)

Williams and Baker's study [24], which they were critiquing, had, in fact, summarized direct documentary evidence of high-severity fires in their study areas in AZ, CO, and OR in this very publication ([24] Appendix S1). This evidence included early journal articles from the turn of the century, forest reserve reports by government scientists, analysis of early aerial photographs, tree-ring and fire scar studies, and paleo-charcoal reconstructions. All this evidence was omitted in Fulé et al. [80] and also omitted in H.

Early aerial photographic evidence of historically severe fires across 178,902 ha of mixed-conifer forests in eastern Washington and Oregon was published by Hessburg et al. [11], another author of H. However, as noted in Section 2, H remarkably omitted any review of the extensive evidence in this publication (e.g., Figure 4). A quote from this paper, also summarizing this omitted evidence, is reproduced in Section 2. Yet another author of H in Merschel et al. [97] thought "the wave of tree establishment that began in ~1900 . . . was likely caused by a variety of factors, including changes in fire regimes, selective tree harvesting, and domestic livestock grazing" [97] (p. 1684), but rejected Baker's [29] finding that moderate- to high-severity fires occurred in the late 1800s, explaining that "it would require moderate- to high-severity fires occurring over an immense area . . . before 1900. Such fires are not recorded in written archives or tree-ring records from the region." [97] (p. 1684). However, Baker ([29] Supplemental Materials Appendix A) presented evidence from written archives in early forest-reserve reports and other scientific reports of extensive high-severity fires in the late 1800s in and near Merschel et al.'s study area, evidence omitted in Merschel et al. [97] and in H.

A large body of independent evidence of historical mixed-severity fires, mentioned in other sections, was also omitted in H. Baker et al. [35] published 43 quotes from ca 1900 forest reserve reports from throughout the Rocky Mountains that showed a diversity of historical fire severities, including abundant evidence of moderate- and high-severity fires. Baker [45] published six early photographs of the aftermath of severe fires in dry forests in the Rocky Mountains, one reproduced here (Figure 3a). Baker ([28] Appendix A) published 208 quotes from early forest-reserve reports and other early scientific reports that documented historical moderate- to high-severity fires in Sierran mixed-conifer forests, including evidence that these fires burned extensive mature forests (Figure 5). Baker [32,33,44] documented that large moderate- to high-severity fires in the late 1800s occurred in dry forests on the Uncompahgre Plateau and in the San Juan Mountains, Colorado. This was based on forest atlases, early photographs, early scientific publications, and other early historical records, including newspaper reports. Figure 2b shows extensive dense tree regeneration after severe fires on the Mogollon Plateau in the late 1800s. All this independent evidence was omitted in H.

H said that " . . . fire scar records remain a primary means of exploring historical ecology" [3] (p. 8) and only used these records and modeling as their basis for evaluating changes in fire. However, there have been ≥18 tree-ring reconstructions that found evidence of moderate- to high-severity fires in historical dry forests, several of which were by authors of H. Many of these fire-scar studies, which found severe historical fires, were already reported in Odion et al. [12], including 6 published studies from the southern Cascades and Sierra in California, 1 from British Columbia, 10 from the Rocky Mountains (e.g., Figures 3b and 10a), and 2 from the Southwest. Others include Wu [98] and Tepley and Veblen [99] in the San Juan Mountains. Remarkably, again, H did not cite or review Brown et al. [100] and Huckaby et al. [101] from the Colorado Front Range, which included an author of H and together documented severe historical fires in dry forests. H also did not cite Taylor and Skinner [102], which included another author of H and showed tree-ring evidence of moderate- to high-severity fires in dry forests in the Klamath Mountains, California. The idea that there are no independent tree-ring reconstructions of historically severe fires in dry forests has been incorrect for over two decades. All this evidence, including studies by authors of H, was omitted in H.

H also did not cite or review that there have been seven paleo-charcoal studies that found evidence of severe fires in the last 500–600 years in dry forests, cited in Table 1 in Baker [4] with his estimates of fire rotation. These include studies by Long et al. [103] from the eastern Cascades, Oregon (estimated fire rotation = 333 years), Fitch [104] from northern New Mexico (~500 years), Pierce et al. [36] and Pierce and Meyer [37] from central Idaho (154–286 years, mean = 220 years), Jenkins et al. [105] from northern Arizona (250 years), Bigio [106] from southwestern Colorado (>471 years), and Colombaroli and Gavin [107] from southern Oregon (500 years). The overall estimated high-severity fire rotation from these studies, cited in Baker [4], had a mean of ~379 years and a range of 154–500 years. The mean is 515 years, and the range 217–849 years from eight land-survey reconstructions [4]. Both sources, which are independent, document and validate each other in showing that infrequent high-severity fires occurred historically in dry forests. All this independent evidence was omitted in H.

The repeated idea that there are no independent records of historically severe fires in dry forests is clearly incorrect. These records have been known since the early 1900s and reported by us and other authors since the 1990s, including in reviews by Odion et al. [12] and Hanson et al. [13], several land-survey reconstructions (Table 1), and other papers. Evidence from eight authors of H earlier in Fulé et al. [80] omitted a large body of evidence of historical moderate- to high-severity fires. Evidence in H again here omitted all evidence from early forest-reserve reports and other early reports, analysis of early aerial photographs and early oblique photographs, landscape-scale tree-ring reconstructions, forest atlases, newspaper reports, and paleo-charcoal reconstructions, including studies by authors of H. This evidence alone is more than sufficient, without land survey reconstructions using WB methods, to reject the low-severity model and support the mixed-severity model.

- Incorrect use of fire scars and age structures omits role of historically severe fires in H

In H Table 5, the citation of Brown [108] as a counter to Shinneman and Baker [10] repeats an incorrect interpretation of evidence by Brown [108]. Prior to Brown [108], Brown et al. [100] and Huckaby et al. [101] studied fire history in the Colorado Front Range. Trees that died about the time of a dated fire and abundant trees that regenerated after a dated fire provided evidence of high-severity fire, as also shown in Figure 3b. However, a little later, Brown and Wu [86] found the same evidence yet interpreted tree regeneration pulses as having an unknowable disturbance cause, but instead regional climate forcing: " . . . cohort structure is uncoupled from any single mortality event and instead appears to be the result of broader scale climate forcing of fire timing that resulted in successful recruitment episodes" [86] (p. 3036). This is not a valid inference, as right before the tree-regeneration pulses was strong evidence of fire, which was not excluded as a cause of post-fire tree regeneration. The flaw in the Brown and Wu [86] interpretation is that disturbance history and climate history can be confounded; to determine the effect of one, the other must be controlled, which Brown and Wu did not do. It is not possible to validly conclude climate forcing alone was the cause without showing fire was not the cause of tree regeneration pulses; more likely, both contributed, with fire being the primary cause.

The next year, Brown ([108] Figure 3) showed the same evidence that should have led to the recognition of confounding and the possible role of high-severity fire, as interpreted earlier [100,101], but Brown said "Abundant synchronous tree recruitment affected by optimal climate forcing is probably the reason for extensive stands of even-aged forests in the Black Hills, rather than widespread crown fires . . . " [108] (p. 2507). However, Brown [108] provided no explanation for how trees present before this period were all killed so that regenerating stands became even-aged. If trees had not been mostly killed prior to a pulse of tree regeneration, resulting stands would not have been even-aged but instead multi-aged. Evidence of a fire and this logic effectively excludes climate forcing by wet periods as the sole cause of regeneration pulses. Again, the more likely explanation was not analyzed, which is that moderate- to high-severity fires, followed by a climate favorable for regeneration, produced the evidence presented in Brown ([108] Figure 3). Failure to exclude a confounded variable, fire, before assuming climate forcing as the sole cause, has been a repeated error, as also made by O'Connor et al. [109].

The climate forcing model of tree recruitment pulses was not supported in a key test. Dugan and Baker [52] directly tested whether fires, fire-quiescent periods, droughts, or pluvials, in some combination or permutation, had separate or combined influences on the occurrence of historical tree recruitment pulses in ponderosa pine forests in Grand Canyon National Park, Arizona. The conclusion was:

> "Permutation analysis showed that mortality-inducing influences of fire and drought played the primary role in initiating pulses as they occurred first for 90% of pulses, significantly more than expected . . . drought was the most important single initiator . . . as the first influence for 65% of pulses. Mixed-severity fire was the initial influence for 30% of fires . . . none of the 20 pulses had a pluvial influence alone". [52] (p. 704)

Table 5. Hagmann et al.'s ([3] Table 5) about severity of historical fires is replicated in the left two columns, with omitted published evidence added in the right column, to show Hagmann et al. omitted published evidence and made incorrect conclusions as a result.

Counter-Evidence		**Evaluation of Counter-Evidence**		**Omitted Rebuttals and Other Published Evidence also Essential to Evaluation of Counter-Evidence**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Shinneman and Baker [10]	Based on early forest inventory age datasets, "nonequilibrium" areas of extensive, high-severity fires in the Black Hills led to landscapes dominated by dense, closed-canopy forests	Brown [108]	Tree-ring reconstructions of ponderosa pine forest age structures and fire regimes across the Black Hills found synchronous regional tree recruitment largely in response to pluvials and longer intervals between surface fires, especially during the late 1700s/early 1800s, which is when early inventory data report similar patterns of recruitment. No evidence of crown fires was found in relation to past fire dates	Omitted evidence in Brown [108], Dugan and Baker [52]	Brown [108] said " . . . dense stands were still present at settlement . . . , and likely contributed to extensive patches of crown fire noted by early explorers and scientists during the late 1800s (Dodge 1965, Graves 1899)" (p. 2509). This is entirely consistent with early reports of severe fires across the Black Hills by Graves and Dodge [10]. However, Brown [108] (p. 2507) also interpreted "abundant synchronous tree recruitment" as caused by climate forcing (e.g., wet periods), without excluding these high-severity fires as also a cause. The lack of control of this potentially confounded causative variable leaves Brown's conclusion invalid. A test of Brown's conclusion at the Grand Canyon did not support his findings [52].
Baker et al. [35]	Most ponderosa pine forests in the Rocky Mountains were capable of supporting high-severity crown fires as well as low-severity surface fires	Brown et al. [83]	Tree-ring reconstruction of ponderosa pine forests in the Black Hills of South Dakota (included in Baker et al., 2007) demonstrated that roughly 3.3% of the study area burned as crown fire between 1529 and 1893; however, tree density in most stands in 1870 could not have supported crown fire	Omitted evidence in Baker [25], Baker et al. [35]	This review [25] emphasized that the historical fire regime in the Rocky Mountains included variable fire severities with some areas having mostly low severity in old-growth forests. The 517 ha Mount Rushmore area of [83] is consistent with this review. Additionally, old growth inherently exists because it lacked high-severity fire for long periods, so it is impossible to draw valid conclusions about larger land areas from these old forests, since they are not random samples of larger land areas [25].
Williams and Baker [24], Baker [28,29]	Fire severity inferred from tree density by size class estimated from GLO bearing trees [41] and surveyors' descriptions suggests low-severity fire dominated only a minority of ponderosa and mixed-conifer forests	Levine et al. [61,62]	Plotless density estimator used by Williams and Baker [41] overestimated known tree densities due to a scaling factor that does not correct for the number of trees sampled and therefore systematically underestimates the area per tree relationship	Omitted Rebuttals by Baker and Williams [34,63]	Levine et al. [61] incorrectly coded and applied the WB method, producing erroneous results that had no bearing on the WB method. Levine et al. [62] corrected their flawed 2017 code [61] but then used incorrect equations. Baker and Williams [63] used corrected equations with their code at their sites and showed that the WB method worked well and that both Levine et al. studies are fatally flawed.

Table 5. *Cont.*

Counter-Evidence		**Evaluation of Counter-Evidence**		**Omitted Rebuttals and Other Published Evidence Also Essential to Evaluation of Counter-Evidence**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Williams and Baker [24], Baker [28,29]	Fire severity inferred from tree density by size class estimated from GLO bearing trees [41] and surveyors' descriptions suggests low-severity fire dominated only a minority of ponderosa and mixed-conifer forests	Fulé et al. [80], Merschel et al. [97], O'Connor et al. [109]	Substantial errors of method and interpretation invalidate inferences about historical fire severity. These include the fact that (1) tree size is an ambiguous indicator of tree age; (2) tree regeneration is an ambiguous indicator of disturbance severity, particularly in dry forests where climate conditions strongly influence regeneration; and (3) lack of direct documentary evidence (e.g., primary observation) of extensive crown fire in historical ponderosa pine forests has been widely noted for nearly 90 yr.	Omitted Rebuttal in Williams and Baker [79], Omitted evidence in Baker [4,25,28,29]	Williams and Baker [79] showed that Fulé et al. [80] mistook the WB method, misquoted WB, misused evidence, and created three new false narratives. Merschel et al. [97] did not contest the WB method but said there were no reports of high-severity fires in the late 1800s, even though direct reports of them were extensively quoted by Baker [28,29]. O'Connor et al.'s. study [109] has no bearing on the WB method. Extensive evidence of crown fires in historical ponderosa pine forests is widely published and reviewed in [4] and the text here. Baker [25] also showed, using tree-ring reconstructions, that low-severity fire was the primary severity across only ~34% of historical dry forests, mostly in the Southwest.
		Stephens et al. [73], Huffman et al. [94], Miller and Safford [110], Hagmann et al. [54]	Multi-proxy records documented substantially lower levels of high-severity fire in ponderosa and Jeffrey pine and mixed-conifer forests in overlapping study areas	Omitted evidence in Baker and Hanson [17] and Baker [29]	Baker and Hanson [17] showed that Stephens et al.'s lower estimate is because they omitted timber inventory documents that recorded high-severity fires. Huffman et al.'s study does not overlap our study area. Miller and Safford repeated critiques we already refuted (see above). However, GLO reconstructions identify fires before the mining era, and their finding of few trees at low elevations today likely is due to loss of low-elevation forests. Hagmann et al.'s [54] estimate of 6% high-severity fire is similar to that of Baker [29] of 8.9% historically.
Baker [29], Baker and Hanson [17]	Estimates of area burned at high severity by Hessburg et al. [11] validate estimates derived using Williams and Baker [41] methods *Note:* [17] *Baker and Hanson 2017 did not belong here, as it has nothing to do with the Hessburg* et al. *matter, so it was not defended*	Hagmann et al. [18], Spies et al. [111]	Inappropriate comparisons are not validation. Baker [29] limited assessment of high-severity fire to tree mortality in dry forests whereas Hessburg et al. [11] estimated high-severity fire in the dominant cover type whether that be grass or tree for "moist and cold forest" type, with lesser amounts of dry forests	Omitted and incorrect evidence in Hessburg et al. [11]	This argument is incorrect. Hessburg et al.'s Table 2 shows that specifically in forest cover types (not grass, shrub), their pooled forest percentages in ESR5 were 20.7% low, 55.0% moderate, and 24.3% high, which are even more similar to the Baker [29] estimates of 18.1% low, 59.9% moderate, and 23.0% high. Hessburg et al. Figure 4 also shows that ponderosa and Douglas-fir cover types had a mean of about 18% low, 59% moderate and 23% high, almost identical to the Baker [29] estimates.

Table 5. *Cont.*

Counter-Evidence		**Evaluation of Counter-Evidence**		**Omitted Rebuttals and Other Published Evidence also Essential to Evaluation of Counter-Evidence**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Odion et al. [12]	Modern, high-severity crown fires are within historical range of variation. Inferred fire severity from current tree-age data for unmanaged forests in the U.S. Forest Service Inventory and Analysis (FIA) program. Compared inferences about modern fire severity to estimates of historical forest conditions and fire severity inferred using Williams and Baker [41] methods	Fulé et al. [80], Levine et al. [61,62], Knight et al. [64]	Overestimation of historical tree density and unsupported inferences of fire severity from GLO records weaken conclusions based on Williams and Baker [41] methods	Omitted Rebuttals in Williams and Baker [79], Baker and Williams [34,63]	Fulé et al. [80] mistook the WB method, misquoted publications, misused evidence, and created three new false narratives [79]. Levine et al. incorrectly coded the WB method [61], then used incorrect equations [62], and both are fatally flawed. Knight et al. did not use or test the WB method and has no relevance.
		Stevens et al. [96]	Substantial errors of method and interpretation invalidate inferences about historical fire severity. These include (1) FIA stand age variable does not reflect the large range of individual tree ages in the FIA plots and (2) recruitment events are not necessarily related to high-severity fire occurrence	Omitted rebuttal in Odion et al. [95]	With same definition of high-severity fire, there was 68% agreement between these two studies; 3/4 of evidence of historical high-severity fire not from FIA data and not disputed; Stevens et al. agreed "High-severity fire was undoubtedly a component of fire regimes in ponderosa pine and drier mixed-conifer forests"
		Spies et al. [111]	In contradiction of the counter-premise, Odion et al. [12] documented only three patches of high-severity fire larger than >1000 ha in OR and WA in the early 1900s, which account for 1% of the area of historical low-severity fire regime managed under the Northwest Forest Plan	Omitted rebuttal in Odion et al. [95]; Omitted evidence in DellaSala and Hanson [112,113]	Two sources in omitted 2015 paper, reviewed in the omitted Odion et al. [95] paper, found high-severity patches ∃14,000 ha in OR and WA, two others [112,113] found many large patches in OR and WA; numerous other large patches > 1000 ha reported in OR and WA in omitted [113] paper.
Baker and Hanson [17]	Stephens et al. [73] underrepresented the historical extent of high-severity fire in their interpretation of surveyor notes in early timber inventory. *Note: because they omitted key records of high-severity fire that were readily available in the inventory records.*	Hagmann et al. [18]	Substantial errors of method and interpretation invalidate inferences about the historical extent of high-severity fire. Inferences were based on (1) inappropriate assumptions about the size and abundance of small trees given the ambiguity of data describing small trees in the 1911 inventory, (2) averaging of values derived from different areas and vegetation classifications, and (3) inappropriate assumptions that the presence of chaparral (common on sites with thin soils and high solar radiation) indicates high-severity fire	Omitted rebuttal in Baker et al. [19]	Hagmann et al. [18] did not dispute that Stephens et al. [73] had omitted most trees, and when omitted trees were included, forests were 7–17 times as dense as they reported, and they also did not dispute the abundant data, from numerous historical sources, showing occurrence of substantial high-severity fire patches, small and large, including chaparral, presented in Baker and Hanson [17]

It remains essential to test for effects of canopy-opening disturbances before assuming that moist periods alone trigger regeneration pulses; this test showed moist periods do not trigger pulses without a canopy-opening event, such as a moderate- to high-severity fire, drought, or possibly a beetle outbreak (not reconstructed). The climate forcing conclusions of the Brown studies are invalid because (1) no evidence was presented to exclude that severe fires were instead, or in addition, the cause of pulses, and (2) regeneration in moist periods cannot alone produce even-aged stands, as existing trees must be killed first. The analyses [52] that must be completed to be able to exclude high-severity fire or other severe disturbances were not performed, invalidating the conclusion of just climate forcing in studies by Brown and others [86,108,109]. Moreover, Dugan and Baker's study [52], which performed valid testing and did not find forcing by wet periods, was omitted in H.

- Evidence historical forests, in general, lacked high-severity fires, falsely based on tree-ring reconstructions of fire targeted in old growth, where high severity is inherently rare

Tree-ring reconstructions of fire history have commonly been biased against the detection of historical moderate- to high-severity fires because tree-ring reconstructions require old trees, which could not have persisted until today without a lack of moderate- to high-severity fires for long periods. Older methods of collecting fire history evidence targeted these old forests, which strongly biased these methods against finding evidence of historical moderate- to high-severity fires. For example, Grissino-Mayer [114] showed this strong and intentional bias against detecting historical high-severity fires when he said of dry forests in volcanic landscapes of northern New Mexico:

> "We found no fire-scarred samples on the kipukas in the northern and eastern portions of the malpais, and found few samples in the southern portions. These areas contained ponderosa forests that appeared younger than elsewhere, perhaps due to more recent, intense stand-replacing fires . . . ". [114] (p. 136)

This study performed no analysis of fire severity and instead just intentionally excluded areas with possible evidence of high-severity fires, as documented in this quote, and targeted older forests with abundant scars and lower-severity fires. Conclusions about historical fire severity from this biased sampling cannot be extrapolated to other areas but often are. This bias is not unusual for fire history studies in dry forests. Baker [25] found that 32% of 342 fire-history sites targeted plots in old forests with concentrations of fire scars, where moderate- to high-severity fires likely had not occurred. Moreover, 74% of fire history sites did not include any analysis of fire severity and just assumed historical fires were low severity. In contrast, where fire severity was studied, some higher-severity fire was usually found, showing the low-severity bias in most studies [25].

Two examples illustrate this bias. Brown's study [108], which is cited in H Table 5 as countering Shinneman and Baker's [10] finding of historically severe fires in the Black Hills, based on historical records, was similarly conducted in mostly old growth, where the probability of finding high-severity fires is inherently low. Therefore, it is expected that Brown [108] would find little evidence of historical high-severity fires because this is a highly biased sample. This evidence from a small area of old growth of course does not counter evidence of moderate- to high-severity historical fires in the much larger Shinneman and Baker [10] study area in the Black Hills. Merschel et al. [97], similarly, intentionally sampled in "areas of older forest" [97] (p. 1673) but nonetheless claimed that "The ubiquitous presence of large, multi-aged ponderosa pine at all sites, regardless of environmental setting, suggests historical fires were frequent and predominantly low severity . . . " These two cases illustrate the inherent bias, not admitted by either author, against finding evidence of historical mixed- and high-severity fires from studying fires in areas of older forest.

Thus, most previous fire-history studies, including those cited in H Table 5, Brown [108], and Merschel et al. [97], do not provide valid inferences about historical fire severity across larger landscapes, as they are not random samples and are mostly from rarer old-growth forests that inherently lacked moderate- to high-severity fires for long periods. This is a bias recognized by Hessburg et al. [11] and expanded by Baker [25]. H also knew this, as they said " . . . landscape-scale assessments and simulation models encompassing multiple forest types can address concerns that sampling bias of fire-scar studies favors detection of low-severity fire regimes (e.g., see arguments in Hessburg et al., 2007)." Yet, all landscape-scale fire histories, including that presented by Hessburg et al. [11], that avoid this known bias from sampling only in older forests, were omitted in H.

- Baker et al.'s [19] rebuttal of Hagmann et al. [18] on high-severity fire, omitted in H

H, in their Table 5, cited Hagmann et al. [18] as evidence ostensibly rebutting Baker and Hanson [17] regarding their findings of historical high-severity fires in ponderosa pine and mixed-conifer forests of the Sierra Nevada. However, Baker et al.'s study [19], which rebutted Hagmann et al. [18], was omitted in H. Baker et al. [19] explained that the Hagmann et al. [18] critique actually did not challenge or dispute the abundant evidence of historical high-severity fire presented by Baker and Hanson [17]. This evidence included (a) extensive U.S. Forest Service field notes and maps documenting the occurrence of high-severity fire, and young, naturally regenerating conifer forests following severe fire from forest surveys circa 1911 in two different areas of the Sierra Nevada and (b) explicit notes and observations from three U.S. Forest Service reports, ca 1904 1912, regarding small and large high-severity fire patches and naturally regenerating conifer forest following a severe fire. The rebuttal [19] and all this evidence was omitted in H.

- Odion et al.'s [95] rebuttal of Stevens et al. [96], showing FIA data can still reconstruct fire severity, omitted in H

H Table 5 argued that Stevens et al. [96] had shown that "errors of method and interpretation invalidate inferences about fire severity" from FIA stand-age data. However, the rebuttal of Stevens et al. [96] by Odion et al. [95] was omitted in H. The Odion et al. [95] rebuttal found/noted that (a) with the same definition of high-severity fire, there was 68% agreement between Stevens et al. [96] and Odion et al. [12] in terms of classifying historical high-severity fire using FIA stand-age plot-data; (b) 75% of the evidence for historical high-severity fire, which did not pertain to FIA, was not disputed or challenged by Stevens et al. [96]; and (c) while Stevens et al. questioned whether the current occurrence of high-severity fire patches >1000 ha is within the natural range of variation, they acknowledged that "High-severity fire was undoubtedly a component of fire regimes in ponderosa pine and drier mixed conifer forests" [96] (p. 3), including patches >50 ha in area. The Odion et al. rebuttal [95] and this evidence were omitted in H.

- Rebuttal/new evidence of historically large high-severity fire patches, omitted in H

H Table 5 argued that Spies et al. [111] had shown that Odion et al. [12] documented "only three patches of high-severity fire larger than >1000 ha in OR and WA in the early 1900s". However, the rebuttal of Stevens et al. [96] by Odion et al. [95] was omitted in H. The Odion et al. [95] rebuttal summarized data presented by DellaSala and Hanson [112] (p. 31), wherein four different sources were discussed regarding the historical occurrence of high-severity fire patches >1000 ha in mixed-conifer and ponderosa pine forests of OR and WA. Two of these sources documented individual high-severity fire patches of 14,000 ha and 24,000 ha, while the other two sources documented dozens of occurrences of such patches. Additional data regarding numerous historical high-severity patches of this size in OR and WA, as well as the Sierra Nevada and elsewhere across the western USA, were presented by DellaSala and Hanson [113], new evidence that was also omitted in H. Baker [28] (p. 26) had reported for the Sierra that " ... the reconstructions show that contiguous areas of historical high-severity fire commonly exceeded 250 ha and reached as high as 9400 ha", which was also omitted in H. Furthermore, in the Colorado Front Range, Williams and Baker [31] found that the maximum historical high-severity patch size was 8331 ha based on direct surveyor reports along section lines, evidence also omitted in H. Thus, all this evidence that rejects the low-severity model was omitted in H.

4.2.3. Evidence about Recent Fire Severity Omitted/Misinterpreted in H Table 6

H (Table 6) claimed that Odion and Hanson [115] stood for the proposition that "High severity fire was rare in recent fires", whereas Odion and Hanson [115] actually stood for the proposition that long unburned forests are not experiencing higher fire severity in modern fires. H also cited Safford et al. [116] as rebutting Odion and Hanson [115] but failed to mention that Safford et al.'s study [116] was refuted by Odion and Hanson [117].

Odion and Hanson [117] found that Safford et al. [116] had arbitrarily combined two time-since-fire categories, which created a false impression of slightly higher fire severity in long unburned forests. Odion and Hanson [117], using the same vegetation severity data, analyzed all time since fire categories and found that forests, that had not burned in the longest period of time, had similar or lower fire severity, not higher severity.

H also cited Spies et al. [118] as rebutting Hanson et al. [119] regarding current fire severity trends but failed to mention that Spies et al. [118] was subsequently refuted by Hanson et al. [120]. Hanson et al. [120] found that a mathematical error, and reliance on an inaccurate anecdotal assertion, had led to an erroneous conclusion that the rate of high-severity fires in old forests of the Pacific Northwest was outpacing the old-forest recruitment rate from growth. Widespread rollbacks of forest protections, and increased logging, were being proposed based on the false data. Spies et al. [118] did not dispute that the errors had been made but hypothesized that the initial conclusion might still hold if a much broader high-severity fire definition was used. Hanson et al. [120] analyzed the Forest Service's own fire-severity field-plot validation data and rates of high-severity fire in old forests from satellite imagery, finding that, even with the broader high-severity fire definition, old-forest recruitment still outpaced the rate of high-severity fire in old forests by 7 to 29 times, depending on the subregion, and most mature trees survived fire under this broader definition.

H listed a few studies as rebutting Williams and Baker's [24] evidence that severity distributions in some modern wildfires were not different from severity distributions in historical fire patterns they reconstructed. However, H did not mention or cite the many published studies, discussed above, that have refuted these critiques, or the rebuttals and other counter-evidence regarding these few studies. Steel et al. [121] reported no relationship between time since fire and high-severity fire for some forest types. They reported such a relationship for mixed conifer, but the model was based on data for only one narrow time-since-fire category, and the authors excluded from their analysis the longest unburned forests, those with no recorded history of fire ([121] Table 4, Figure 4). Evidence presented by Odion et al. [122], Miller et al. [123], and van Wagtendonk et al. [124], which included the longest unburned forests and all time-since-fire categories, and found similar or lower proportions of high-severity fire in the longest unburned forests, was omitted in H. Steel et al. [121] also reported historical high-severity fire proportions of 4–8% for mixed-conifer forests, based on only a theoretical model, but both Steel et al. [121] and evidence in H omitted mention of numerous studies finding much higher historical proportions of high-severity fire in these forests based on historical field data, maps, and reports, including those by Baker [28], Hanson and Odion [76,78], and Baker and Hanson [17]. Steel et al. [125] reported an increase in high-severity fire proportion since 1984 in some regions but used a fire-history database that is known to disproportionately omit large, severe fires in the earlier years of the dataset, causing a bias and potential to report false trends [126]. Evidence in H omitted Hanson and Odion [126] and Baker [4], who used more comprehensive data and found no trends in high-severity fire proportion in the same regions. Guiterman et al. [127] analyzed a single 38 ha high-severity fire patch, with very limited inferential potential for landscapes. Reilly et al. [56] reported no increase in high-severity fire proportion in the Pacific Northwest since 1985 but an increase in large high-severity fire patches. Evidence in H omitted DellaSala and Hanson [113], who found that the increase in large high-severity fire patches occurred from the 1980s through the 1990s but found no statistically detectable increase over about the past two decades. H cited Safford et al. [128] as rebutting Hanson and Odion [129] but neglected to cite or mention that Safford et al.'s study [128] was refuted by Hanson and Odion [126]. Safford et al. [128] questioned fire severity trend analyses reported by Hanson and Odion [129] for the Sierra Nevada and hypothesized several potential methodological flaws. Hanson and Odion [126] re-analyzed their initial data, using the new methods proposed by Safford et al. [128], and found their initial conclusions were robust to re-analysis under Safford et al.'s new methods. All this substantial evidence in published papers and rebuttals was omitted in H.

Table 6. Hagmann et al.'s study ([3] Table 6) about severity of modern fires is replicated in the left two columns, with omitted published evidence added in the right column, to show Hagmann et al. omitted published evidence and made incorrect conclusions as a result.

Counter-Evidence		**Evaluation of Counter-Evidence**		**Omitted Rebuttals and Other Published Evidence also Essential to Evaluation of Counter-Evidence**	
Citations	*Counter-premise*	*Citations*	*Implications of evaluation*	*Citations*	*Implication of omitted evidence*
Odion and Hanson [115]	High-severity fire was rare in recent fires in the Sierra Nevada based on analysis of Burned Area Emergency Response (BAER) soil burn severity maps	Safford et al. [116]	BAER maps greatly underestimate stand-replacing fire area and heterogeneity in burn severity for vegetation. BAER maps are soil burn-severity maps, not vegetation burn-severity maps.	Omitted rebuttal in Odion and Hanson [117]	Safford et al. [116] arbitrarily combined two time-since-fire categories, creating slightly higher fire severity in long unburned forests. Odion and Hanson [117] used all categories and found similar or lower fire severity in long unburned forests.
Hanson et al. [119]	Change in conservation strategies for northern spotted owl (NSO) were unwarranted due to overestimation of high-severity fire in the NSO recovery plan	Spies et al. [118]	Use of a higher relative delta normalized burn ratio (RdNBR) threshold substantially increased misclassification errors and reduced estimates of high-severity fire extent. Hanson et al. [120] used an RdNBR threshold of 798 rather than 574 as recommended in the literature in Miller et al. [130] they cited as the source of the threshold used	Omitted rebuttal in Hanson et al. [120]	Spies et al. [118] had cited evidence with a math error and incorrect anecdotal evidence to conclude high-severity fire was outpacing old-forest recruitment but did not dispute these and then tried a broader high-severity fire definition. Hanson et al. [120], however, showed this new definition still led to old-forest recruitment outpacing high-severity fire by 7–29 times
Williams and Baker [24]	Severity distributions in recent fires do not depart from historical	Steel et al. [121], Guiternam et al. [127], Reilly et al. [56], Steel et al. [125]	Extent and spatial patterns of fire severity in some recent fires have departed from pre-fire exclusion range of variation for some forest types	Omitted evidence in Odion et al. [122], Hanson and Odion [126,129], Della-Sala and Hanson [113], and many others (see text)	Steel et al. [121] based historical high-severity proportions on only a theoretical model. Guiterman et al. [127] was from only one 38 ha patch, with little inferential power. Reilly et al. [56] found no trend in high-severity proportion and more large, high-severity patches, but H omitted the study by DellaSala and Hanson [113] who found no such increase over the last two decades. Steel et al. [125] used a database that Hanson and Odion [126] showed can produce false trends.
Hanson and Odion [129]	Previous assessments overestimate extent of high-severity fire in modern fires	Safford et al. [128]	Use of coarse-scale, highly inaccurate, and geographically misregistered vegetation map and averaging across unrelated vegetation types and diverse ownerships undermine confidence in Hanson and Odion [129]	Omitted rebuttal in Hanson and Odion [126]	Hanson and Odion [126] re-analyzed Safford et al.'s [128] initial data, using new methods that Safford et al. proposed, and found Hanson and Odion's [129] initial conclusions were robust to re-analysis using Safford et al.'s [128] proposed new methods.

4.2.4. Conclusions—Abundant Multi-Proxy Evidence of Historical Moderate- to High-Severity Fires, including in Their Own Publications, Omitted in H

Fire-history research has moved beyond old composite fire interval (CFI) rate measures, as reviewed in the Introduction, but H cited old debates about CFIs. Publications on new methods that use the much sounder fire-rotation measure and have corrected old CFI measures to fire rotations [25] were omitted in H. These new estimates show that frequent low-severity fire was much less prevalent than previously thought (Figure 8). Low-to moderate-severity fire remains supported as having been at least temporarily dominant historically across a substantial area in the Southwest and scattered elsewhere (Figure 8, Table 1), usually at lower elevations and on drier sites (e.g., Figure 10a). However, frequent low-severity fires with rotations <25 years only covered 14% of dry-forest areas [25]. Even in these areas, it was historically possible for fires to infrequently burn extensive areas at moderate to high severity (e.g., compare the Mogollon Plateau and nearby Black Mesa in

Figure 2). Hessburg et al. [11] (p. 20) articulated this contingent equilibrium in eastern Washington mixed-conifer forests:

> “Low-severity fires and equilibrium dynamics likely occurred in eastern Washington dry forests, where they fostered fire tolerant, park-like pine stands, however, these dynamics were perhaps ephemeral in nature, lasting one or more centuries at a location, and then switching concordant with regional climate forcing to non-equilibrium states”.

Table 7. Reported early timber inventory tree-density estimates and corrected estimates with 1.6–2.3 correction multipliers applied, along with estimated total tree density (conifer and hardwood). Data are from studies that used early timber inventories to estimate historical tree density in dry forests.

Study Area	Source	Tree Diam. Recorded (cm)	Trees Recorded	Reported Tree Density (Trees/ha)	Corrected Tree Density (Trees/ha)	Estimated Conifer Plus Hardwood Tree Density (Trees/ha)
Two-chain-wide timber inventories that underestimate tree density by 16–2.3 times (Baker et al., 2018 [19])						
E. Ore. Cascades-N	Hagmann et al. [70]	15.0+	Main conifers	66	106–152 [a]	106–152 [a]
E. Ore. Cascades-S	Hagmann et al. [69]	15.0+	Main conifers	65	104–150 [a]	106–152 [a]
E. Ore. Cascades-S	Hagmann et al. [71]	15.0+	Main conifers	68	109–156 [a]	109–156 [a]
S. California Sierra	Collins et al. [131]	15.2+	Only conifers	44–52	70–120 [a]	90–155 [b]
S. California Sierra	Collins et al. [72]	15.2+	Only conifers	48	77–110 [a]	99–142 [b]
S. California Sierra	Scholl & Taylor [132]	15.2+	All trees	99	158–228 [a]	158–228 [a]
One-chain-wide timber inventory not known to underestimate tree density at this time (Baker et al., 2018 [19])						
S. California Sierra	Stephens et al. [73]	30.5	Only conifers	55	244 [c]	498 [d]

[a] Estimate is calculated, as in the text here, as 1.6–2.3 times “Reported tree density”. [b] Estimate is calculated from direct tallies of trees by species in the land-survey records for the southern Sierra, which found that a mean of 22.4% of total trees were oaks; thus, conifer plus hardwood tree density is estimated as corrected tree density/0.776.
[c] Stephens et al. [73] were unique in omitting data for conifers < 30.5 cm dbh. Baker and Hanson [17] reconducted the Stephens et al. inventory count of trees for their study area and found that for all conifers, tree density had a mean of 196–292 trees/ha for pine/ponderosa and mixed conifer, which are averaged here to be 244 trees/ha.
[d] Estimate is calculated by the recorded percentages of total trees in the land surveys that were conifers and non-conifers in ponderosa pine (59.5%) and mixed-conifer forests (38.5%) in the area of the Stephens et al. [73] inventory, which averaged together equals a fraction of 0.49. The corrected tree density is thus divided by 0.49 to estimate conifer plus hardwood tree density. Note, 49% of non-conifer trees is high but not historically outside the HRV in the southern Sierra overall, where the third quartile of oaks as a percentage of all trees begins at 34.9% [28].

In other areas away from the lower elevations and driest areas, where low severity had fire rotations > 25 years (Figure 8), landscapes had greater proportions of moderate- to high-severity fire (Table 1) and were likely more frequently vulnerable to rapid change, as on the Uncompahgre Plateau, Colorado, after extensive severe fire in the late 1800s [32].

Regarding historical fire severity, (1) research that suggested climate forcing, not high-severity fires, led to pulses of tree regeneration did not separate these confounded variables, and their conclusions are invalid; (2) research from rarer old-growth forests, showing a lack of high-severity fires, is invalid evidence that other large parts of landscapes without old trees lacked severe fires; (3) early timber inventories, reported in H to show low-severity fires dominated, had omitted key documents showing evidence of high-severity fires; and (4) H and some of its authors claimed there was no evidence of historically severe fires in dry forests but omitted abundant published evidence of these fires, including by authors of H.

The very large body of evidence omitted in H included hundreds of quotes from early historical documents, many direct observations by land surveyors and observations by scientists in early forest-reserve reports, detailed mapping in early forest-atlases performed by the Forest Service, direct newspaper accounts, early oblique photographs, extensive analysis of early aerial photographs, ≥18 tree-ring reconstructions, 7 paleo-charcoal reconstructions, 15 land survey reconstructions (Table 1), and extensive reconstructions using modern forest inventory and analysis (FIA) age data. Of course, each source has limitations and warrants some critiques, but not omission. Nearly all available evidence that found historically severe fires in dry forests was omitted in H. Omitted evidence clearly shows dry forests historically had infrequent moderate- to high-severity fires, rejecting the low-severity model and supporting the mixed-severity model.

Moreover, entire bodies of scientific evidence and rebuttal studies regarding time since fire and fire-severity trends were omitted in H. This created the false impression that long unburned forests experience higher fire severity and that high-severity fire is increasing, when, in fact, the strong weight of scientific evidence indicates that long unburned forests experience similar or lower fire severity and that high-severity fire rates are not outside HRV. This was also found in the three large studies H cited [56–58], as reviewed in Section 3, but these were misreported in H.

5. Conclusions and Implications of False and Omitted Evidence in H

5.1. All Evidence Not Supporting the Low-Severity Model Omitted in H, Leaving Falsified Science

H framed their review as an independent and objective critique of "dissent in the scientific literature" and an "incomplete assessment of the best available science" by providing "a framework for objectively assessing change" [3] (p. 3). This critique-of-dissent approach, however, quickly turned from objectivity and the best available science to false evidence and omission of evidence. As we have shown throughout, it is H that is an incomplete and biased assessment of the best available science due to extensive false and omitted evidence.

H's model is that historical fires burned at low to moderate severity, with little to no high severity, but the primary evidence basis in H shows this to be false. The evidence for their model, in H Table 2, that they claimed shows recent high-severity fire is outside the HRV, instead was shown to be false based on evidence and quotes in the three key papers and largest study, omitted in H. These four studies show that high-severity fire was burning recently at rates near or below rates under the HRV.

In the rest of H, there is a pattern of consistent omission of evidence. Most evidence was omitted in H when it does not support their low-severity model, including 10 published rebuttals of their papers (Table 8) and 25 other very germane published papers (Table 9), as well as papers by the authors of H that do not support H's model. To elucidate the extent of omission and misrepresentation in H, our review included (1) corrected replacement tables (Tables 3–6) that add the evidence omitted in H in their published tables, (2) summary tables that list all omitted rebuttals (Table 8) and omitted published studies with evidence that does not support their model (Table 9), and (3) extensive text detailing these omissions, including the omission of papers, by authors of H, that do not support H's low-severity model. Together, this large body of evidence shows H's evidence about their model, in both text and tables, is incorrect and rebutted in publications omitted in H.

We suggested this also may be a pattern, as it has occurred before. Earlier we showed in Baker et al.'s study [19], in a rebuttal omitted in H, that Hagmann et al. [18] cited 11 papers that they said pointed out "errors in methodology or misrepresentation of the work of others" [18] (p. 8). However, evidence for these alleged misrepresentations and errors was not presented at all in the paper. There also was no presentation of the evidence in 9 published studies that had specifically rebutted these 11 papers [19]. Additionally, earlier (Section 4.2.2), we mentioned that Fulé et al. [80] said there was no evidence of historical high-severity fires in dry forests, when this evidence was actually detailed in Williams and Baker's study [24] itself, the paper Fulé et al. were critiquing. Finally, in the case of the early timber inventories, which we showed were known before the 1930s to underestimate tree density [17], Hagmann et al. [18] replied and we rebutted their reply [19]. However, as we explained earlier, in Section 4.1.2, Hagmann et al. [18] did not reject a central conclusion of [17] that early timber inventory data substantially underestimate tree density and require the use of 1.6–2.3 correction multipliers before reporting tree-density estimates. However, since the 2018 exchange, three new applications of early timber inventory data have appeared in studies by Stephens et al. [74], Bernal et al. [133], and North et al. [134] that include authors of Hagmann et al. [18], who knew about the original paper [17] and rebuttal [19]. Yet, none of these three new papers cited or discussed either of these papers or made any of the necessary corrections to tree-density estimates (Table 7). Omission and false evidence are now a repeating pattern.

We want to be very clear that we focus here on evidence "omitted in H", which simply describes the state of the evidence in H and the resulting state of the broader scientific record. We have no evidence about the authors' intentions or motivations or how or why all this evidence was omitted in H. Nonetheless, the major false evidence and omission of evidence in H show that H is invalid and not replicable science. H leaves a falsified state of the scientific record regarding historical dry-forest structure and fires. The mixed-severity model, which is that dry forests had a heterogeneous structure and a mixture of fire severities, was not refuted in H and remains supported by the large body of scientific evidence, as shown in Tables 1–9 and the text, that was omitted in H. The low-severity fire model is rejected by this large body of false and omitted evidence in H.

The U.S. Office of Research Integrity (https://ori.hhs.gov/investigations, accessed on 10 January 2023) indicates that potential scientific misconduct is particularly important where there are significant public policy implications or where there may be more than one instance. We showed that there is a repeated pattern of omission in H, and that pattern of omission continues [74,133,134]. Omission of evidence and false evidence in H have significant land management implications, as millions of hectares of dry forests could be inappropriately managed in a futile and ecologically damaging attempt to prevent high-severity fires that are well documented in the omitted evidence to have occurred historically. The two accompanying public policy papers [22,23], which are substantially based on the false and omitted evidence in H, are thus shown here to not have a sound scientific basis.

Table 8. Published rebuttals, omitted in H, of ten publications used as evidence in H. Listed are the tables containing a summary of the omitted evidence, which refuted the rebutted articles and H's conclusions. Details of these rebuttals are in the text.

Omitted Rebuttal	Article Rebutted	Rebuttal Summarized in Table(s)
Baker and Williams [34]	Levine et al. [61]	Tables 3 and 5
Baker and Williams [63]	Levine et al. [62]	Tables 3 and 5
Baker and Williams [63]	Johnston et al. [65]	Table 3
Baker et al. [19]	Hagmann et al. [18]	Tables 3 and 5
Hanson and Odion [78]	Collins et al. [77]	Table 3
Williams and Baker [79]	Fulé et al. [80]	Table 5
Odion et al. [95]	Stevens et al. [96]	Table 5
Odion and Hanson [117]	Safford et al. [116]	Table 6
Hanson et al. [120]	Spies et al. [118]	Table 6
Hanson and Odion [126]	Safford et al. [128]	Table 6

Table 9. Twenty-five original publications, with evidence of historically heterogeneous forest structure and mixed- to high-severity fires, omitted in H.

Omitted Evidence in These Sources	Evidence Omitted in H
Williams and Baker [40]	Omitted all evidence showing low bias and error in land-survey records.
Williams and Baker [41]	Omitted all evidence of validations of the WB method.
Williams and Baker [24]	Omitted all evidence of validations of the WB method and evidence of historically variable tree density and fire severity in dry forests in Arizona, Colorado, and Oregon.
Williams and Baker [31]	Omitted all direct evidence of extensive moderate- to high-severity fire in historical dry forests in the Colorado Front Range, evidence validating the WB method of reconstructing historical moderate- to high-severity fires, and evidence of very large high-severity fire patches (up to 8331 ha).
Baker and Williams [34]	Omitted all evidence of validations of the WB method and all evidence of historically variable tree density and fire severity documented in multiple historical sources cited in this paper.
Baker et al. [35]	Omitted all evidence from tree-ring reconstructions, forest-reserve reports, and other early scientific reports showing that historical dry forests in the Rocky Mountains had tree densities varying from 17 to 19,760 trees/ha.

Table 9. *Cont.*

Omitted Evidence in These Sources	Evidence Omitted in H
Baker [29]	Omitted quotes from early forest-reserve reports and other early scientific reports showing that historical dry forests in the eastern Cascades of Oregon had variable tree density as well as many direct reports of moderate- to high-severity fire.
Baker [28]	Omitted 47 quotes from early forest-reserve reports and other early scientific reports documenting that Sierran mixed-conifer forests were highly variable in tree density, but typically dense, and omitted numerous early reports of extensive moderate- to high-severity fire in historical Sierran mixed-conifer forests. Omitted 208 quotes from early forest reserve reports and other early scientific reports that documented historical moderate- to high-severity fires in Sierran mixed-conifer forests. Omitted evidence of high-severity fire patches commonly > 250 ha and up to 9400 ha in area.
Baker [25]	Omitted all evidence in this monograph analyzing why old CFI-based estimates of historical rates of fire are too short, why moderate- to high-severity fires were seldom found using these old methods, and how these old estimates can be corrected to accurately estimate fire history.
Farris et al. [15], Dugan and Baker [52]	Omitted any mention of the development of new landscape-scale methods of conducting fire history studies that overcome the limitations of earlier CFI-based fire history studies that H cite.
Hessburg et al. [11]	Omitted evidence of severe fires in northwestern dry forests; even though Hessburg is an author of H, and also authored this publication, H did not review its evidence. Hessburg et al. studied 303,156 ha in E. OR and E. WA and found "widespread evidence of partial stand and stand-replacing fire" [11] (p. 5) in mixed-conifer forests.
Baker [45]	Omitted evidence in six early photographs of the aftermath of severe fires in dry forests in the Rocky Mountains.
Baker [32,33,44]	Omitted evidence that documented that large moderate- to high-severity fires occurred in the late 1800s in dry forests on the Uncompahgre Plateau and in the San Juan Mountains, Colorado, based on forest atlases, land survey records, early photographs, early scientific publications, and other early records, including newspaper reports.
Pierce et al. [36], Pierce and Meyer [37], Long et al. [103], Fitch [104], Jenkins et al. [105], Bigio [106], Colombaroli and Gavin [107]	Omitted evidence in these paleo-charcoal studies from Arizona, Colorado, Idaho, New Mexico, and Oregon that infrequent moderate- to high-severity fires occurred historically in western USA dry forests.
DellaSala and Hanson [112,113]	Omitted evidence of numerous large historical high-severity fire patches in OR, WA, CA, and other parts of the western USA

5.2. After Correcting False and Omitted Evidence in H, What Are Key Findings?

First, high-severity fire rates in dry forests are within or lower than under the HRV, based on our correction of the evidence in H Table 2. The four studies with adequate samples [4,56–58] showed that recent fire rotations were within or longer (413, 608, 695, 875, 1045, and 1693 years) than the historical range of 217–849 years documented by Baker [4], based on land-survey reconstructions, paleo-charcoal studies, and reconstructions from early aerial photographs. The central premise of H that high-severity fires are burning at rates that exceed the HRV is refuted by H's own evidence in their Table 2, as shown here in Section 3, and in the larger study [4] that H omitted. This evidence shows that there is no ecological need to reduce high-severity fire through fuel reduction; doing so successfully would likely have effects similar to fire suppression, which is widely understood to have deleterious ecological effects [7]. The primary fire restoration need is to just focus on restoring low- to moderate-severity fires, which is likely to also continue to include high-severity fires not expected to lead to rates exceeding historical rates. As Mallek et al. [58] explained, virtually all fires burning under moderate conditions are put out, so simply reducing fire suppression is likely to allow fires to burn closer to the HRV. Of course, it is sensible to periodically monitor rates of all severities of fires.

Second, the mixed-severity model of historical fires in dry forests is not rejected, and thus still supported, and the low-severity model is rejected by the evidence reviewed here, particularly based on newer landscape-scale evidence and newer methods, where more variability in historical fire has been found. H recognized that " . . . landscape-level assessments . . . can address concerns that sampling bias of fire-scar studies favors detection of low-severity fire regimes" [3] (p. 8), but H did not review and use the available landscape-scale assessments. There are three major sources, at this point, that provide landscape-level assessments for historical wildfire: (1) tree-ring reconstructions at the landscape scale (e.g., Farris et al. [15], Sherriff et al. [16], and Dugan and Baker [52]), (2) land survey reconstructions (Table 1), and (3) early aerial photography [11]. This landscape-scale evidence of historical mixed-severity fires is also supported by multiple other sources, including paleo-charcoal reconstructions, early newspaper accounts, early scientific publications, early forest-reserve reports, early forest atlases, and early oblique photographs (Table 2). Evidence in H omitted all these sources, as detailed in this paper. This evidence is sufficiently extensive and compelling, as reviewed in this paper and in earlier syntheses [12,13,34] to conclude that the low-severity model is rejected. The mixed-severity model is the best available science for the HRV of wildfire in all western USA dry forests.

Third, for forest structure, landscape-scale tree-ring and land-survey reconstructions have been shown through cross-validations to produce congruent findings, reviewed in this paper, that also strongly support the mixed-severity model and reject the low-severity model. Land survey reconstructions can cover larger land areas (Table 1) than can tree-ring reconstructions, but tree-ring reconstructions can provide more detailed evidence, if over a smaller area, as the base unit for land survey reconstructions is ~518 ha. However, tree-ring reconstructions are often biased toward older forests, which typically lack severe fires, by the need to have older trees to provide evidence from the historical period. Early aerial photographs can reconstruct categories of forest structure (e.g., old single-story forests vs. closed-canopy stem exclusion) but not the details of tree density and basal area [11]. The best source of landscape-scale historical forest structure may be from both landscape-scale tree-ring and land-survey reconstructions, possibly aided by early aerial photography, in conjunction with other sources (Table 2), which can provide certain evidence (e.g., maps and histories) that cannot otherwise be obtained.

The mixed-severity model is supported, and the low-severity model is rejected also for forest structure, which means dry forests had both low and high tree density and substantial heterogeneity in density from interaction with mixed-severity fires.

5.3. Implications and Outlook

It appears it is primarily the high-severity component of mixed-severity fires that concerns proponents of the rejected low-severity fire model. Are they forever hoping to retain the false image of low- to moderate-severity fires, in perpetual balance with old growth, which has now even been labeled "good fire" by some scientists [1]? Will they continue the fight to eliminate high-severity "bad fire", using expensive mechanical fuel reductions and fire suppression even though, as shown here, high-severity fire was part of historical fire regimes in dry forests and is occurring at rates that recently are below or within the HRV? Will false evidence, omission of evidence, and misleading labeling of historical high-severity fires be ongoing? This study shows this is an unnecessary, futile, and false effort—Section 3 demonstrates that H's own evidence shows no increase, at this point, relative to historical rates of high-severity fires. Moreover, the high-severity component of mixed-severity fires was and still is quite infrequent, with fire rotations from 175 to 2000 years (Table 1), allowing for considerable, if temporary, persistence of old, park-like dry forests. This finding is very consistent with Hessburg et al.'s [11] (p. 20) finding of contingent equilibrium in historical eastern Washington mixed-conifer forests: "Low-severity fires and equilibrium dynamics likely occurred in eastern Washington dry forests, where they fostered fire tolerant, park-like pine stands, however, these dynamics were perhaps ephemeral in nature, lasting one or more centuries at a location, and then switching concordant with regional climate forcing to non-equilibrium states." We end by noting again that H did not even mention the findings of this large, key study, by the second author of H, that supports the mixed-severity fire model and rejects H's low-severity fire model. H is documented here to have left behind a falsification of the scientific record, yet was used as a key basis for public land-management policy proposals [22,23] likely to have ecologically detrimental effects on dry forests [7].

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