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Does large area burned mean a bad fire year? Comparing contemporary wildfire years to historical fire regimes informs the restoration task in fire-dependent forests

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ABSTRACT

Wildfires and fire seasons are commonly rated largely on the simple metric of area burned (more hectares: bad). A seemingly paradoxical narrative frames large fire seasons as a symptom of a forest health problem (too much fire), while simultaneously stating that fire-dependent forests lack sufficient fire to maintain system resilience (too little fire). One key to resolving this paradox is placing contemporary fire years in the context of historical fire regimes, considering not only total fire area but also burn severity distributions. Historical regimes can also inform forest restoration efforts by illuminating the pace and scale at which fires historically maintained (i.e., 'treated') fire-resilient landscapes. Here we ask, for a broad extent of the inland Pacific Northwest (eastern Oregon and Washington, USA), a region predominated by drier forest types and recently experiencing record-breaking fire years: 1) How much annual fire area would have been needed to support historical fire regimes?; and 2) How do contemporary fire years (1985–2020) compare to historical fire amounts and severities?

To meet historical fire frequencies for each forest type, annual area burned would have averaged at least 224,000–291,000 ha per year regionally prior to the 20th century (notwithstanding interannual variability) – presumably arising from both indigenous-cultural and lightning-ignited fires. Drier forests would account for 82–88% of annual burn area. In contrast, despite the seemingly fiery contemporary era, contemporary fire years average just ~49,100 ha·yr^{-1} (~17–22% of historical), with only one year approximating historical area burned. Contemporary years average well under historical rates for virtually all severity classes across dry and moist (but not cold) forests. Annualized fire deficits relative to historical rates are especially conspicuous for low-severity area in dry forests (on average missing 127,000–161,000 ha·yr^{-1} regionally) and moderate-severity area in both dry (missing 34,000–44,000 ha·yr^{-1}) and moist (missing 9000–12,000 ha·yr^{-1}) forests. Ten-year moving averages in burn area are increasing in recent years, but remain below historical levels. Trends are similar across states and major land ownerships.

With current forest restoration efforts occurring at a fraction of historical fire rates, our findings highlight that successful restoration and maintenance will require a) increasing active treatment rates, and b) incorporating managed wildfire to attain substantially more treated area. As such, beneficial fire years may be those not with less, but rather more, area burned – with characteristic severity and patch distributions, minimal clearly-negative impacts (e.g. loss of life and property), and contribution to restoration/maintenance objectives.

1. Introduction

Recent decades have seen a marked increase in the area burned by wildfires across forests of the western U.S. (Parks and Abatzoglou 2020; Coop et al., 2022), tracking similar global trends. Several record-breaking fire seasons or events have occurred in many forest regions

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since the turn of the 21st century, driven by a combination of warming climate, increasing drought, and fuel alterations due to fire exclusion and other land use. Such fire seasons are often dubbed the ‘worst fire years,’ based not just on obviously negative impacts such as loss of life and property, but often simply on the large number of hectares burned – in both the popular media and the fire science literature (e.g., Le Page et al., 2008; Palombo 2017). Similarly, at the individual fire scale, the term ‘mega-fire’ commonly casts large fires as problematic based mainly on their size (typically > 10^4-105 ha; Linley et al., 2022). Concern over these large fires and fire seasons, by themselves, underpins much of the scientific and public dialogue about fire management and forest resilience (e.g., USFS, 2022). But is rating fire years as problematic based mainly on large area burned too simplistic, or even misguided?

In parallel to this narrative regarding too much fire, there is at the same time a seemingly contradictory narrative of too little fire. It is broadly recognized that many fire-dependent forests (especially those that historically experienced predominantly low- to moderate-severity fire every one to several decades) are currently lacking the fire that once helped maintain them in a resilient state by modulating tree densities, fuel loads, and landscape patchiness of seral stages (Haugo et al., 2019, Reilly et al., 2017, Hessburg et al., 2015, North et al., 2021, Stephens et al., 2021, Churchill et al., 2022). The often densified or simplified forests of contemporary dry forest landscapes are considered less resilient to both changing climate and a range of disturbances (Hessburg et al., 2019). This recognition has added urgency to calls for ecological restoration of fire-dependent forests, usually with the aim to move forest structure toward more climate- and fire-resilient conditions by reducing the density and continuity of fuels (biomass) and promoting large fire-resistant trees via mechanical thinning, prescribed burning, and managed wildfires (Stephens et al., 2020, Prichard et al., 2021). Wildfire can contribute to these aims to varying degrees, recognizing that its area generally far exceeds that of planned mechanical and prescribed fire treatments (Barros et al., 2018; Laughlin et al., 2023; WA DNR, 2022a,b, North et al., 2021, Ager et al., 2022).

Resolving this seeming conflict in narratives is important to more meaningfully interpret wildfire years, to better inform the scale of the forest restoration task, and most importantly to highlight the link between the two. Often the restoration task is expressed as a number of hectares currently in need of treatment due to altered forest structure (i.e. a more or less static expression of a backlog; WA DNR, 2020; Haugo et al., 2015; Laughlin et al., 2023) or as desired treatment frequencies (striving to align treatment intervals with historical fire intervals). There is general recognition that treatment rates are not catching or keeping up with restoration needs (North et al., 2021; Kolden 2019; USFS, 2022), but often there is little certainty regarding the necessary pace and scale to achieve objectives.

One way to inform the necessary scale is by considering the rates that fire historically affected forest landscapes; i.e. for each forest type to experience fire at published historical frequencies, how much area would have burned over time? In essence, this approach quantifies the amount of land area that would have been ‘treated’ each year, on average, under active fire regimes that presumably maintained fire-resilient forests via both lightning-ignited fires and cultural burning by Native American tribes. The intent of such an assessment is not to re-establish historical fire regimes or frequencies, but rather to contextualize the general order of magnitude and types of fire involved in maintaining fire-resilient landscapes. Such an approach was put forth for the Sierra Nevada region of California (North et al., 2012, North et al., 2021), but has yet to be widely adopted.

A recent analysis (Haugo et al., 2019) made a key step in this direction by comparing total fire extent over a recent 32-year period (1984–2015) to an ‘expected’ burn area based on historical fire rotations for the ecoregions of the Pacific Northwest (USA). That analysis showed a large deficit of ‘missing fire’ had accumulated during those three decades across all severities, and that severity proportions were also different (more higher-severity fire) over that span compared to expected (historical) burn area. This placed numbers on the cumulative scale of fire area missing from the landscape over the last several decades, consistent with a growing recognition of accruing ‘fire deficits’ across many fire-dependent forests (Marlon et al., 2012; Parks et al., 2015). To make this information as operationally relevant and actionable as possible, a key next step is to compare contemporary wildfire area to historical estimates in terms that can be directly utilized by management agencies to set restoration and maintenance targets, and to evaluate the impact of individual wildfire years. Doing so requires calculating annual rates of historical fire using ecoregion-specific fire regimes, parsed along jurisdictional boundaries of land management entities (e.g. federal and state agencies, private lands) that are commonly used in planning and reporting.

Here, we quantitatively compare contemporary wildfire years with historical fire regimes in terms of annual burn area by severity class, for a broad extent of the interior Pacific Northwest (8.9 million forested hectares across eastern Washington and Oregon) – a region predominated by drier, fire-prone forest types and that recently experienced the largest fire years in the modern record (e.g., WA DNR, 2022a). We ask:

1. What was the long-term average of annual area burned by severity class under known historical fire rotations (presumably including both lightning-ignited fires and indigenous cultural burning), and how did these rates vary by forest type and current land ownership?
2. How has annual area burned in the contemporary era (36 fire seasons spanning 1985–2020) compared to historical rates of annual area burned?

Given findings from these questions, we then explore the degree to which contemporary fires may be contributing to or hindering forest restoration objectives vis-à-vis reducing or diversifying stand/fuel densities, considering both scale and severity of the fires (i.e. the “work of wildfire”).

2. Materials and methods

2.1. Geographic scope and strata

Our study region encompasses all the forested areas of eastern Washington and Oregon states (USA), defined as east of the Cascade Range crest (Fig. 1). Broadly speaking, forest types include cold subalpine forests near the Cascade crest and other high elevations, moist mixed-conifer forests at middle elevations, and dry mixed-conifer and ponderosa pine forests at low elevations. Ecoregions include mainly the Washington and Oregon East Cascades, Washington Northeast - Okanogan, and the Oregon Blue Mountains; plus additional small forested areas of the Washington Columbia Basin and Oregon Southeast (Fig. 1; see Appendix A for details on ecoregions and specific potential vegetation types within). Annual precipitation ranges from ~ 400–600 mm yr^{-1} in the driest forest types to ≫1000 mm yr^{-1} (with a large fraction as snow) in cold forests, and includes a pronounced summer dry (fire) season (Franklin and Dyrness 1973). Mapped fire regimes range from dry forests with relatively frequent return intervals (~10–50 years) of predominantly low-severity fire and small patches of stand-replacement, to cold subalpine forests with infrequent (~75–300 years), predominantly moderate- to high-severity (stand-replacing) fires; intermediate are moist forests with low- to mixed-severity fire regimes at intervals of ~ 20–100 years (Agee 1993, Agee 2003; Landfire 2018; landfire.gov; see Appendix A and Haugo et al., 2019 for full list of forest biophysical settings and fire rotations).

The study region comprises the lands of the traditional peoples of the Columbia and eastern Klamath basins, which today are represented in large part by the Confederated Tribes of the Colville Reservation, the Kalispel Tribe, the Spokane Tribe of Indians, and the Yakama Nation, based in what is now the state of Washington; the Nez Perce Tribe, today based in adjacent Idaho; and the Confederated Tribes of the Umatilla

Fig. 1. Study area encompassing all forested areas of eastern Oregon and Washington (i.e. east of the Cascade crest).

Indian Reservation, the Confederated Tribes of Warm Springs, the Klamath Tribes, and the Burns Paiute Tribe, based in what is now Oregon. Cultural burning practices were widespread among many of these groups (Boyd 1999, Knight et al., 2022).

Current land management in the study area is primarily federal lands (US Forest Service: 5.3 million ha; other federal lands [e.g. National Park Service, Bureau of Land Management]: 0.3 million ha), followed by private lands (2.2 million ha), tribal lands (0.7 million ha), and state and local government lands (e.g., Oregon Department of Forestry, Washington Department of Natural Resources, Washington Department of Fish & Wildlife; 0.5 million ha).

We stratified our study area by ecoregion, potential vegetation type (PVT), and broad land ownership categories. Ecoregion and PVT layers were originally developed through the Integrated Landscape Assessment Project (ILAP, Halofsky et al., 2014), where each PVT represents the dominant treed vegetation present following succession and absent disturbance. We updated the ownership map from DeMeo et al. (2018) to account for ownership changes. Combining these three layers together resulted in our strata layer, the finest unit of analysis, representing ~ 8.9 million ha after removing non-forested areas and freshwater bodies. Within each ecoregion, we also related each PVT to a finer vegetation unit called biophysical setting, using a crosswalk originally developed by the US Forest Service and later refined by Haugo et al. (2019); this was necessary to develop historical estimates of area burned (described below).

2.2. Historical annual area burned

We built on the methods of Haugo et al. (2019), who estimated the area burned at low-, moderate-, and stand-replacing severity for Pacific Northwest forests under historical fire regimes by using Landfire biophysical setting models (Landfire 2018). For each biophysical setting model, Landfire developed estimates of the minimum, mean, and maximum fire return interval for low, moderate, and high severity fire under pre-European settlement conditions through an extensive literature and expert review process (Keane et al., 2002, 2006, 2007; Pratt et al., 2006; Rollins, 2009; DeMeo et al., 2018; LANDFIRE, 2018). These fire return intervals are intended to capture variability across a range of climatic conditions prior to the era of European colonization. In comparison to the original Landfire biophysical setting models, Haugo et al. (2019), and consequently this study, incorporated model updates gathered through the Landfire 2016 biophysical settings review (www.landfirereview.org). We used the same FRI values for the same biophysical settings (strata) from Haugo et al. (2019) to calculate historical annual area burned by solving for the parameter a_b in the basic fire rotation equation:

$$FR = t/(a_b/A) \tag{1}$$

where FR (fire rotation; in years) is mathematically interchangeable with point mean fire return interval (or FRI), A is the total area of interest (e.g. PVT area or region), t is time (in this case 1 year, in seeking annual rates), and a_b is area burned over time t (annually, when t is set at 1). For the purposes of solving the equation, all parameters but a_b are known quantities from either the literature (Landfire 2018; Haugo et al., 2019) or spatial data. This straightforward algebraic approach provides a way to translate estimated fire frequencies to estimates of fire area over time. We verified that estimates of burn area using this method are within ~5% of those derived from STSM analyses sensu Haugo et al. (2019).

We included a range of fire rotations for each stratum to incorporate uncertainty inherent in FRI estimates. Landfire-derived FRIs from Haugo et al. (2019) typically include mean, minimum, and maximum values. We computed burn area estimates using both the mean and maximum (longest) FRI for each stratum. These equate, respectively, to average and minimum area burned. Similar to North et al. (2012), we excluded the minimum (shortest) FRIs, representing maximum annual area burned, because the resulting values could be so large as to have low management relevance or practicality. This analysis of historical annual burn rates does not incorporate interannual variation in burn area; rather it is a broad assessment of long-term averages under active fire regimes. The 'minimum' and 'mean' historical burn areas we evaluate are both effectively long-term averages, under differing assumptions reflecting maximum and central estimates of long-term fire rotations, respectively. Interannual variation around those long-term averages is also important ecologically, but such variation does not impact the overall burn area over time needed to meet historical fire frequencies.

We calculated historical annual area burned using equation 1 for both total burn area and separately for each severity class using severity-specific FRIs for each PVT (low severity, primarily surface fire with <25% overstory mortality; moderate severity, 25–75% overstory mortality; high severity, >75% overstory mortality). In some instances, FRI was entirely absent for a given severity or was only provided for the mean but not for the longest FRI – this mostly affected non-high-severity fire in cold forests. To simplify summarization, we grouped all PVTs into dry, moist and cold forest types based on a preexisting ILAP crosswalk (Burcsu et al., 2014). We then summed area burned for each stratum (forest type, state, ownership) to develop relevant historical annual area burned estimates by severity class.

2.3. Contemporary annual area burned

Following methods by Parks et al. (2018, 2021), we developed burn severity maps for all fires in our study extent >400 ha from 1985 to 2020. We first uploaded fire perimeters into Google Earth Engine to develop Relative differenced Normalized Burn Ratio maps (RdNBR; Miller and Thode 2007). Fire perimeters for Washington State were collected from the Washington Department of Natural Resources (WA DNR) Large Fires database (https://geo.wa.gov/datasets/6f31b076628d4f8ca5a964cbefd2cccc) and Monitoring Trends in Burn Severity (MTBS) data. Washington DNR Large Fires data were collected from the National Interagency Fire Center (NIFC) at the conclusion of each fire season, and checked and adjusted for accuracy. Perimeter data for Oregon were compiled from a combination of NIFC and MTBS data. The datasets we analyzed included prescribed fires meeting the same 400-ha minimum (consistent records on smaller prescribed fires are lacking for much of the study area and were not added). However, where the most complete records are available (eastern Washington), large and small prescribed fires combined account for only ~ 7% of contemporary burn area, meaning that our analysis is largely of wildfire area.

Using RdNBR thresholds from Saberi and Harvey (2023), we classified each pixel within each fire into low (<25% overstory mortality), moderate (25–75%), and high (>75%) severity. Our low-severity category spanned collectively the unburned/very-low/low area within fire perimeters rather than splitting these sub-classes, given low confidence in the ability of remotely-sensed burn-severity metrics to reliably distinguish truly unburned areas. Pixels classified as nominally unburned make up ~ 7% of the average total burn area, or 3279 ha, annually (Appendix B). The classified data were then smoothed using a 3x3 pixel (90 m) moving window in order to minimize minor spatial errors (e.g., Landsat errors). We then overlaid each wildfire with our strata layer to identify the area burned at each severity by forest type, ecoregion, and ownership. We summed the contemporary fire data by year and compared with historical fire area estimates.

3. Results

3.1. Historical annual area burned

Regionally, across all forest types: For each forest type to burn at published historical frequencies, annual area burned would have averaged at least 224,400 to 291,100 ha (2.5–3.3% of forested area) across eastern Oregon and Washington (estimates derived from varying input between longest to mean published fire rotations, respectively) (Table 1). Of this total, 89,000–115,000 ha·yr^{-1} would have occurred in eastern Washington and 135,000–176,000 ha·yr^{-1} in eastern Oregon (Appendix C). Low-severity fire would account for 61–64% (143,700–178,000 ha·yr^{-1}) of annual burn area across the region. However, moderate-severity fire (25%; 56,800–72,500 ha·yr^{-1}) and high-severity fire (11–14%; 24,000–39,900 ha·yr^{-1}) would also cover substantial area across all forest types (Table 1).

By forest type: Because dry forests account for both the largest portion (60%) of the region and the most frequent fire regimes, they would account for 82–88% of annual burn area (194,300–248,300 ha·yr^{-1})–(Table 1). Dry forest burn area would include 74,800–93,900 ha·yr^{-1} in Washington and 119,500–154,417 ha·yr^{-1} in Oregon, 69–72% of which would be low severity and 7–10% of which would be high severity (Table 1; Appendix C). Moist forest annual burn area would average an order of magnitude less than in dry forests, but would still be substantial at 21,700–29,600 ha·yr^{-1} (8600–11,500 ha·yr^{-1} in Washington, 13,100–18,100 ha·yr^{-1} in Oregon) with a plurality (49–54%) of moderate-severity area (Table 1; Appendix C). In cold forests, which account for the smallest land area and the most infrequent fire regimes, annual burn area would average 8500–13,200 ha·yr^{-1} (6000–9400 ha·yr^{-1} in Washington, 2500–3800 ha·yr^{-1} in Oregon), with a plurality (49–62%) of high-severity area (Table 1; Appendix C).

By land ownership: Because forest type distributions are qualitatively similar among ownerships, overall trends and those by forest type are essentially similar for each ownership (Table 2). For example, dry forests predominate on all major land ownerships (50–78% of area); thus all ownerships would be characterized by large annual areas of low-severity fire historically (along with large areas of other severities) (Table 2).

See Appendix C for further detailed estimates of historical annual area burned by state and ownership within each state.

Table 1
Estimates of historical area burned by severity class for the three grouped forest types across eastern Oregon and Washington.

Forest type*	Total area (ha) [% of study region]	Predominant nominal fire regime	Historical: Annual hectares burned by severity class (historical average, under *longest* rotations)	Historical: Annual hectares burned by severity class (historical average, under *mean* rotations)	Contemporary average annual hectares burned, by severity class (1985–2020)
Cold	1,527,291 [17%]	Infrequent, high severity	Low: 300 (4%)Mod: 3700 (44%)High: 4500 (53%) *Total: 8500*	Low: 500 (4%)Mod: 5500 (42%)High: 7200 (54%) *Total: 13,200*	Low: 3829 (29%)Mod: 3296 (25%)High: 6306 (47%) *Total: 13,430*
Moist	2,063,564 [23%]	Moderately frequent, mixed severity	Low: 5100 (24%)Mod: 11,300 (52%)High: 5300 (24%) *Total: 21,700*	Low: 6200 (21%)Mod: 14,800 (50%)High: 8500 (29%) *Total: 29,600*	Low: 3612 (44%)Mod: 2534 (31%)High: 2120 (26%) *Total: 8265*
Dry	5,311,868 [60%]	Frequent, low severity	Low: 138,300 (71%)Mod: 41,800 (22%)High: 14,200 (7%) *Total: 194,300*	Low: 172,000 (69%)Mod: 52,100 (21%)High: 24,200 (10%) *Total: 248,300*	Low: 12,062 (44%)Mod: 8592 (31%)High: 6752 (25%) *Total: 27,406*
Total	8,902,723		Low: 143,700 (64%)Mod: 56,800 (25%)High: 24,000 (11%) *Total: 224,400*	Low: 178,700 (61%)Mod: 72,500 (25%)High: 39,900 (14%) *Total: 291,100*	Low: 19,503 (40%)Mod: 14,421 (29%)High: 15,178 (31%) *Total: 49,102*

* The top three PVTs by area in each broad forest type are: Cold (subalpine fir-cold/dry, mountain hemlock-cold/dry, subalpine parkland); Moist (grand fir-cool/moist, mixed conifer-cool/moist, western redcedar/western hemlock-moist); Dry (Douglas-fir-dry, mixed conifer-dry, ponderosa pine-xeric). See Appendix A for further details relating PVTs to forest types.

† Predominant nominal fire regime refers to the most common published fire frequency/severity for PVTs within each forest type. Area-burned values are rounded to nearest hundred hectares for visual clarity and to account for the broad nature of the estimates.

Table 2
Comparison of historical and contemporary annual area burned by land ownership.

Land manager	Forest type	Total acres (% of ownership)	Hectares burned per year historically† (*contemporary averages in parentheses*)			
			Low severity	Moderate severity	High severity	Total burn area
Forest Service	Cold	1,276,696 (24%)	245–386 (*3227*)	3210–4800 (*2769*)	3760–6010 (*5579*)	7200–11,200 (*11,575*)
	Moist	1,370,286 (26%)	3410–4140 (*2653*)	7444–9798 (*1704*)	3538–5709 (*1532*)	14,391–19,642 (*5889*)
	Dry	2,624,345 (50%)	69,482–87,297 (*6969*)	21,139–26,099 (*4805*)	6994–11,740 (*4367*	97,615–125,136 (*16,141*)
	All	5,271,328	73,135–91,818 (*12,849*)	31,788–40,701 (*9278*)	14,295–23,455 (*11,479*)	119,218–155,974 (*33,605*)
Other federal	Cold	49,426 (18%)	14–23 (*56*)	191–272 (*42*)	115–169 (*36*)	321–464 (*135*)
	Moist	37,514 (14%)	150–190 (*40*)	224–323 (*47*)	101–164 (*31*)	475–677 (*118*)
	Dry	186,972 (68%)	3620–4540 (*494*)	1350–1780 (*397*)	497–828 (*248*)	5471–7140 (*1140*)
	All	273,912	3790–4750 (*591*)	1770–2370 (*486*)	713–1160 (*316*)	6270–8290 (*1393*)
State & local	Cold	66,371 (14%)	16–25 (*84*)	94–149 (*75*)	204–344 (*114*)	313–518 (*273*)
	Moist	91,599 (19%)	212–248 (*88*)	510–668 (*105*)	236–372 (*71*)	958–1290 (*264*)
	Dry	332,876 (68%)	8960–10,850 (*553*)	2580–3220 (*598*)	900–1590 (*436*)	12,440–15,660 (*1587*)
	All	490,847	9190–11,100 (*724*)	3180–4030 (*779*)	1340–2310 (*621*)	13,700–17,500 (*2124*)
Tribal	Cold	98,935 (14%)	34–54 (*417*)	162–241 (*371*)	288–427 (*537*)	464–722 (*1324*)
	Moist	131,165 (19%)	359–415 (*467*)	715–969 (*417*)	305–495 (*376*)	1379–1880 (*1260*)
	Dry	460,212 (67%)	12,600–15,100 (*2255*)	3440–4320 (*1425*)	1250–2250 (*589*)	17,280–21,700 (*4269*)
	All	690,312	13,000–15,600 (*3139*)	4320–5530 (*2213*)	1820–3170 (*1502*)	19,100–24,300 (*6853*)
Private	Cold	35,861 (2%)	4–6 (*46*)	40–72 (*38*)	130–225 (*39*)	174–303 (*123*)
	Moist	433,000 (20%)	984–1200 (*365*)	2380–3080 (*260*)	1130–1810 (*109*)	4490–6080 (*735*)
	Dry	1,707,463 (78%)	43,600–54,200 (*1790*)	13,300–16,700 (*1367*)	4540–7780 (*1112*)	61,500–78,700 (*4269*)
	All	2,176,324	44,600–55,400 (*2200*)	15,500–19,800 (*1666*)	5790–9810 (*1261*)	66,100–85,100 (*5127*)

† Historical burn areas reflect minimum to mean estimates of annual area burned under, respectively, the longest and mean fire rotations.

3.2. Contemporary annual area burned

Regionally, across all forest types: Annual area burned in the contemporary era has been well below historical levels nearly every year (Fig. 2). The 36-year average for 1985–2020 was 49,100 ha·yr^{-1} total (all burn severities) across the region (Fig. 2; Table 1), with 23,000 ha·yr^{-1} in Oregon and 26,100 ha·yr^{-1} in Washington (Appendix C).

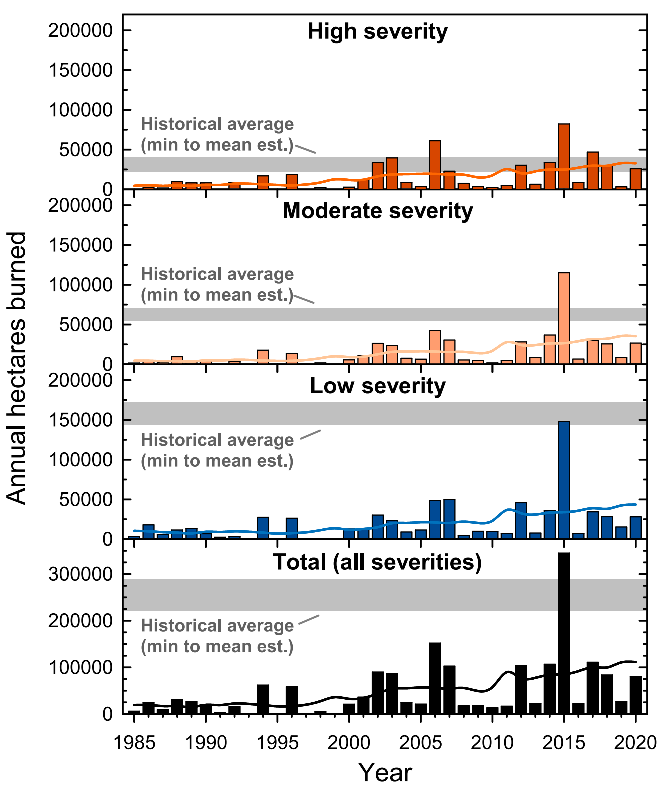

Fig. 2. Annual hectares burned each year in the contemporary era (1985–2020), region-wide across all forest types, compared to backdrop of historical average annual area burned. Trend lines depict a spline-smoothed 10-year running mean. Historical estimates (horizontal gray bars) span minimum to mean averages of annual area burned under, respectively, the longest and mean fire rotations from Haugo et al. (2019) and Landfire.

These levels represent just 13–29% of historical rates, depending on the state and whether using minimum or mean historical burn areas. Only one contemporary year met or exceeded historical area burned regionally (2015, driven by large fires in Washington). No other contemporary year attained>67% of the low-end estimate of historical area burned regionally. Further, 34 of 36 years burned less than half of the historical minimum estimate (Fig. 2). The latter part of the contemporary period generally had the largest fire years, but 10-year running averages – and nearly every year – were still well below historical averages.

Contemporary trends in area burned by severity class largely follow those for overall burn area, with fires of all severity classes generally well below historical levels (Fig. 2). However, there were monotonic trends among severity classes in terms of deficit between contemporary and historical annual burn area, with low- and moderate-severity fire having the largest deficits, and high-severity having a smaller but still present deficit. Of the 36-year record, only nine years met or exceeded historical levels of high-severity fire, and just one year approached or exceeded historical levels of low-severity and moderate-severity fire (2015) (Fig. 2). Further, a strong majority of contemporary years had less than half of historical averages of area burned for every severity class (high severity, 25 of 36 years; moderate severity, 32 of 36 years; low severity, all 36 years) (Fig. 2).

On a proportional basis, there was relatively more high severity fire and less low severity fire than historical levels. Low-severity fire has accounted for an average of 46% of contemporary wildfire area (range 0–100% annually; Figs. 2, 3), and moderate-severity fire for another 27% (range 0–39% annually; Figs. 2, 3). That is, low- to moderate-severity fire combined accounts for 73% of contemporary fire years on average. High-severity fire accounts for an average of 27% of contemporary burn area (range 0–55% annually; Figs. 2, 3). This 46:27:27 ratio of low:moderate:high severity differs substantially from historical estimates of 61:25:14 L:M:H proportions – mostly in the shift of low-severity area to high-severity area (Table 1; Fig. 3).

By forest type: Contemporary annual burn areas are much lower than historical rates for dry and moist forests covering the large majority of the study area – for all burn severities (Fig. 3). By far the largest deficits between contemporary and historical rates are in dry forests, where low-severity fire is missing 126,000–160,000 ha·yr^{-1} and moderate-severity fire is missing 33,000–44,000 ha·yr^{-1} (Fig. 3). The next tier of deficits are those for moderate-severity fire in moist forests (missing 9000–12,000 ha·yr^{-1}) and high-severity fire in dry forests (missing 7000–17,000 ha·yr^{-1}; which stems from a low historical proportion but

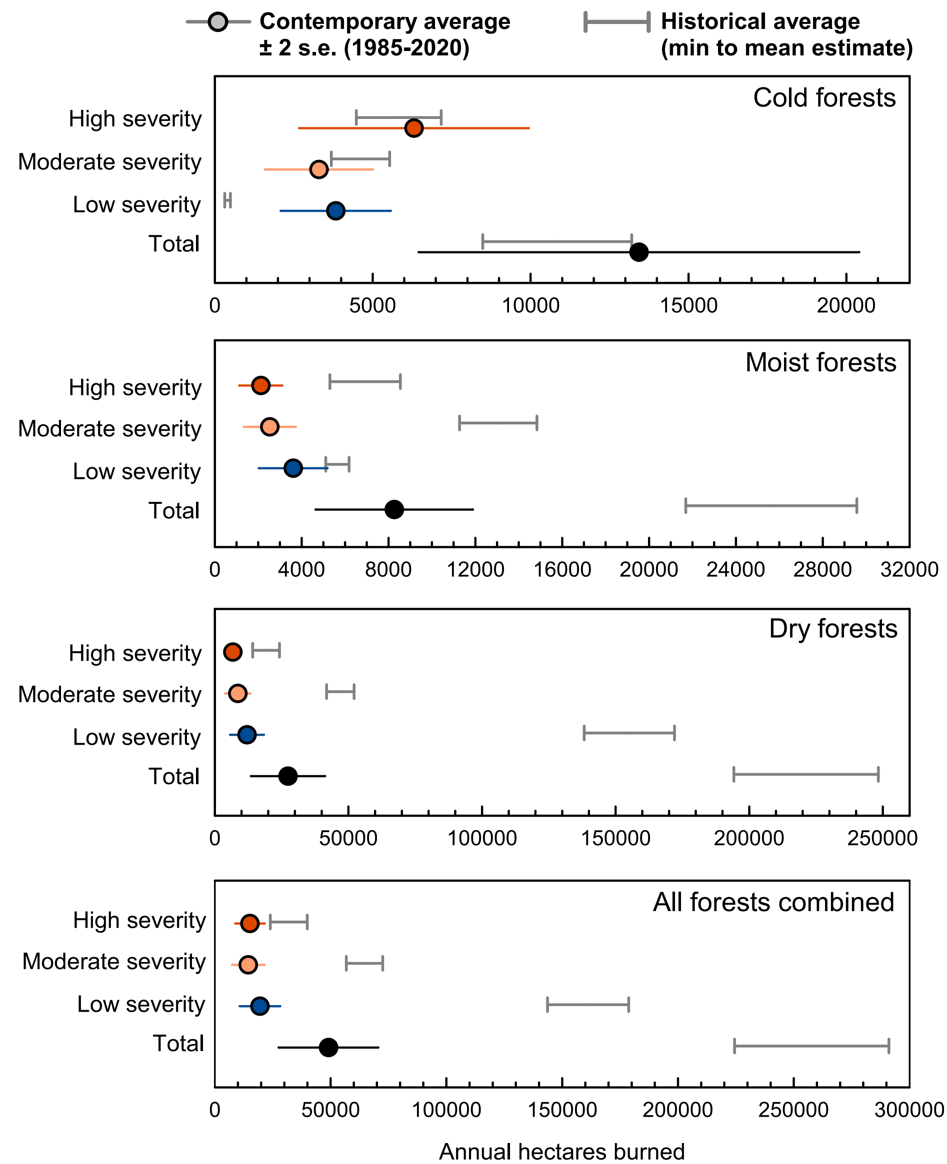

Fig. 3. Comparison of historical estimates of annual area burned (bars) to contemporary levels (circles) by forest type and severity class. Historical estimates span minimum to mean averages of annual area burned under, respectively, the longest and mean fire rotations from Haugo et al. (2019) and Landfire. Contemporary data are means and 2 standard errors across the 36-year period.

large land area) (Fig. 3). Moist forests also currently have deficits of low-severity (missing 1500–2600 ha·yr^{-1}) and high-severity fire (missing 3000–6000 ha·yr^{-1}) (Fig. 3). Cold forest burn area in the contemporary period is closer to historical averages for moderate- and high-severity fire, and has relatively large areas of low-severity fire compared to historical estimates (Fig. 3).

Trends by severity class are generally similar by forest type, with most contemporary burn area in dry and moist forests being low (44%) or moderate severity (31%) (Fig. 3). This L:M:H ratio of ~ 44:31:25 differs from estimated historical ratios of 69:21:10 in dry forests and 21:50:29 in moist forests (Table 1; Fig. 3). In cold forests, contemporary severity ratios (30:26:49) differ from historical ratios (4:42:54) mainly in more low-severity and less moderate-severity fire (Fig. 3).

By land ownership: Annual area burned in the contemporary era is far less than historical rates across all land ownerships (Table 2). Federal lands and private lands account for the vast majority of fire deficits, owing to being the largest land bases and, for private lands, being heavily dominated by dry forest types (Table 2).

See Appendix C for further detailed comparisons of contemporary and historical annual area burned by state, ownership, and ecoregion.

4. Discussion

Our findings illustrate the estimated rate and spatial extent of burning that maintained fire-dependent forests. Historical rates of annual area burned dwarf both contemporary wildfire area and current forest restoration treatment rates, providing important context for understanding the connections among the three. Three key takeaways emerge: 1) historically, for all the forest types of the inland Pacific Northwest to have burned at published frequencies, a significant fraction of the land base – hundreds of thousands of hectares – would have burned each year, albeit with substantial year to year variation; 2) the contemporary era (1985–2020) has been much less fiery than the historical era – by nearly an order of magnitude when comparing averages of annual area burned; and 3) these burned-area rates demonstrate that successful forest restoration and maintenance will likely require both increasing active treatment rates and incorporating managed wildfire.

4.1. Historical rates of annual area burned

Fire frequencies that historically maintained fire-dependent forests are widely recognized and understood (e.g., Agee 1993, Agee 2003; Hagmann et al., 2021), but these frequencies are rarely appreciated in terms of rates of annual area burned (North et al., 2012, North et al., 2021; Haugo et al., 2019). In short, for all the forest types of a region to burn at published historical frequencies, a certain fraction of the land base – hundreds of thousands of hectares, in the case of the inland Pacific Northwest – would have burned each year, on average (Figs. 2-3; Tables 1-2). The benefit in understanding these rates is not necessarily to suggest a return to historical fire regimes, as the contemporary landscape (both ecological and social) presents different realities and constraints on what is practical or desirable. Nonetheless, quantifying the amount of fire that maintained vegetation structure, composition, and pattern resilient to frequent disturbance and drought through time (Hessburg et al., 2019, Keane et al., 2009) does provide illustrative context. Understanding rates of area burned historically not only helps better contextualize current fire years, but also provides a guidepost for the relevant order of magnitude when setting treatment targets for landscape level restoration and climate adaptation efforts (e.g., WA DNR, 2020; Raymond et al., 2014) – including maintenance needs.

A similar assessment can be readily conducted for virtually any forest type, provided there are published estimates of historical fire rotations (ideally by severity class). In essence, this approach is a straightforward exercise that reduces Equation 1 to simply dividing the landscape area by its fire rotation(s), yielding an average annual area burned. There are caveats to these estimates of historical area burned. First, they are only as good as the underlying certainty in published fire rotations; if the latter are inaccurate, uncertain, or based on metrics that can be scale-dependent like composite fire intervals (rather than the most mathematically pertinent metrics of fire rotation or point mean fire return interval), the resulting area-burned estimates will propagate these limitations. One example in our dataset includes low-severity fire in cold forests, for which historical fire rotations are scarcely available or indicate very low amounts/frequencies (Fig. 3); it is likely that cold forests also had a substantial fraction of low-severity fire (as even high-severity regimes tend to include) that doesn't register well in tree-ring or remotely-sensed data (Cansler et al., 2018) – making our historical hectares burned for that category likely to be underestimated. (Similarly, this approach could be used to reveal and address shortcomings or inconsistencies in historical fire regime parameters.) Even so, for most forest types with a literature base of fire history studies, a general (and useful) order of magnitude of area burned can be derived despite some uncertainties in fire rotations.

Additionally, interannual variation must also be acknowledged, as our approach yields only long-term averages of annual area burned. This long-term average, and the resulting cumulative burn area over decadal time scales (Haugo et al., 2019), is ultimately what drives ecological conditions over time. Historically, many years likely burned substantially less or more than the average based on variations in climate, ignitions, and fuels – potentially ranging over an order of magnitude (see Heyerdahl et al., 2008). This is particularly true in moist and cold forests with longer fire return intervals. Thus while historical annual averages provide a useful benchmark for assessing an individual year, it is also useful and important to assess how an individual year contributes towards longer term averages (e.g. as part of a 5-, 10-, or 20-year running mean; see Fig. 2).

One key to assessment of historical area burned is separation by burn severity class (Figs. 2-3, Tables 1-2). Overall area burned provides an initial sense of scale, but burn area by severity class is ultimately the most relevant basis for evaluation. It is also important in showing that all severities occur in all forest types and fire regimes, just in differing proportions. For example, even dry forests, known primarily for low- and moderate-severity fire regimes, also have a characteristic component of high-severity fire, albeit in smaller proportions (i.e. long severity-specific rotations) (Fig. 3; Table 1; Haugo et al., 2019; Landfire 2018). Our analysis does not consider patch sizes of each severity class (see below); however, high-severity (stand-replacing) patches are generally considered to have been smaller in dry forests than in moist and especially cold forests under active fire regimes (Hessburg et al., 2015). Analysis by burn severity is also important in showing that, for forests predominated by higher-severity fire (e.g., cold subalpine forests), stand-replacement is a characteristic phenomenon, generating substantial areas of early-seral habitat, long-term meadows and openings, and generally structuring the landscape in terms of seral-stage abundances (Fig. 3; Table 1). Overall, however, a prevailing takeaway from historical regimes is the overwhelming abundance of low- and moderate-severity fire in dry and moist forests, which would have accounted for 86–89% (~200,000–251,000 ha) of annual area burned across the region (Table 1).

Such large area burned historically likely reflects the sum of both Native American fire management (Boyd 1999, Knight et al., 2022) and lightning ignitions. In particular, the preponderance of low- and moderate-severity fire is consistent with both fuel-limited conditions (i.e. fire-fuel feedbacks) in many dry and moist forests, as well as cultural-burning ignitions that may have focused on setting fires outside of extreme-weather conditions (e.g. shoulder seasons, moderate weather). Native peoples set fires in interior Pacific Northwest forests to produce food and fiber, support ceremonial practices, clear travel corridors, and promote hunting, among other uses (Boyd 1999; Knight et al., 2022). These fires were presumably a major component of the frequent fire regimes that maintained inland Pacific Northwest forests. The substantial reduction in ignition frequency (particularly under moderate conditions) in the modern era compared to the era of widespread Native American land management is an important piece of context in comparing contemporary and historical fire regimes.

4.2. Contemporary annual area burned

The contemporary era (1985–2020) has been much less fiery than the historical era – by nearly an order of magnitude (Figs. 2-3). Not only are averages across contemporary years a fraction of historical averages, but recent "record-breaking" fire years (e.g., 2002 in Oregon, 2015 in Washington, 2015 regionally; Fig. 2, Appendix C) are actually only records by contemporary standards; they were in fact the only years that attained historical averages (Fig. 2). While contemporary wildfires have produced a range of impacts, including many that have been destructive to human communities and some landscapes, it is also clear that from at least the perspective of comparing to historical amounts, most contemporary fire years are best characterized not as too much fire, but rather too little. This notion remains true when looking at the most recent 10 years: despite the increase in fire over this time, the 10-year contemporary average remains below historical levels (Fig. 2).

Fire of all severities is relatively lacking across dry and moist forest types that account for most of the region's forested area (Fig. 3; Table 2). The most striking deficits are those for low-severity in dry forests and moderate-severity fire in both dry and moist forests (Fig. 3). However, perhaps somewhat surprisingly, there is also a deficit of high-severity fire across most of the study region – even in dry forests – when comparing to historical area burned (Fig. 3). (Note this does not account for potential shifts in patch sizes, discussed below.) Cold subalpine forests are the only zone in which contemporary area burned approaches that of the historical era (Fig. 3). It is important to note that these regional totals for fire can mask different trends in specific areas. North Central Washington, for example, has experienced a particularly large amount of high-severity fire in dry forests, at levels and in patch sizes that likely exceed historical levels (Reilly et al., 2017, Churchill et al., 2022, WA DNR, 2022a,b).

While shifts toward greater proportions of higher-severity fire are clearly among the important trends of the contemporary era, it is also worth noting that a strong majority (69%) of contemporary area burned has still been of low to moderate severity (Figs. 2-3). Applying a basic (albeit perhaps imperfect) assumption that low-severity fire is broadly consistent with common forest restoration objectives (as low-severity fire is defined as consuming fine surface fuels, reducing small-tree/understory densities, and causing little overstory mortality; Agee 1993; Pyne et al., 1996, Stephens et al., 2021), this suggests that on average, each year a substantial area of dry and moist forest (~15,700 ha) is being 'treated' by wildfire in a manner similar to prescriptive treatments. (Cold forests are excluded from this estimate, as low-severity treatments are less commonly needed or prescribed in such forests naturally structured by higher-severity fire regimes.) If including moderate-severity fire, which has many of the same effects as low-severity fire and also thins overstory trees (and recognizing that moderate levels of tree mortality/removal can be beneficial in restoring structure in dense stands; Greenler et al., 2023), another 11,100 ha of dry and moist forest are receiving some form of non-stand-replacing fuel treatment (Figs. 2-3) – meaning that a total of 26,800 ha per year are receiving such wildfire-driven treatments. Even so, in some cases fire (particularly moderate-severity fire) can act as an initial treatment entry that may need additional treatments to maintain fuel loads within target ranges (Larson et al., 2022; Greenler et al., 2023).

Comparing with rates of active management treatments (e.g. mechanical thinning, prescribed fire), using eastern Washington as an example: the contemporary average annual area of low- and moderate-severity wildfire amounts to 13,200 ha·yr^{-1} in dry and moist forests, while active forest health treatments over the 5 years spanning 2017–2021 averaged ~ 23,500 ha·yr^{-1} (~1800 ha·yr^{-1} for prescribed fire and ~ 21,700 ha·yr^{-1} for other treatments [WA DNR, 2022b]; Oregon numbers are not readily available). This active treatment area represents our estimate of forest health treatment hectares (from WA DNR, 2022b) that are relevant to mitigating fuels and potential fire severity. Each of these modern rates—and their combined total of 36,700 ha·yr^{-1}—is a fraction of historical rates (e.g., 75,900–92,200 ha·yr^{-1} of low + moderate severity in dry and moist forests in eastern Washington). This comparison underscores the need to both increase active treatment rates and to recognize the substantial area of additional treatment effected by wildfires. Our findings are consistent with other research indicating that current rates of mechanical treatment and prescribed fire are not sufficient to both restore landscapes and maintain restored conditions (North et al., 2021; Kolden 2019), especially as vegetation and fuels grow and accumulate every year. In fact, rates of prescribed fire decreased in eastern Washington over the past decade (Podschwit et al., 2021; foresthealthtracker.dnr.wa.gov/).

Given climate change projections and recent increases in drought and associated insect outbreaks and high-severity fires across the western US (Stephens et al., 2018; Field et al., 2020), the timeframe to create more climate- and wildfire-adapted landscapes is short. This underscores the role of landscape-level wildfire response strategies based on informed risk analysis that can allow fires to accomplish positive work during moderate fire weather, while suppressing and containing fires in high-risk locations or during unfavorable weather periods (Barros et al., 2018, Thompson et al., 2018; Young et al., 2019; Dunn et al., 2020; Ager et al., 2022). Without significantly greater use of managed wildfire, in combination with major increases in prescribed fire or other treatments, it will be challenging to achieve wildfire risk reduction and landscape climate adaptation goals in a meaningful timeframe (North et al., 2012, North et al., 2021; Ager et al., 2022).

These observations about wildfire treatments in the contemporary era account only for area burned (by severity), not other critical factors such as patch sizes or trends in severity proportions within the contemporary period. Although historical patch size distributions have not been thoroughly quantified across forest types, the generally expected pattern based on theory (Keane et al., 2002) and empirical evidence (White 1985; Hagmann et al 2021; Agee 2003) is that stand-replacement patches were relatively small in dry forests, with median and maximum patch sizes increasing in size through moist forests, to cold forests where large patches of stand-replacement were common and characteristic. Many fires in the contemporary era have included large patches of high-severity fire across all forest types, including dry forests where large patches may have been rare before (Reilly et al., 2017; WA DNR, 2022a; Churchill et al., 2022; Buonanduci et al., in press). Thus, while the absolute amount of high-severity fire in dry forests may be below historical rates, uncharacteristically large stand-replacement patches could present different or novel ecological conditions such as major limitations on seed sources over broad areas (Donato et al., 2016; Coop et al., 2020).

Also, trends in severity proportions toward more high-severity and less low-severity fire during the 36-year contemporary record suggest a drift in how contemporary fires interface with restoration objectives. Fire years in the first half of the record generally contained larger proportions of low-severity fire, and smaller portions of high-severity fire than those in the second half (see trendlines in Fig. 2) – similar to trends in other regions (Harvey et al., 2016; Parks and Abatzoglou, 2020). Even so, many of the later years in the record remain below historical levels for all severity classes (Fig. 2). Detailed unpacking of this temporal trend, its causes, and how we may consider them under a changing climate (e.g., the relative importance of historical context versus developing new expectations) are beyond the scope of this paper, but merits attention when considering the role of future wildfire seasons.

4.3. Does large area burned mean a bad fire year?

This analysis suggests that area burned – and, notably, large area burned – is by itself not a useful indicator of a problematic or bad fire season. Other criteria in current use relating to social impacts, such as loss of life or property and impacts to human health, are universally accepted as relevant now and into the future. For area burned, however, while small fire seasons minimize certain short-term risks, they also further deepen accumulated fire deficits, limit the treatment effect of large portions of burn footprints (e.g., low and moderate severity in dry forests), and often result in further departure from fire- and climate-resilient conditions (North et al., 2012, North et al., 2021; Haugo et al., 2019; Laughlin et al., 2023). This study puts numbers to this notion, quantitatively underscoring the degree to which small fire seasons, as well as a management focus on minimizing the occurrence or size of fires, extends long-running fire deficits that are the core of a key forest resilience issue.

A broader assessment of fire impacts could place fire seasons in a more meaningful context. Rather than a narrative centered simply on absolute area burned, a broader evaluation would consider both the impacts and the 'work' accomplished by wildfires. The 'work' of wildfire can be thought of as the degree to which stand- and landscape-scale fire effects are consistent with science-based objectives for ecosystem resilience or planned forest restoration/maintenance treatments. In essence, the question shifts from "how many hectares burned?" to "how many hectares burned that produced desired versus deleterious outcomes – ecologically and socially?" (See WA DNR, 2022a,b). Relevant factors in this broader analysis would include the analysis presented here: whether area burned by forest type (fire regime) and severity class approach historical annual rates. Other factors could include how much area received desired treatment effects, whether departure from resilient conditions increased or decreased (Laughlin et al., 2023), whether patch size distributions (by burn severity and forest type) were consistent with historical and/or future landscape resilience, whether large fire-resistant (and hard to replace) trees or critical wildlife habitat were lost at rates or in areas that preclude future management options, as well as a range of human/social impacts (e.g., Bowker et al., 2008; Calkin et al., 2014). These factors can be evaluated in aggregate or individually, recognizing that virtually every fire year will comprise a mix of these effects. Post-fire management needs such as density and fuel reduction treatments to complete the "work" of low- and moderate-severity treatments could also be assessed (Larson et al., 2022. Stevens et al., 2021; Greenler et al., 2023).

Similarly, individual fires can be viewed through this broader lens. For example, the term 'mega-fire' is often tied to simply having a large footprint, but even (or perhaps especially) large fires have the potential for both negative impacts and positive ecological work (Keane et al., 2008; Stephens et al., 2014). In light of the data we present here, very large burn footprints would likely be mathematically necessary for landscapes to have attained such large area burned historically. Thus, while some large fires can be clearly detrimental or create conditions outside historical/characteristic behavior for a given landscape (e.g., very large stand-replacement patches in dry forests; Cansler and McKenzie, 2014; Coop et al., 2020; Cassell et al., 2019; Singleton et al., 2021; Churchill et al., 2022, Povak et al., 2020; Cova et al., 2023), simply being large is not itself sufficient to count a fire as problematic.

Promising approaches to more comprehensively evaluating fire years and individual fires are beginning to emerge. For example, recent fire years have been evaluated for the state of Washington, including the work affected by wildfire in the context of historical/active fire regimes (Churchill et al., 2022; WA DNR, 2022a). These works recognize the potential role of wildfires relative to forest restoration objectives, and assess relevant portions of burned areas toward or against those objectives (WA DNR, 2022a). These assessments also further link observed wildfire behavior and impacts to active treatments by evaluating the degree to which prior treated areas were used or leveraged in fire operations (WA DNR, 2022a); this has relevance not only for safety and efficacy of operations, but also for landscape fire management approaches such as Potential Operational Delineations (PODs; Dunn et al., 2020) that can increase the role of wildfire use as a management tool. It can also provide recognition of when fire management teams achieve beneficial fire effects, from the many decision points that occur during wildfire operations and planning (Dunn et al., 2020).

5. Conclusion

Although recent large fire years have broken modern records and can be destructive in important ways, it is perhaps surprising to see exactly how small most contemporary years are relative to those under historical/active fire regimes, in which lightning- and Native American-ignited fires maintained forest resilience over time (Figs. 2-3). Because those processes occurred at rates that dwarf today's active treatment rates, combined with the observation that well over half of contemporary wildfire area is likely contributing to forest restoration objectives, there is potential benefit in re-evaluating the role of wildfire and what constitutes a 'good' or 'bad' wildfire year. Annual area burned, by itself, is arguably not an overly useful metric of a fire year. In the least, the narrative around area burned could be more nuanced – or even flipped, in some respects. Although wildfires are an inherently blunt tool with both positive and negative impacts (Churchill et al., 2022), forest and fire management approaches that recognize the beneficial effects of wildfire will become increasingly important. Indeed, given trends in drought, fires, insect outbreaks, and the enormous scale of the restoration backlog compared to rates of active treatment, the only realistic way to treat forest landscapes fast enough - and maintain them over time - is by not only increasing rates of active treatment but also harnessing the work of wildfire in appropriate places and under safe conditions, while minimizing negative impacts. Over time, doing so would likely provide managers increasing flexibility to use both prescribed fire and wildfire to foster forest resilience and maintain fire-dependent ecosystems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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