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Spatial and temporal changes in wildfires and their attributes across the western United States

Amirhossein Montazeri[1], **John Abatzoglou**[2], **Jeffrey Prestemon**[3], **Karen Short**[4], **Erin Belval**[5], **Zachary Holden**[4], **Jennifer Pierce**[6], **Jodi Mead**[7], **Yavar Pourmohamad**[1], **Ata Akbari Asanjan**[8] and **Mojtaba Sadegh**[1,9,*]

[1] Department of Civil Engineering, Boise State University, Boise, ID, United States of America
[2] Management of Complex Systems Department, University of California, Merced, CA, United States of America
[3] U.S. Forest Service, Southern Research Station, Research Triangle Park, NC, United States of America
[4] USDA Forest Service Rocky Mountain Research Station, Missoula, MT, United States of America
[5] USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, United States of America
[6] Department of Geosciences, Boise State University, Boise, ID, United States of America
[7] Department of Mathematics, Boise State University, Boise, ID, United States of America
[8] Research Institute for Advanced Computer Science (RIACS) at Universities Research Space Association (USRA), Mountain View, CA, United States of America
[9] United Nations University Institute for Water, Environment and Health, United Nations University, Richmond Hill, ON, Canada
[*] Author to whom any correspondence should be addressed.

E-mail: mojtabasadegh@boisestate.edu

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Supplementary material for this article is available online

Abstract

It is widely perceived that wildfire activity has increased across the western United States (WUS), with studies generally focusing on large wildfires. This study examines changes in the number of wildfire ignitions and burned area in the WUS using a comprehensive record of more than 750 000 wildfire incidents from 1992 to 2020 across biophysical gradients, seasons, and ignition causes. It further analyzes the environmental conditions associated with elevated fire activity. Our analysis comparing the periods 1992–2006 and 2007–2020 indicates that the annual number of recorded wildfires (>0.04 ha) in the WUS declined by 31% despite a 40% increase in burned area. This finding denotes that although wildfire prevention and mitigation strategies have decreased the overall number of fires, environmental conditions promoted larger fire sizes. Burned area increased in both forested and non-forested areas and across human- and naturally-ignited fires, with the greatest increase (84%) observed in lightning-caused forest fires. The seasonality of natural ignitions remained largely unchanged from 1992 to 2020, whereas the average day of year of ignition for human-caused wildfires shifted >12 d earlier (statistically significant), driven by an increasing number of springtime ignitions across the WUS. Ignitions increasingly occurred on days with abnormally drier-hotter weather compared to their climatology. Our analysis also showed that the median energy release component activation threshold associated with wildfire ignitions was ∼42 (interquartile range, IQR: 34–50 across ecoregions). Activation threshold refers to the fire danger level beyond which the number of ignitions increases markedly. This threshold for fire size area was ∼50 (IQR: 43–60). Findings of this study provide critical information for the development of wildfire prevention and mitigation strategies.

1. Introduction

Wildfires, hereafter 'fires', have been increasingly impacting natural and human systems (Dennison *et al* 2014, Bowd *et al* 2019, Kampf *et al* 2022, Nelson *et al* 2022). Widespread increases in fire activity, including a notable surge in burned area (Littell *et al* 2009, 2018) and the number of large fires (Dennison *et al* 2014), have been reported across the western United States (WUS) in recent decades. These trends co-occur with decades of fire exclusion that led to anthropogenic fire deficits (Littell *et al* 2018, Parks et al 2025a) and increased fuel loads in forests of the WUS, which, when combined with warming and drying in the region, made the landscape more conducive to large fires (Bowman et al 2011, Kitzberger et al 2017, Holden et al 2018).

Understanding the drivers and controls of fire activity is ever more essential to mitigate the adverse impacts of increasingly destructive fires (Alvarado et al 2020, Seydi et al 2025). Fire is a threshold-dependent, nonlinear, ecoregional phenomenon (Zhao et al 2025). Each ecoregion, defined by similar biogeographic conditions, has characteristic fire drivers, and as a result, the thresholds that 'activate' fire ignition and/or area burned differ across ecoregions (Bradstock 2010). Characterization of these thresholds can elucidate the social and environmental circumstances that facilitate fire ignition and growth, and can be used to devise fire management and response strategies. Although fire growth thresholds for a limited number of fire drivers have been examined (Riley et al 2013, Khorshidi et al 2020, Carmo et al 2022), literature review (section S1 and table S1 in the Supplementary Information) indicates that ecoregion-specific fire activation thresholds (i.e. fire weather/danger level beyond which the number of ignitions or burned area increases sharply) across various ignition causes (one natural and 11 human-caused ignition sources) and land cover types (general categories of forest versus non-forest) remain underexplored. Additionally, it is not clear if these fire activation thresholds remain stationary over time (Pourmohamad et al 2025). In other words, it is uncertain whether or not anthropogenic factors, including population and wildland–urban interface (WUI) growth, and fire prevention and mitigation activities, have fundamentally changed the relationship between socioenvironmental factors and fire outcome. Finally, while trends in fire activity have been identified (Weber and Yadav 2020, Zhuang et al 2021, Iglesias et al 2022), changes related to specific ignition causes and the biophysical factors driving fire occurrence and growth remain under-investigated.

To address these gaps, we answer three research questions in this study, focusing on each ecoregion across the WUS, as well as all ecoregions combined:

(1) How did the number of fires and total burned area change between 1992–2006 and 2007–2020, in each season, land cover type, and ignition cause?

(2) How did weather and fire danger indices associated with fires change from 1992 to 2020 among different land cover types and ignition causes?

(3) What are the thresholds of weather and fire danger indices associated with increased fire activity, both in terms of ignition and burned area? How do these thresholds vary between different ignition sources and ecoregions? Did these thresholds change in the past three decades?

Investigating these questions deepens the understanding of the fire dynamics in the WUS, shedding light on the temporal and spatial patterns and trends of the biophysical conditions that modulate fire activity in a changing climate. This nuanced understanding is important from both scientific and management perspectives.

2. Materials and methods

2.1. Study area

This study covers the WUS, defined as the 11 westernmost contiguous states in the United States. We focused on understanding changes in fire activity and their attributes across the WUS from 1992 to 2020. To provide additional context, we considered trends and relationships at Omernik level II and III ecoregions (Omernik 1987) in the WUS (figures S1 and S2). Despite heterogeneity, ecoregions are generally characterized by distinct climate, soil type, topography, and vegetation characteristics, which govern the ecosystems and species and their relationship with fire (McLauchlan et al 2020). They are widely used in the literature as spatial units with generally similar fire characteristics (Khorshidi et al 2020, Alizadeh et al 2023).

2.2. Data sources and fire records

We used the FPA FOD-Attributes dataset (Short 2022, Pourmohamad et al 2023), which includes information on the location, discovery time, ignition cause, and final size of >2.3 million fire records across the United States from 1992 to 2020, as well as a multitude of fire attributes related to biophysical factors (e.g. weather, fire danger indices, land cover, topography), social variables (e.g. population density), and management information (e.g. national preparedness level) on the date and at the location of ignition.

From 1992 to 2020, 752 461 fires were recorded across the WUS. Following Jorge et al (2025), we applied selection filters to account for changing investigation and reporting protocols, as well as access to human and technological resources, especially in local fire departments and for small fires. Specifically, we only included fires that (1) were larger than 0.1 acres (≈0.04 ha), (2) were not associated with ignition locations in developed areas (classified as Developed, Low Intensity; Developed, Medium Intensity; or Developed, High Intensity in the National Land Cover Dataset), AND (3) were not reported by local or county (i.e. fire department) sources. Consequently, 305 370 fire records remained for further analysis.

2.3. Analytical methods and fire attributes

First, we explored changes in the number of fire ignitions and fire sizes, categorizing incidents by season, general land cover types (forest versus non-forest), and general ignition causes (human- versus naturally-ignited fires) from 1992–2006 to 2007–2020. The term 'forest' refers to situations in which forest is the dominant land cover type, based on the National Land Cover Dataset, within a 1 km radius of the reported ignition point. We also examined temporal trends in two key variables connected to fire activity in the study area: energy release component (ERC; based on fuel model G) and vapor pressure deficit (VPD) on the date of ignition. ERC is an index from the United States National Fire Danger Rating System that indicates how dry and hot the fuels are based on time-integrated weather information, and VPD is a measure of atmospheric dryness with less memory compared to ERC. Both ERC and VPD are widely used as proxies for fuel and atmospheric dryness and fire potential across the WUS (Abatzoglou *et al* 2023). Refer to section S1 and table S2 for more details on the sources of data for the fire attributes and their characteristics. Additionally, we investigated the day of year (DOY) of ignition and ERC climatology (ERC-Normal, defined as the daily average during 1990–2020) when the ignition occurred. The difference between ERC and ERC-Normal indicates the deviation from long-term average on the date of ignition. In all analyses, we used least-squares linear regression and *t*-tests to determine statistical significance (5% level). Trends are presented for the entire WUS and each Omernik level II ecoregion across the WUS.

Second, we focused on estimating activation thresholds beyond which the number of ignitions and burned area increase markedly. Activation threshold indicates the inflection point on the graph displaying fire outcomes as a function of fire attributes, referring to the attribute level associated with a change of slope in the cumulative fire outcome metric. We analyzed fire metrics for level III ecoregions across the WUS separately (figure S2). To find activation thresholds, we used piecewise regression (segmented regression), a statistical technique that fits multiple lines to a set of data that does not follow a single line. Specifically, we used Muggeo's segmented regression algorithm, which iteratively estimates both the breakpoints and segment-specific slopes by maximizing the likelihood function (Muggeo 2003). We fit piecewise linear models to the cumulative number of ignitions and burned area as a function of a fire attribute (e.g. ERC) to discover changepoints. To construct the cumulative distributions, we first sorted fire events based on each attribute in ascending order and then computed the cumulative sum of fire ignitions and burned area. Each driver reaching its critical threshold can be thought of as turning a switch to the 'on' position, signifying a marked change in fire outcomes (Bradstock 2010, Srock *et al* 2018). In the case of cumulative burned area distributions, large fires occurring within narrow covariate ranges can introduce substantial gaps, making it difficult for the model to detect abrupt changes in slope. To address this issue, we applied the Savitzky–Golay filter to smooth the data while preserving the underlying trend and key inflection points (Gorry 1990), improving the stability and interpretability of the segmented regression. We used sample-with-replacement bootstrapping (1000 iterations) to estimate the 95% uncertainty range for activation thresholds. Additionally, we report fire attribute levels corresponding to the 5%, 10%, and 20% thresholds of cumulative ignitions and burned area as complementary metrics to the activation thresholds.

We examined eight fire attributes that have been linked with fire ignition and size (Williams *et al* 2014), including ERC, VPD, normalized difference vegetation index (NDVI), reference evapotranspiration (ETR), and 100 h dead fuel moisture (FM100), as well as ERC-Normal, VPD-Normal, and FM100-Normal (see table S2 for more information). Normal values (e.g. ERC-Normal) refer to the long-term average of the indicator on the DOY that the fire started, whereas other attributes refer to actual values corresponding to the date and location of ignition.

Third, we applied the piecewise regression technique to separately investigate threshold behavior among forest and non-forest environments, and between human- and naturally-ignited fires, because fires arising under these different conditions often exhibit distinct characteristics. Differences in fuel availability, land use, suppression accessibility, and ignition load and timing can lead to divergent fire–climate or fire–weather relationships (Faivre *et al* 2016, Newberry *et al* 2020, Pourmohamad *et al* 2025). Recognizing these distinctions is critical for fire managers, as it allows for more context-specific strategies. We separately established activation thresholds for 12 individual ignition causes classified by the National Wildfire Coordination Group, including: arson or incendiarism (arson); debris and open burning (debris); equipment and vehicle use (equipment); firearms and explosives use (firearms); fireworks; missing or unknown (missing); misuse of fire by a minor (misuse by minor); natural; power generation, transmission, or distribution (power); railroad operations and maintenance (railroad); recreation and ceremony (recreation); smoking; and other causes. Disaggregating by ignition cause helps capture the nuanced and cause-specific dynamics that may be obscured in aggregated analyses, supporting more targeted risk assessment and mitigation efforts (Pourmohamad *et al* 2025).

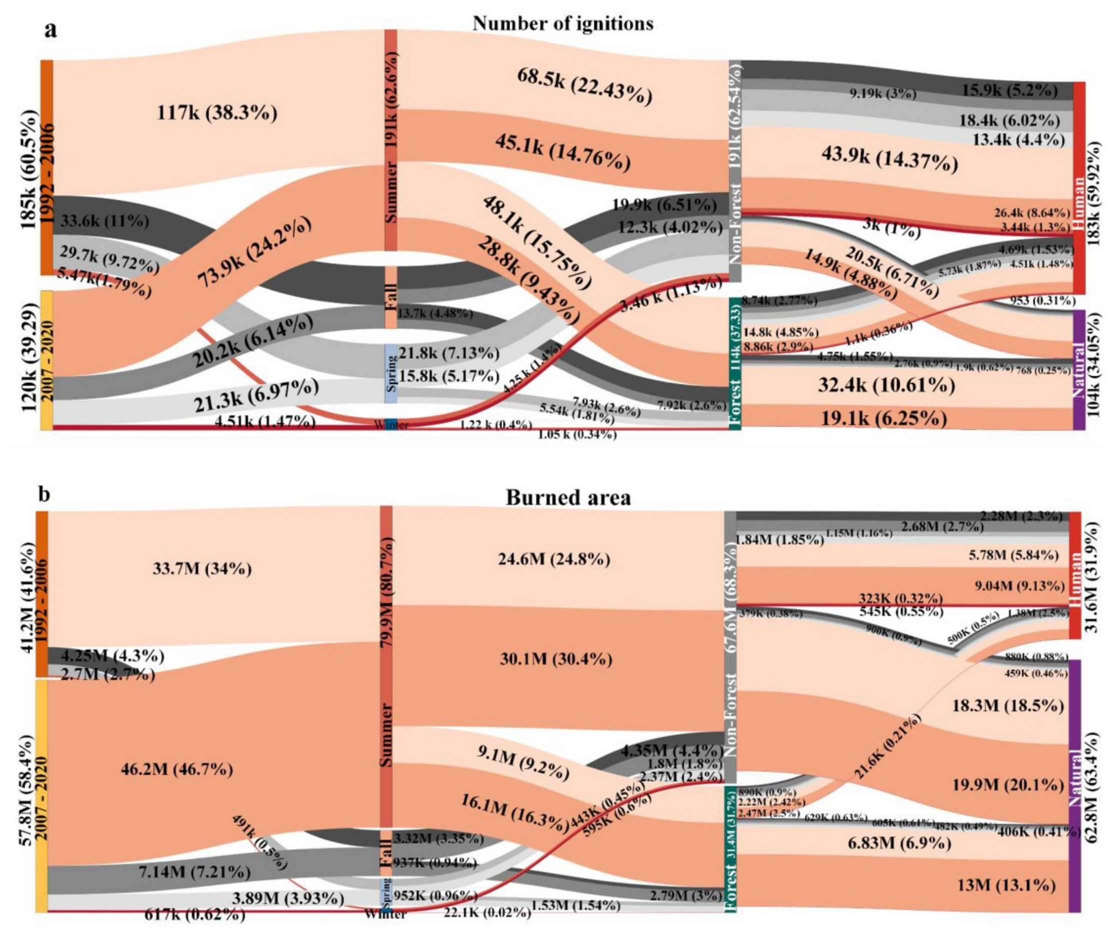

Figure 1. Flow of (a) the number of fire ignitions, and (b) burned area (acres) from 1992–2006 to 2007–2020, and among seasons, forested versus non-forested land covers, and natural versus human-started ignitions. Each color represents a specific category within its division. For the number of fire ignitions and burned area, the width of each flow is proportional to its contribution to the next division. The color continuity represents how divisions transformed from left to right.

3. Results

3.1. Patterns and trends of fires and their attributes

An average of ∼10 500 fires were reported annually from 1992 to 2020 across the WUS, of which 80% remained smaller than 10 acres (≈4 ha). We note that this number does not reflect fires that were not officially reported or were removed from our analyses due to perceived reporting inaccuracies. Across the WUS, a total of 99 million acres (≈40 million ha) burned from 1992 to 2020, 81% of which occurred in summer (June–August), 12% in fall (September–November), 7% in spring (March–May), and 1% in winter (December–February). These seasonal patterns generally hold for both forest and non-forest fires, noting that fires started in non-forested land accounted for more than twice as much burned area as fires that started in forested land across the WUS. Naturally-started fires accounted for 67% of the total burned area, as compared to the 33% by human-started fires (figure 1).

3.1.1. Temporal changes in the number of fire ignitions and burned area

Fire ignitions across the WUS demonstrated notable changes from 1992–2006 to 2007–2020, culminating in a 31% decline in the annual number of reported fires (figure 1(a)). Decreases were found for counts of fires smaller than 10 acres (≈4 ha; −33%) and larger than 10 acres (−23%), despite an increasing number of fires larger than 1000 acres (≈405 ha; +3%), 25 000 acres (≈10 117 ha; +63%) and 125 000 acres (≈50 586 ha; +136%). The annual number of both natural (−38%) and human-started (−33%) fires declined between the two periods. The same pattern applies to ignitions both in forested and non-forested land and both for fires smaller than 10 acres (≈4 ha; forest: −41%, non-forest: −34%) and greater than 10 acres (≈4 ha; forest: −18%, non-forest: −25%). Spatial patterns of fire ignitions did not show a major shift from the first study period to the second. There are, however, distinct, expected spatial patterns between natural (concentrated over

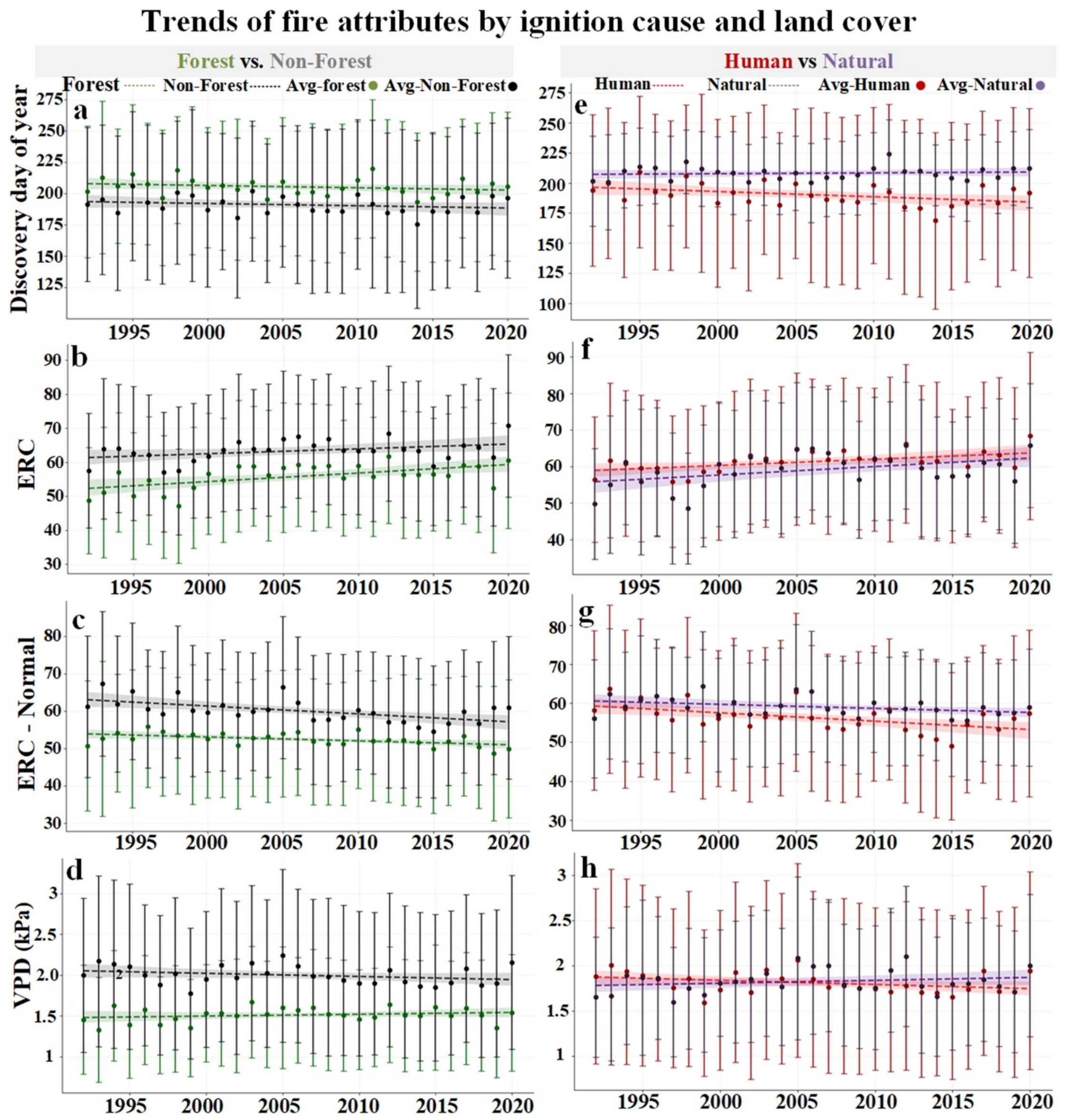

Figure 2. Temporal trends in fire attributes by land cover (forest vs non-forest; panels: (a)–(d)) and by ignition causes (human vs natural; panels: (e)–(h)) across the western United States, 1992–2020. Circles denote annual averages, and whiskers represent the standard deviation of attribute in each year. Fire attributes include discovery day of year (DOY), energy release component (ERC) on the date of ignition, long-term mean ERC on the DOY of ignition (ERC-Normal), and vapor pressure deficit (VPD; kPa) on the date of ignition.

mountainous regions) versus human-started (concentrated where human presence prevails) fires, and between forest versus non-forest ignitions (following land cover patterns; figure S3).

Annual average burned area increased by 40% from 1992–2006 to 2007–2020 (figure 1(b)), despite a decline in fire ignitions (−31%). Burned areas increased across all seasons, ranging from a 26% increase in winter to a 68% increase in fall (figure 1). Nuanced differences emerged when examining the seasonal burned area changes among forested and non-forested lands. While fires started in non-forested land almost uniformly increased among all seasons (22%–34%), changes in burned areas resulting from fires ignited in forests show marked seasonal differences, from almost tripling in fall to declining in winter, acknowledging the small winter fires' sample size. Large forest fires in the fall often coincided with downslope wind events across the WUS in the past decades, particularly along the West Coast (Abatzoglou *et al* 2023). Burned areas both for human- and naturally-started fires in forested and non-forested land increased from 1992–2006 to 2007–2020, with the largest increase (84%) in natural fires ignited in forests and the smallest increase (9%) in natural fires in non-forested land (figure 1).

3.1.2. Trends in fire attributes

Attributes associated with fires also changed across the WUS over our study period (figures 2 and S4). For both forested and non-forested land covers, ERC on the date of ignition averaged annually across the

WUS showed a statistically significant positive trend from 1992 to 2020 (7.4 and 4.1 units over 29 years for forested and non-forested ignitions, respectively) (figure 2(a)), coincident with background warming and drying patterns across the region (Zhuang *et al* 2024). The increasing ERC values for the WUS ignitions coincided with statistically significant negative trends in ERC-Normal (−3.0 and −6.1 units from 1992 to 2020 for forested and non-forested ignitions, respectively; figure 2(c)), indicating that (1) ignitions are increasingly occurring on dates that the weather is anomalously dry-hot compared to historical conditions, and/or (2) ignitions occur at times of year when the climate was historically cooler-wetter. Finally, trends in the DOY of ignition did not reach statistical significance for either forest nor non-forest ignitions (figure 2(a)).

ERC associated with both human and natural ignitions showed statistically significant increasing trends across the WUS (5.0 and 6.7 units over 29 years for human and natural ignitions, respectively; figure 2(f)). ERC-Normal for human and natural ignitions significantly declined in the study period (−6.3 and −3.0 units over 29 years for human and natural ignitions, respectively). Average atmospheric aridity, in terms of VPD, on the date of ignition over the WUS showed a marginally increasing trend for natural ignitions, but a marginally declining trend for human ignitions (figure 2(h)). The latter is attributed to a statistically significant declining trend in DOY of human-started fires, which increasingly occur in spring, when VPD is climatologically lower. The DOY for natural ignitions did not show a statistically significant trend, indicating a rather constant seasonality for lightning-started fires (figure 2(e)).

Changes in fire attributes among WUS ecoregions are presented in figures S5–S13, revealing differences between wetter-cooler and drier-warmer ecoregions. Trends within each ecoregion reflect not only climatic influences but also the compounding and confounding effects of topography, ecology, and human activity.

3.2. Activation thresholds for fire ignitions and burned area

3.2.1. Fire activation thresholds among ecoregions

Median ERC to activate fire ignitions among the 35 WUS level III ecoregions was 42 (interquartile range: 34–50; table S3). Southern ecoregions characterized by dry-hot climate and a high ERC baseline have the highest ERC ignition activation thresholds (>70), whereas coastal ecoregions and northern high-elevation ecoregions have lower ERC activation thresholds (figure 3(a); table S3). In addition to the background climatic, topographical, and ecological conditions, human population density in these regions, and the share of human versus naturally-started fires, contribute to these threshold levels. Figure S14 and table S4, for example, show that ERC activation threshold values for fires ignited in forests are generally higher than those ignited in non-forested areas. In a majority of ecoregions, naturally-started fires are associated with higher ERC ignition activation thresholds compared to human-started fires, largely due to the seasonality of lightning that mainly occurs in summer (figure S15 and table S5).

The median VPD activation threshold for ignitions among the 35 WUS level III ecoregions was 0.9 kPa (interquartile range: 0.8–1.2 kPa; table S3). Spatial patterns of VPD activation thresholds for fire ignition, similar to ERC, closely followed the climatology of ecoregions (figure 3(b)). VPD activation thresholds for forest ignitions were also generally higher than those of non-forest ignitions (figure S16 and table S4). This pattern, however, does not hold for some ecoregions in the Northwest and along the west coast, which we attribute to non-forest ignitions occurring in lower elevations associated with higher background VPD. Pattern differences in VPD and ERC activation thresholds are in part because ERCs are estimated using fuel model G (conifer forest), which is not as sensitive to temperature as VPD. We also note that ERC has a longer memory compared to VPD and is hence more dependent on antecedent weather. Human-started fires in a majority of the ecoregions were associated with lower VPD activation thresholds for the number of ignitions compared to the lightning ignitions (figure S17 and table S5).

Activation threshold for fire size (i.e. incident burned area) had a median ERC of 50 (interquartile range: 43–60; table S3) among ecoregions (figure 3(c)). Burned area activation thresholds also widely followed background climatology. ERC activation thresholds for burned area were generally higher for forested ignitions than non-forested ignitions (figure S14 and table S4), due to (1) their generally moister and more complex fuel structures, which demand more intense and prolonged dry-hot conditions for large fires to occur, and (2) their fire seasonality that generally centers in summer with higher ERC climatological baselines. Patterns were less apparent when comparing human- with naturally-ignited fires (figure S15 and table S5). Activation thresholds for ecoregions with a limited number of fires and/or burned area should be used with careful consideration (see figures S18 and S19). Median VPD activation threshold for burned areas among

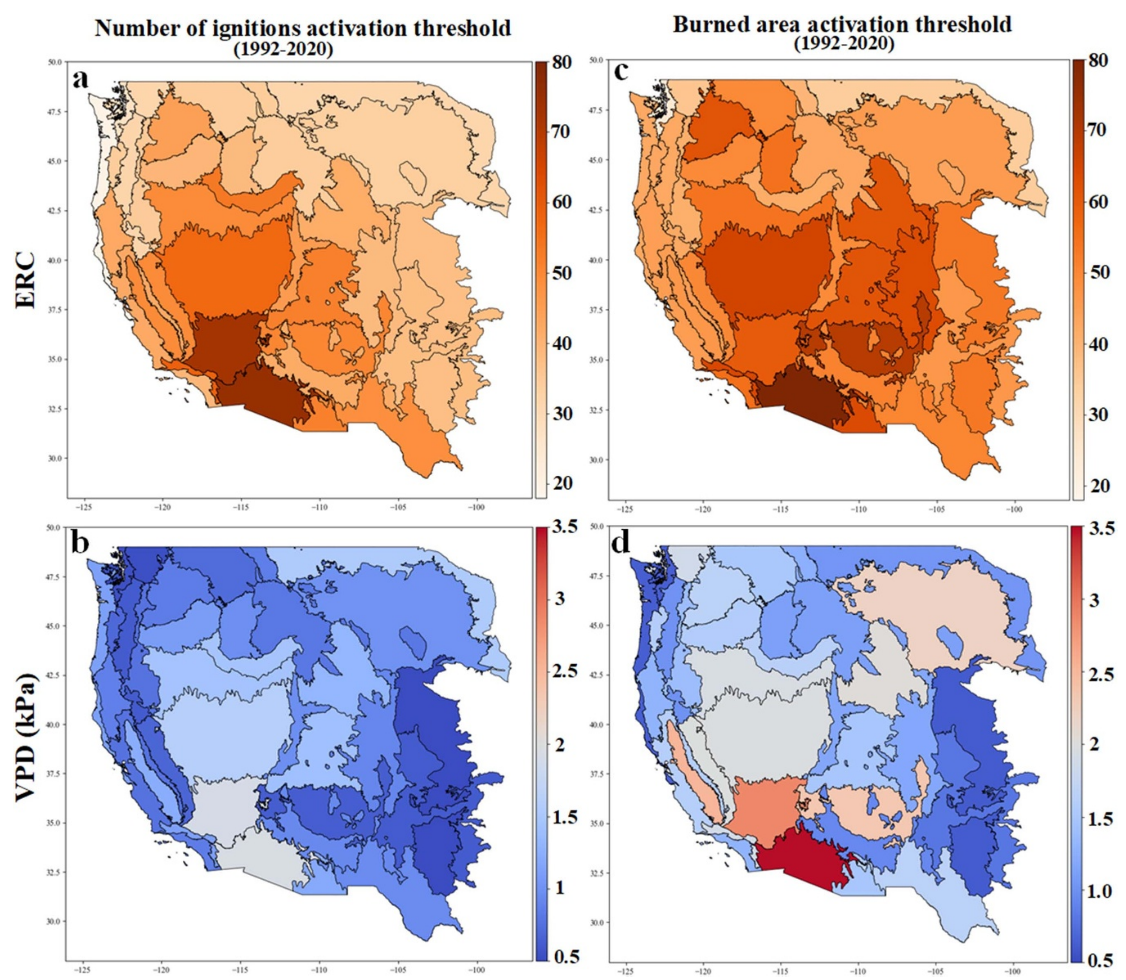

Figure 3. Activation thresholds for fire ignitions and burned area in terms of (a) and (c) energy release component (ERC) and (b) and (d) vapor pressure deficit (VPD).

the ecoregions was 1.5 kPa (interquartile range: 1.1–1.9 kPa; table S3). Similar to ERC, VPD activation thresholds also followed climatic gradients across the WUS (figure 3(d)), and thresholds for fire size were generally larger than those associated with ignitions.

Figures S20–S29 show 95% uncertainty ranges associated with ERC and VPD activation thresholds for both ignitions and burned area, and based on general land cover types and ignition sources, for all ecoregions. Additionally, tables S6–S10 list ERC and VPD levels corresponding to the 5%, 10%, and 20% thresholds of cumulative ignitions and cumulative burned area within each level III ecoregion based on the general land cover and ignition types, offering complementary information to the activation thresholds discussed here. Finally, activation thresholds for individual fire causes are presented in section S2 and figures S30–S32.

3.2.2. Temporal changes in activation thresholds

Activation thresholds across many ecoregions and for various fire covariates were predominantly similar between 1992–2006 and 2007–2020 (figures 4 and S33), with minor differences generally attributable to the uncertainties in the methodological approach (see figures S34 and S35 for the 95% uncertainty ranges). This finding indicates that the fire relationship with its biophysical drivers for the most part remained stationary from 1992 to 2020. However, nuanced differences in activation thresholds were also observed in some ecoregions, which were more pronounced for ERC than VPD and for ignitions than burned area. For example, the ERC activation threshold for ignitions in Coastal Southern California and Southern California Mountains increased significantly during the second period (figures 4(d) and S34), indicating that higher levels of fuel dryness are now required to support elevated ignition activity. A similar pattern was observed for other fuel-limited (energy-abundant) ecoregions, although not all, including Arizona/New Mexico Plateau and Central California Valley (figure S34). Changes in activation threshold for other variables were more nuanced than weather and fire danger indices, indicating compounding and confounding impacts of

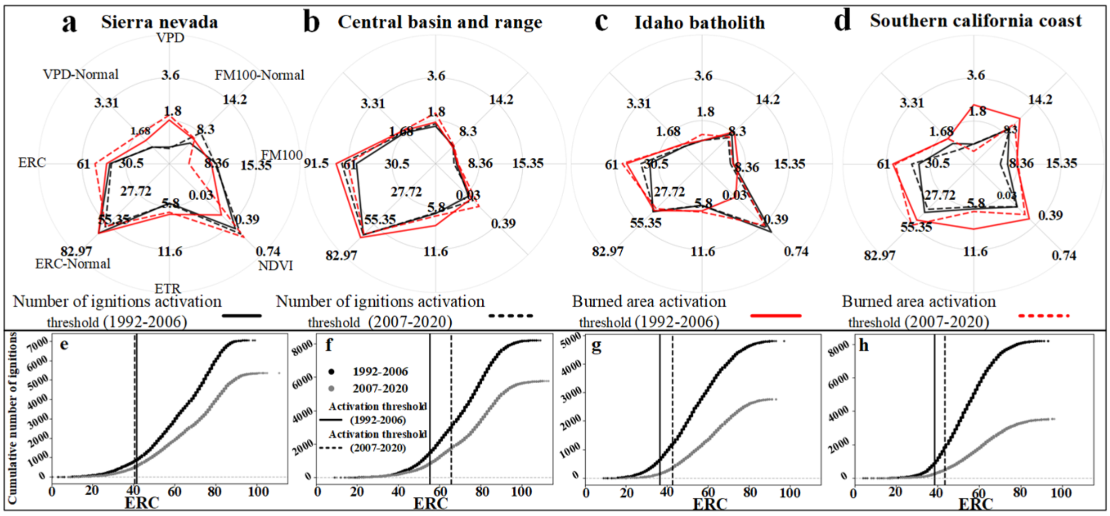

Figure 4. Activation thresholds for four selected ecoregions for eight fire attributes over 1992–2006 and 2007–2020. (a)–(d) Activation thresholds for burned area (red) and number of ignitions (black) from 1992–2006 (solid) and 2007–2020 (dashed). (e)–(h) Cumulative number of ignitions as a function of ERC, as well as the detected activation threshold (vertical line) for the two periods of this study (1992–2006: black; 2007–2020: gray).

bottom-up factors such as topography, soil type, and human influences (figures 4 and S33).

4. Discussion and conclusion

This study provides insights into the evolving patterns of fire activity in the WUS, indicating a 40% increase in annual burned area despite a 31% decline in reported annual fire ignitions from 1992–2006 to 2007–2020. This paradox is best understood as a product of both human influences and the warming and drying trends in the western US (Syphard *et al* 2017). The number of human-started fires decreased despite population growth and WUI expansion across the WUS (Radeloff *et al* 2018), implying the effectiveness of fire prevention efforts (Prestemon *et al* 2010, Abt *et al* 2015), as well as investments in fire mitigation programs (Hesseln 2018, Finney *et al* 2021). Simultaneously, environmental conditions promoted larger individual fires, leading to an increased burned area (Iglesias *et al* 2022, Parks *et al* 2025b).

Our results offer evidence-based activation thresholds for the number of ignitions and burned area. This information indicates switch-like environmental conditions that are conducive to increased fire activity, providing critical information for operational decision support, targeted fire prevention, and improved resource allocation and planning (Jolly *et al* 2019). Our findings offer consistency and transparency to both management decisions, for example, when to issue burn bans or close public lands to visitors, and to scientific fire risk assessments, for example, trend analyses of the number of days conducive to increased fire activity (Jolly *et al* 2019, Potter and McEvoy 2021, Wang *et al* 2025). Management decisions are generally based on experience-based heuristics (Rapp *et al* 2021). Scientific studies either use percentile-based fire weather thresholds without recourse to the interactions between biophysical factors and fire outcomes (Carvalho *et al* 2008, Argañaraz *et al* 2018, Kudláčková *et al* 2024) or use a constant threshold (e.g. ERC = 60 for forest fires as in Alizadeh *et al* 2023 and Riley *et al* 2013) without recourse to biophysical gradients among ecoregions.

We found an increase in the activation thresholds for the number of ignitions, i.e. fire-weather conditions under which ignitions tend to occur more frequently, in some regions. This finding may be a product of enhanced fire prevention efforts, public education, early suppression tactics, and fire-adapted engineering solutions (Hesseln 2018). In this context, fires that do escape prevention and/or initial attack are increasingly those occurring under extreme conditions where suppression is less feasible (Prestemon *et al* 2010, Abt *et al* 2015, Kreider *et al* 2024). It is also plausible that changes in fire detection and reporting practices contributed to the observed decline in reported small fires (Butry and Thomas 2017). For instance, a proportion of ignitions that might have been reported previously could now be self-extinguishing before detection, or, conversely, delayed detection driven by strained resources in an era of increasingly synchronous fire danger could lead to small fires growing into larger events before they are officially recorded (Moris *et al* 2023). The possibility of multiple ignition points merging into a single, larger reported fire also complicates the interpretation of raw fire counts (Coogan *et al* 2022). Further research is needed to understand potential shifts in fire reporting rates by different stakeholders (e.g. landowners, recreationists, land managers).

On the other hand, the lack of significant change in the activation thresholds associated with the number of ignitions in other regions points to the confounding impacts of warming and drying trends, population growth, WUI expansion, and fire prevention and mitigation strategies, among other factors (Ellis *et al* 2024). Nevertheless, longer and more extreme fire seasons, coupled with drought-stressed fuels on the backbone of overgrown forests in the WUS, have pushed fires that do escape the initial suppression attack into more destructive territory (Modaresi Rad *et al* 2023, Balch *et al* 2024).

Our findings also indicate distinct patterns and trends linked to specific ignition causes, land cover types, and seasonal dynamics. More human-caused fires are now initiating earlier in the year (Madakumbura *et al* 2025), while natural fires continue their historical patterns but with amplified impacts due to the background conditions conducive to extreme fire behavior (Balch *et al* 2017). Burned area associated with ignitions in forested lands during the fall season tripled in the later study period (2007–2020), likely due to increasingly dry and stressed forest vegetation driven by reduced summer precipitation and warmer temperatures, which extend vegetation dryness into fall coincident with intensified downslope winds (Abatzoglou *et al* 2023). Furthermore, changes in fuel loads associated with antecedent drought and increased fuel accumulation in landscapes that experience fire deficit contribute to higher initial spread rates (Parks *et al* 2025a). Fires originating in non-forest vegetation (grass/shrub) also contributed disproportionately to total area burned, presumably due to their rapid initial spread making early containment difficult (Radeloff *et al* 2023).

Finally, despite the reduction in fire counts, the increasing total area burned underscores the growing influence of climate-driven factors that operate beyond the scope of traditional management approaches. The WUS has experienced a clear trend towards longer and more extreme fire seasons (Littell *et al* 2016, Iglesias *et al* 2022). These climatic shifts are profoundly influencing both human-caused and natural ignitions, pushing them to occur under increasingly extreme conditions. Addressing these challenges necessitates continued investment in research and monitoring of fire-related drivers within a warming climate, alongside adaptive management strategies that consider the complex interactions between human interventions, fuel dynamics, and climatic shifts.

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Data availability statement

The data used in this study is available at: https://doi.org/10.5281/zenodo.8381129 (Pourmohamad *et al* 2023, 2023).

Supplemental Text & Data available at https://doi.org/10.1088/1748-9326/ae58c0/data1.

ORCID iDs

John Abatzoglou 0000-0001-7599-9750
Jeffrey Prestemon 0000-0001-8850-5668
Karen Short 0000-0002-3383-0460
Jodi Mead 0000-0002-4403-9228
Mojtaba Sadegh 0000-0003-1775-5445

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