ADVANCING EARTH AND SPACE SCIENCES

Earth's Future

RESEARCH ARTICLE
10.1029/2025EF007077

Key Points:
- Wildfire frequency in the western United States significantly decreased during 1992–2020
- Human-caused wildfire ignitions decreased most significantly in California and increased significantly in Wyoming
- Pyric transition, a non-linear relationship between fire frequency and human population, explains regional trends in the fire frequency

Supporting Information:
Supporting Information may be found in the online version of this article.

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Citation:
Madakumbura, G. D., Williams, A. P., Short, K. C., Moritz, M. A., Wang, B., & Juang, C. S. (2026). Evolving fire frequency in the western United States and its links to human influence. *Earth's Future*, *14*, e2025EF007077. https://doi.org/10.1029/2025EF007077

Received 2 AUG 2025
Accepted 26 MAR 2026

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Evolving Fire Frequency in the Western United States and Its Links to Human Influence

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Abstract Burned area and wildfire damages in the western United States (WUS) have increased dramatically in recent decades. Wildfire frequency, however, has shown trends that vary by data set, region, and fire size. Using a comprehensive fire occurrence data set screened for reporting artifacts from 1992 to 2020, we show a significant downward trend in annual fire frequency in WUS, with a significant contribution from decreasing human ignitions. Human-caused fires significantly declined in California and Arizona, but increased in Wyoming. The relationship between human-caused fires and population suggests a pyric transition, where fire frequency correlates positively to population in areas with very low population such as Wyoming and negatively where population is denser, such as in California and Arizona. Understanding the human influence on fire frequency trends beyond anthropogenic warming has strong implications for future projections of wildfire activity.

Plain Language Summary Burned area and damages from wildfires in the western United States have increased in recent decades. Contrary to the common belief that the frequency of wildfires has also increased, trends in the number of fires have been less clear than trends in area burned, and they vary by data set, region, and fire size. Using a comprehensive fire occurrence data set, we find a significant decline in the annual number of wildfires in the western United States over the past three decades. Decreases in human-caused ignitions are most evident in California and Arizona, while human-caused ignitions increased in Wyoming. When examining how the number of human-caused fires relates to population patterns, we find that the relationship varies. In areas with very low population, fires increase as population increases. However, after the population reaches a certain level, further population growth is associated with fewer fires. Considering the influences of human populations and demographics on wildfire could improve both global and western United States estimates of future wildfire activity compared to estimates based on climate change alone.

1. Introduction

Wildfires in the western United States (WUS) have changed substantially in recent decades. Increases in burned area and fire-related damages have been documented (Abatzoglou & Williams, 2016; Burke et al., 2021; Higuera et al., 2023), as well as changes in fire size distributions and frequency in the 2000s (Iglesias et al., 2022). Anthropogenic warming has been suggested as a primary driver behind the increasing burned areas (Abatzoglou & Williams, 2016; Westerling, 2016) across all or much of the forested WUS. Fire frequency, or the number of ignitions, however, can be strongly influenced by anthropogenic factors beyond climate, as the number of fires depends not only on ignition potential related to climate variability and change (Abatzoglou et al., 2016), but also on human demographics, which influence both ignitions and fire suppression efforts (Bowman et al., 2011; Riley et al., 2019). Therefore, fire frequency can exhibit a wide range of spatial and temporal patterns beyond the common expectation of a ubiquitous increasing trend driven by anthropogenic warming or increased human activity (Doerr & Santín, 2016).

Observed wildfire frequency trends in the WUS have been shown to vary depending on the data set used (e.g., whether limited to "large" fires), the time period assessed, and the region of focus. Long-term perspectives from sedimentary charcoal records, fire scar data, and historical observations indicate that until the 18th century,

10.1029/2025EF007077

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temporal variation in regional mean fire activity across the WUS was primarily driven by climate (Margolis et al., 2025; Marlon et al., 2012). Increased ignitions during Anglo-European contact and territorial expansion were associated with land clearing, logging, agriculture, and railroad operations (Marlon et al., 2012). After the 1800s, however, a downward trend emerged, likely associated with land-use changes and an increased focus on protective measures like fire prevention and suppression (Marlon et al., 2012; Parks et al., 2025).

In recent decades, although the frequency of very large wildfires has increased (Dennison et al., 2014; Westerling, 2016), trends in the frequency of all wildfires have been less clear. Syphard et al. (2025) found a decreasing trend in wildfire ignitions on US Forest Service (USFS) lands from 1940 to 2019, with variation by region. In Pacific and Southwestern regions of the USFS, ignition numbers increased until the 1980s and then declined but fire frequency remained stable or increased slightly in the two WUS regions with the lowest housing density (Syphard et al., 2025). Considering California alone, and using data from both the USFS and the state fire service (CAL FIRE), Keeley and Syphard (2018) found increasing ignitions throughout climate divisions from the early 1900s to circa 1980, followed by a marked decline to the end of the study period in 2016. Based on just the CAL FIRE historical fire perimeter data, Li and Banerjee (2021) found a subsequent increase in ignitions during 2000–2019 and a shift in the fire size distribution compared with 1920–1999. Specifically, the shift reflects a marked increase in the frequency of "small" (i.e., <40 ha) human-caused fires (Li & Banerjee, 2021), which could be an artificial function of changes in geospatial reporting practices and capabilities (e.g., minimum fire size) over time.

Identifying whether apparent trends in fire frequency are driven by anthropogenic influences is complicated by the various ways humans affect ignition frequency and distribution, fuel structure, and temporal fire season characteristics (Balch et al., 2017; Bowman et al., 2009, 2011; Scott et al., 2014). The spatial pattern of human-caused ignitions is highly correlated with human activity (Chen & Jin, 2022), and this correlation might suggest that increasing population and development lead to a ubiquitous rise in human ignitions. However, fire activity and human demographic patterns often exhibit a nonlinear, hump-shaped relationship, where fire activity increases with population in sparsely populated areas, peaks at intermediate levels of human presence, and then declines as population density and development increase beyond a certain population density (Bistinas et al., 2014; Bowman et al., 2011; Knorr et al., 2014; Scott et al., 2014; Syphard et al., 2007). This modern pattern parallels the *pyric transition* (Pyne, 2019), which captures how fire activity initially exceeds natural background levels due to human use of fire to modify the landscape (e.g., for agriculture), and then declines with advancing technological development, land fragmentation, and increased suppression capacity (Bowman et al., 2011; Butsic et al., 2015; Scott et al., 2014). Space-for-time aggregated empirical wildfire modeling studies have observed the hump-shaped pyric transition-like relationship between fire activity and human demographic levels across regions in the WUS, in the form of chronosequences (Mann et al., 2016; Mansuy et al., 2019; Parisien et al., 2016; Park et al., 2021; Syphard et al., 2007). Human ignitions, represented through the pyric transition concept in a global fire model (Pechony & Shindell, 2009), showed an increasing trend following the Industrial Revolution, followed by a decline in fire activity from around 1900 onward. This decrease has been attributed to enhanced fire suppression and increased vegetation fragmentation (Pechony & Shindell, 2010). Therefore, the pyric transition framework offers a promising approach for understanding and interpreting trends in fire frequency in the recent past.

In this study, we investigate the spatial patterns of trends in annual fire frequency across the WUS using a comprehensive fire occurrence data set for 1992–2020 that was screened for reporting artifacts (Short, 2022). Using the pyric transition concept, we then assess whether human influences can be identified spatially, by comparing regions at different phases of the transition (Balch et al., 2016; Bowman et al., 2011), as well as temporally, by examining how changes in pyric transition over time may be linked to trends in fire frequency.

2. Methods

We use the Fire Program Analysis Fire-Occurrence Database (FPA FOD) version 6 (Short, 2022) to investigate trends in fire frequency in the WUS during the period 1992–2020. We use several attributes from the data set, including discovery date, ignition location, final fire size, ignition cause classification (human-caused or natural), general cause (e.g., arson/incendiarism, misuse of fire by a minor, debris and open burning, recreation and ceremony, equipment and vehicle use, power generation/transmission/distribution, smoking, railroad operations and maintenance, other causes, fireworks, firearms and explosives use, and natural causes), and reporting agency

(Short, 2014). To identify the land cover type at each ignition location, we use annual maps from the National Land Cover Database (United States Geological Survey, 2024). The land cover type for each fire is assigned as the most common type within a 500-m radius of the reported ignition location, using the appropriate map for the ignition year.

Large uncertainties in total fire counts can arise from inconsistencies in state and county/local (ST/C&L) fire reporting, as records are sourced from multiple entities with varying reporting standards and criteria (Short, 2014, 2015; Short, Ahrens, et al., 2020). We examine different reporting sources by state to identify potential data artifacts stemming from these inconsistencies. For example, at the beginning of the record, fires with a final size smaller than 0.04 ha (0.1 acre) are entirely absent from some states, such as California (Figure S1 in Supporting Information S1). Jorge et al. (2025) noted that increased local fire department reporting resulted in the abrupt addition of a large number of fires in Arizona with a reported size of exactly 0.04 ha. We found that fires smaller than 0.04 ha or exactly 0.04 ha are either missing or extremely rare in earlier years, but their counts subsequently surge, particularly in developed lands, exceeding 4,000/year in Arizona, 1,000/year in California, and 2,000/year in Colorado (Figure S1 in Supporting Information S1). Fires smaller than or equal to 0.04 ha in undeveloped land cover exhibit consistent annual reporting, with exceptions in Colorado for fires ≤0.04 ha and in California for fires equal to 0.04 ha. This suggests that the inconsistencies are largely limited to developed areas, where local fire departments may be the sole responders and reporting entities.

Another source of uncertainty comes from fires where the cause classification, which designates fires as human- or natural-caused, is listed as "Missing data/not specified/undetermined" (hereafter referred to as *missing cause*) (Pourmohamad et al., 2025). We find that the majority of these fires originate from ST/C&L reports (Figure S2 in Supporting Information S1) and predominantly occur on developed lands (Figure S3 in Supporting Information S1), with highly inconsistent counts over the study period. For instance, there were very few fires with a missing cause classification prior to the 2000s, followed by a sharp increase, particularly for fires smaller than or equal to 0.4 ha (1 acre). Nearly all fire size categories reach their peak number of entries with missing causes in 2020, during COVID-19 restrictions and a transition in interagency fire reporting standards and practices (Jorge et al., 2025). Based on these findings and the screening approach used by Jorge et al. (2025) to identify potential data artifacts, we apply the following filters to our data set: (a) Fires with a dominant land cover classification of high- or medium-density developed are excluded; (b) Fires ≤0.04 ha are removed from developed land cover areas in all states. For Colorado, this fire size category is removed from all land cover types. For California, fires smaller than 0.04 ha are removed from all undeveloped areas. (c) Fires with the cause classification listed as *Missing data/not specified/undetermined* are excluded. After the screening, the annual fire frequency estimates lack the dramatic step increases observed in the unscreened data set (Figures S2 and S3 in Supporting Information S1), and this holds across reporting agencies (Figure S4 in Supporting Information S1) and land cover types (Figure S5 in Supporting Information S1). The correlation between annual fire frequency and total burned area or estimates of structures threatened or damaged (sourced for 1999–2020 from St. Denis, Short, McConnell, Cook, Mietkiewicz, et al., 2023; St. Denis, Short, McConnell, Cook, Buckland, et al., 2023) is higher after the screening (Figure S6 in Supporting Information S1), suggesting that some noise from data artifacts has been effectively removed. The increased correlations between human-caused fire frequency and burned area, as well as the number of structures threatened or damaged, particularly align with previous findings that wildfires caused by human ignitions are the primary drivers of structural loss in the WUS (Higuera et al., 2023).

We calculate the annual number of fires for the whole WUS and the 11 states within: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. To identify small-scale spatial patterns in the trends, we also rasterize the fire occurrence data set to a 9 km grid (Muñoz-Sabater et al., 2021). This resolution is chosen considering the tradeoff between capturing high-resolution spatial features and having a sufficient number of fires in each grid to estimate meaningful trends. Results are also presented for pyromes in the WUS (Figure S7 in Supporting Information S1), which are areas with relatively homogeneous contemporary fire regimes (Short, Grenfell, et al., 2020).

The pyric transition behavior during the study period may arise from two opposing dynamics: an increase in human-caused ignitions due to growing population, and a decrease due to enhanced suppression efforts, regulations, public awareness, and land cover change. Population density serves as a direct measure of human ignition potential and may also act as a proxy for fire mitigation measures. Moreover, population data allow us to assess this relationship both spatially and temporally, as comprehensive data sets are available across both dimensions.

We also use housing density to verify the results obtained from population density, as prior studies have shown this variable to be a strong indicator of human influence on fire activity (Mann et al., 2016; Park et al., 2021). Both population density and housing density are analyzed at the 9 km grid scale. For population, we use annual data for 1992–2020 from the GlobPOP data set (Liu et al., 2024a, 2024b). Population density is available at a 30 arc s resolution (approximately 1 km^2 at the equator) and we calculate the average value for each 9 km grid cell. We calculate the 15-year running average of the fire frequency and population density for each grid to investigate the relationship between the two variables, for each 15-year period. Housing density data are obtained from the Spatial Analysis for Conservation and Sustainability Lab database (Radeloff et al., 2023). Housing density data are available only for years 1990, 2000, 2010 and 2020. Therefore, the average fire frequency of the periods 1992–2010 and 2009–2020 are plotted against the housing density data of 2010 and 2020, respectively. To fit curves between fire frequency and the demographic variables, we first bin the fire frequency into 20 quantile-based intervals so that each bin contains an equal number of data points. A third-degree polynomial is then fit to the binned data.

To relate the pyric transition to state-level expenditures on fire protection and fire management-related activities, we use annual financial data from the Annual Survey of Local Government Finances (ALFIN), collected by the United States Census Bureau (Barnett et al., 2014; United States Census Bureau, n.d.). These records span from 1993 to 2020, with the exception of missing records in 2001 and 2003. We identify three variables related to fire protection and management based on definitions provided in the ALFIN glossary. The first variable is *Fire Protection*, which is defined as prevention, avoidance, and suppression of fires and provision of ambulance, medical, rescue, or auxiliary services provided by fire protection agencies. This consists of: employees of regular fire departments, including financial, technical, and operational support of volunteer fire forces; rescue squads; fire inspection, investigation, and regulation; fire marshals; fire prevention education; fire suppression training; auxiliary services; and these other activities handled by a fire department: ambulances, emergency medical technicians, paramedic squads, and arson investigation. The second variable is *Natural Resources*, which includes expenditures for forest conservation and development, as well as forestry and fire protection. Forest-fire protection and suppression are reported under the section Natural Resources. The third variable is *Protective Inspection and Regulation*, which includes the regulation of private enterprises for public protection and the inspection of hazardous activities. To adjust for inflation in the expenses, Consumer Price Index (CPI) values for each year were obtained from the United States Bureau of Labor Statistics (Archived Consumer Price Index Supplemental Files, 2026). The annual average CPI for 2020 was used as the baseline and divided by the CPI value for each year to calculate the inflation adjustment factor for that year.

Trends are estimated using ordinary least squares, and all significance estimates are adjusted using false discovery rate correction (Benjamini & Hochberg, 1995).

3. Results

3.1. Trends in Annual Fire Frequency in the WUS

In the WUS, a statistically significant increasing trend ($p < 0.05$) in annual burned area and in the number of threatened and damaged structures due to wildfires is observed for the periods 1992–2020 and 1999–2020, respectively (Figure 1a). However, statistically significant *decreasing* trends are observed for human-caused, natural, and total annual fire frequency (Figure 1b). The correlation between detrended burned area and detrended fire frequency is statistically significant (Figure 1c). Interannual variability in both burned area and fire frequency can be linked to modes of natural climate variability, such as the El Niño–Southern Oscillation (Abatzoglou et al., 2017; Keeping et al., 2024). Despite statistically significant coupling between interannual variations in fire frequency and area burned, the opposing long-term trends in burned area versus fire frequency are attributable to the dominance of a small number of very large fires over the total area burned in the WUS (Juang et al., 2022; Strauss et al., 1989).

Figure 2 and Figure S8 in Supporting Information S1 show the geographic distribution of fire frequency trends across the WUS. Regions with decreasing trends are in California, Oregon, Arizona, New Mexico, and Idaho. In California, these decreases are largely associated with human-caused fires, particularly in the Sierra Nevada foothills, Southern California, and the Coastal Range. Natural fires also show decreasing trends in California, particularly in higher-elevation pyromes such as the Northern and Southern Sierra Nevada, Klamath Mountains, Southern Cascades, and Eastern Cascades Slopes and Foothills. In the rest of the WUS, decreasing trends in

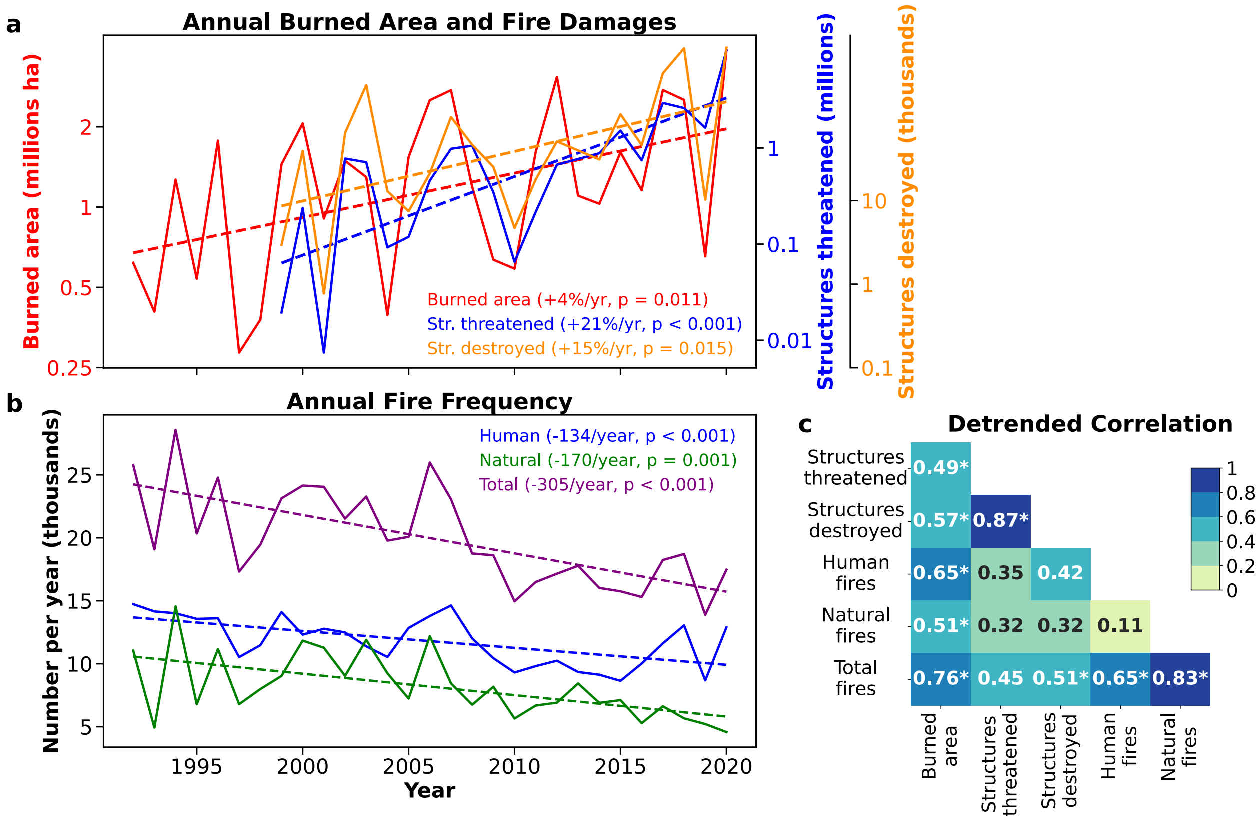

Figure 1. Annual burned area, number of threatened and destroyed structures, and number of fires in the western United States. (a) Annual total burned area (red), number of threatened structures (blue), and number of destroyed structures (orange). (b) The number of human-caused (blue), natural (green), and total fires (purple). Burned area and fire frequency are shown for the period 1992–2020, while structure data (threatened and destroyed) are shown for 1999–2020. Linear trend values and associated p-values (rounded to the third decimal place) for each fire category are shown in the legend of the top and bottom panels. (c) Cross correlation between detrended time series in panels (a, b). Statistically significant correlation ($p < 0.05$, false discovery control $\alpha = 0.05$) values are indicated with an asterisk.

natural fires are observed in the Eastern Cascades Slopes and Foothills (extending from California to Oregon), the mountains of northeast Oregon, the Arizona/New Mexico Mountains in both Arizona and New Mexico, Idaho Batholith, and the Northern Rockies in Idaho and Montana. Increasing trends in human-caused fires are evident in urban areas of Southern California (Los Angeles, Long Beach, Anaheim, San Diego), Northern California (San Jose, San Francisco, Sacramento, Fresno, Bakersfield), Arizona (Phoenix, Mesa, Tucson), and Colorado (Fort Collins, Denver, Colorado Springs, Pueblo, Grand Junction) (Figure S8 in Supporting Information S1). These increasing trends in WUS cities were much larger before screening for reporting inconsistencies, and mainly driven by increased reporting of very small fires in developed areas (Figures S3 and S5 in Supporting Information S1). It is possible that our screening procedure did not fully eliminate artificial increases in fire frequency caused by changes in reporting practices in developed areas, so the apparent increases in fire occurrence in these areas may be overestimated.

To identify the contribution from individual states, we examine statewide trends in annual fire frequency (Figure 2, Figure S9 in Supporting Information S1). Increasing trends in developed areas within each state are observed, but they are smaller in magnitude compared to trends in undeveloped lands (Figure S9 in Supporting Information S1), making the spatial patterns of all fires resemble those of the latter. In California and Arizona, the total frequency of wildfires reduced significantly ($p < 0.05$), mainly due to decreased human ignitions in undeveloped lands. Natural fires in Arizona and Idaho also show statistically significant decreasing trends. Significant increasing trends in human-caused fires in both undeveloped and developed lands of Wyoming and Utah are observed, while in Nevada and Colorado, developed lands exhibit statistically significant increasing trends in human-caused fires. Wyoming and Colorado also show significant increasing trends in natural fires over

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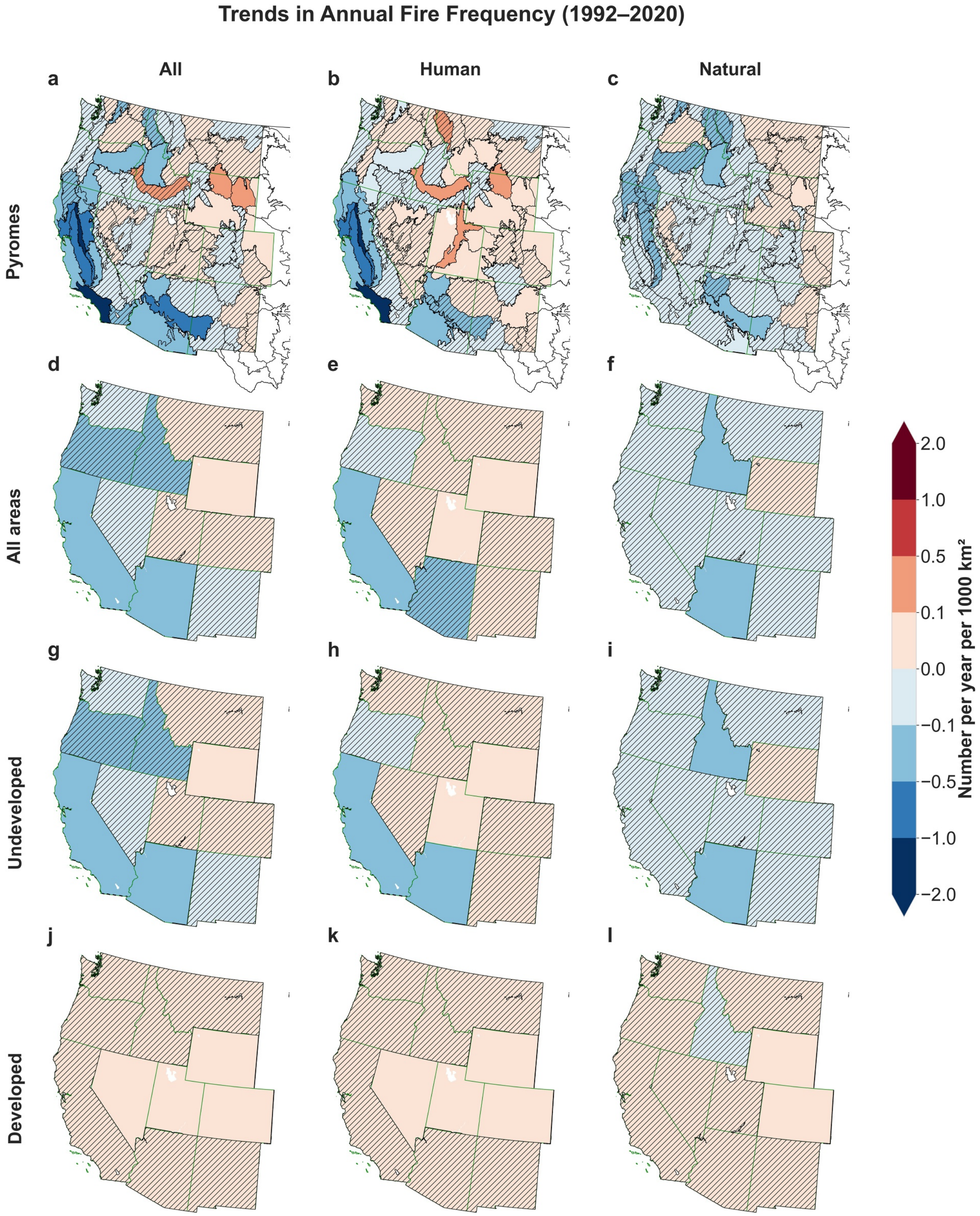

Figure 2. Spatial maps of linear trends in annual fire frequency during 1992–2020. Trends for all fires (a, d, g, j), human-caused fires (b, e, h, k), and natural fires (c, f, i, l). (a, b, c) Fire counts are aggregated at the pyrome level to calculate annual totals and derive linear trends. State boundaries are outlined in green, and pyrome boundaries are shown in black. (d-l) Trends are presented across three categories for each state: all areas (d, e, f), undeveloped land cover types (g, h, i), and developed land cover types (j, k, l). Areas with statistically significant trends ($p < 0.05$ with false discovery rate control at $\alpha = 0.05$) are indicated without hatching, while non-significant trends are shown with hatching. All trend values are presented per 1,000 km^2 to allow comparison between pyrome data, state-level data, and across states.

developed lands. To understand how these significant trends vary across fire size classes, we next examine the time series of fire frequency across the fire size distribution.

3.2. Time Series and Trends Across the Fire Size Distribution

We investigate whether the significant trends observed in Section 3.1 (Figure 2) are robust across the fire size distribution. We look at the human-caused fire frequency for different fire size classes for undeveloped lands in WUS as a whole and for California and Wyoming, states with significant decreasing and increasing trends, respectively (Figure 3). Undeveloped lands in WUS showed statistically significant trends. The smallest fire size class (≤0.04 ha, ≤0.1 acre) shows a statistically significant increase of 9.2 fires/year, whereas the largest size class (404.7–404,686 ha, 1,000–1,000,000 acre) shows an insignificant increase of 0.5 fires/year. Statistically significant decreasing trends can be seen for all other fire size classes, with the magnitude of the decrease being largest for smaller fire size classes. In general, trends in small fire frequency have greater capacity for larger changes because smaller fires are more common than larger fires. California's trends in human-ignited wildfires are qualitatively similar to those of the WUS, with the difference being that all fire size classes have statistically significant decreasing trends. Overall, the frequency of human-ignited wildfires in undeveloped areas of California decreased by −167.9 fires/year and the largest size-class specific trend is −73.8 fires/year for the small 0.04–0.12 ha (0.1–0.3 acre) class. Wyoming, on the other hand, has increasing trends in human-caused fire frequency for all size classes, with statistically significant increases for all but one of the larger size classes. Notably, however, the increases in fire frequency in Wyoming are relatively small despite their statistical significance. Overall, the trend in human-caused fire frequency in undeveloped areas is 16.8 fires/year and the largest size-class specific trend is 7 fires/year for size class 0.4–1.21 ha. The decreasing trends across all size classes in California (and WUS, with the exception of the smallest and largest fires) represent a scaling down of the fire frequency distribution from the first 10 years to the last 10 years of the study period (Figures 3b and 3d insets). For Wyoming, the effect of trends has an opposing effect: a scaling up of the fire frequency distribution (Figure 3f inset). The systematic decreases in human-caused fire frequency in California and other areas with higher populations, in contrast to the increases in fire frequency in sparsely populated Wyoming, suggests that the spatial distribution of observed trend in fire frequency may be in part explained by human population density.

3.3. Relationship Between Changing Fire Frequency and Human Demography

Next, we investigate the potential link between fire frequency trends and population changes in the WUS (Figure 4). At the 9 km grid resolution used in this study (Figures S8 and S9 in Supporting Information S1), plotting the 15-year mean of annual human-caused fire frequency against average population density, after binning by population, reveals a nonlinear relationship between the two variables. Lower population densities are associated with increasing fire frequency; the fire frequency reaches a peak and then declines as population continues to increase. This pattern resembles the pyric transition pattern, which has been hypothesized to represent how human use of fire on the landscape changes with increasing levels of human activity (Bowman et al., 2011; Scott et al., 2014). This hump-shaped curve appears generally stable over time, as indicated by the similar positions of the curves for the first (1992–2006) and second (2006–2020) 15-year periods. When plotting annual average population values for the states of California and Wyoming, we find that California is to the right of the peak and Wyoming to the left. Plotting state-average population for approximately the midpoint years of the first and second halves of the study period, 2000 and 2013, indicates that with increasing population, Wyoming experienced increasing fire frequency, while California experienced decreasing fire frequency, based on the curve for the first 15 years (1992–2006) alone. This is consistent with the trend analysis results, shown in Figure 2, which use the full period of spatially and temporally comprehensive fire occurrence data. These results indicate stable pyric phases in these regions throughout the study period. The pyric transition behavior is also observed when using decadal housing density data instead of population. The peak of the pyric transition curve occurs at similar bin-averaged fire frequency values for both population and housing density (Figure S10 in Supporting Information S1), indicating the robustness of the relationship.

In theory, pyric transition behavior represents different levels of human control over fire through mechanisms such as suppression effort and effectiveness, flammable landscape fragmentation, and land use/land cover change (Bowman et al., 2009; Scott et al., 2014). In the observational record, fire frequency by general cause of ignition indicates that the decreasing and increasing trends in California and Wyoming, respectively, are present across the majority of general causes (Figures S11 and S12 in Supporting Information S1). In California, however, the

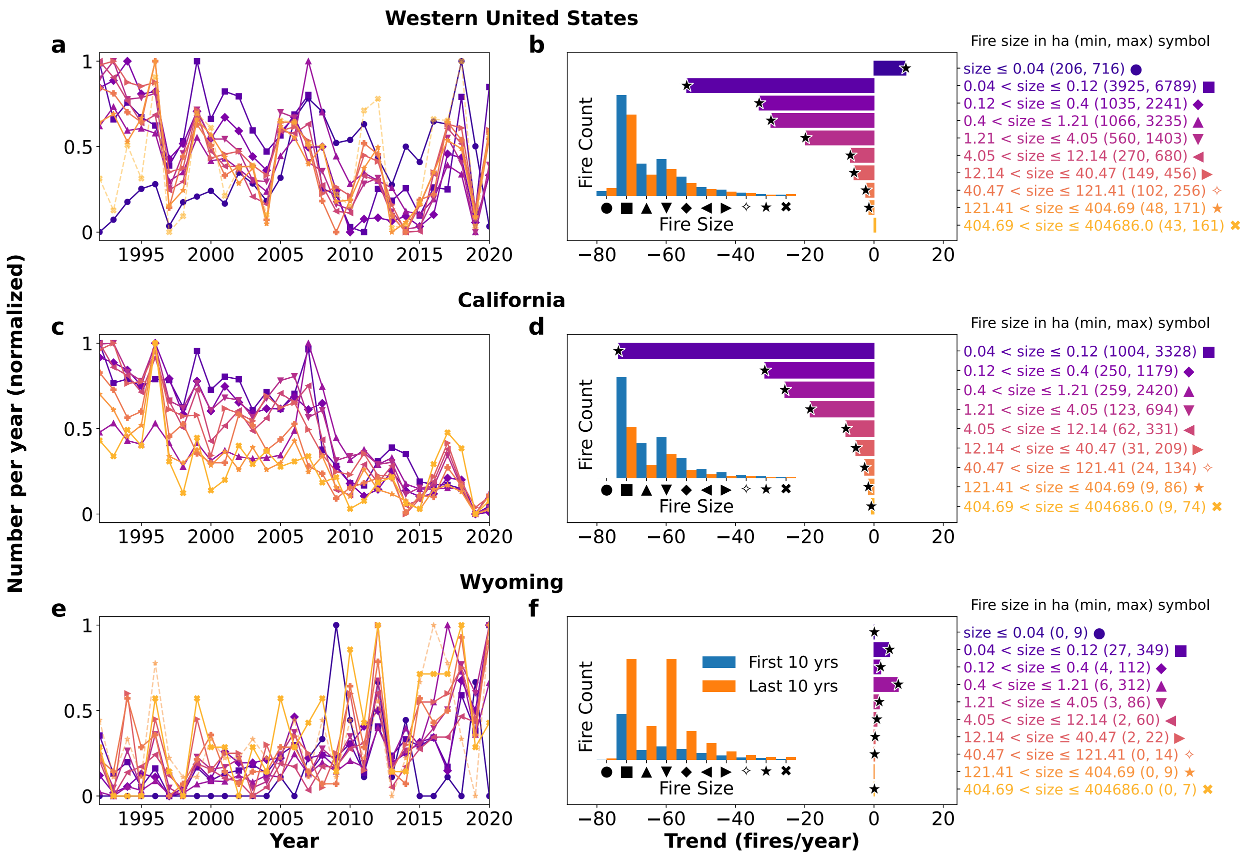

Figure 3. Time series and trends of annual human-caused fire frequency by fire size bin for the western United States, California, and Wyoming in undeveloped lands. Data for (a, b) western United States (c, d) California and (e, f) Wyoming. Annual fire frequencies are shown on the left (a, c, e), with each time series normalized to a range of 0–1, where 0 and 1 represent the minimum and maximum values, respectively. Corresponding trend values are shown on the right (b, d, f). Solid lines in the left panels and asterisks in the right panels indicate statistical significance at $p < 0.05$ and false discovery rate control at $\alpha = 0.05$. *Y*-axis tick labels in the right panels indicate the fire size bin, the original minimum and maximum values of the time series (in parentheses), and the corresponding symbol used in the left panels and insets. The insets show the fire size distribution across fire size classes for 1992–2001 (blue) and 2011–2020 (orange).

largest decrease in ignitions is observed in the *equipment and vehicle use* category, which occurs across various land cover types (Figures S11 in Supporting Information S1). In Wyoming, the increasing trend in human-caused ignitions is dominated by *debris and open burning* primarily in agricultural and shrubland areas (Figures S12 in Supporting Information S1).

We hypothesize that the pyric transition relationship for fire frequency observed here for WUS is linked to fire suppression and fire protection measures and increased awareness, which result in an inverse relationship with increasing population and housing density (Pechony & Shindell, 2009). To investigate this, we examine the annual expenditures of state and local governments on fire protection from 1993 to 2020, excluding 2001 and 2003 due to missing data (Figure 4b, Figure S13 in Supporting Information S1). These expenditures represent the amount of money each state allocated to activities such as firefighting, fire inspection and investigation, and fire prevention. A strong power-law relationship is evident between population density and fire protection expenditure ($r = 0.82$, $p < 0.001$). Individual states also exhibit this relationship. The overall relationship across all states suggests that fire protection expenditure is proportional to the population density raised to the power of 1.25, indicating that as population increases, spending on fire protection increases at a proportionally faster rate. Population increase is associated with more residential and commercial structures, expanded infrastructure, and growth in the wildland–urban interface, where wildfire risk can be high (Radeloff et al., 2018). As exposure to wildfires increases in more densely developed landscapes, institutional capacity expands even more rapidly, possibly contributing to reduced fire frequency. At the same time, this pattern highlights the growing economic burden of sustaining fire resilience in increasingly urbanized regions.

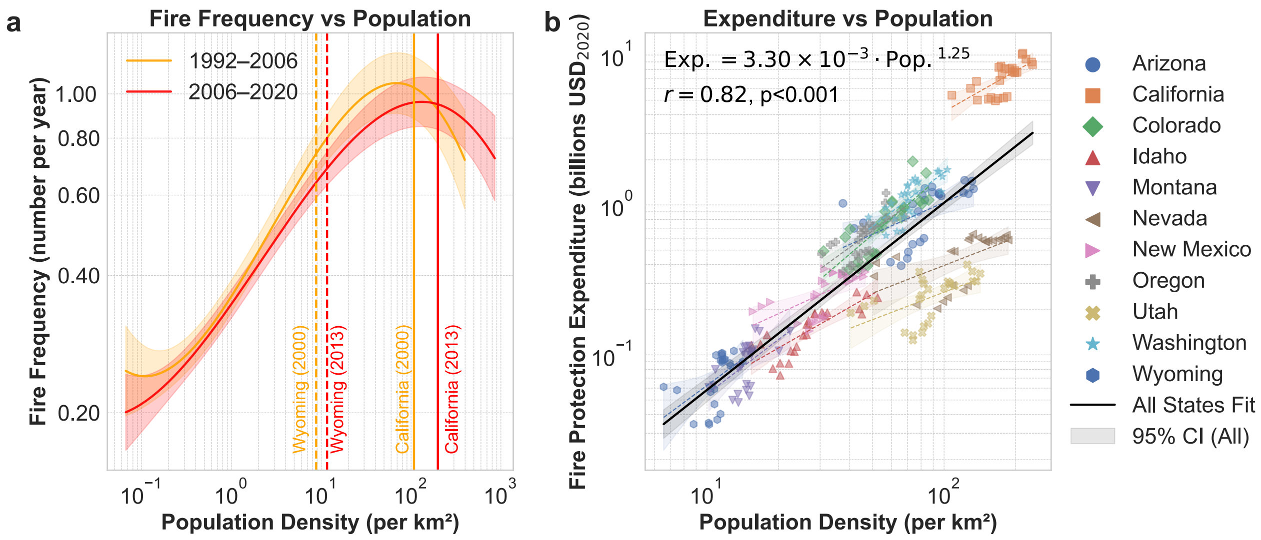

Figure 4. Relationship between human-caused fire frequency and population demographics over the western United States. (a) The annual human-caused fire frequency is plotted against population density, based on 9 km grid-level data. For the first and second 15-year periods, 1992–2006 (yellow line) and 2006–2020 (red line), respectively, the mean annual number of human-caused fires and the mean population density are computed. Values are binned into 20 quantile-based intervals along the *x*-axis, and the median values of both axes for each bin are used to fit a third-degree polynomial. The shaded region around each curve represents the 95% confidence interval. State-average population values are shown for California (solid vertical lines) and Wyoming (dashed vertical lines) for the years 2000 (orange) and 2013 (red). Population density has the unit number per 1 km^2, averaged for each 9 km grid cell. (b) Annual state and local government expenditures on fire protection are plotted against the average population density for each state in the western United States from 1993 to 2020. An ordinary least squares fit is shown for each state and for all data combined (solid line for all data, dashed lines for individual states), along with the 95% confidence interval. The r value, *p* value, and equation for the overall relationship are annotated. Expenditure values are adjusted for inflation and expressed in 2020 USD.

The states that consistently spend the most on fire protection are California (annual average of 7.21 billion USD), Washington (1.17 billion USD), Arizona (0.97 billion USD), Colorado (0.81 billion USD), and Oregon (0.64 billion USD). With the exception of Washington and Colorado, these states have also experienced decreasing trends in human ignitions in undeveloped lands (Figure 2). In contrast, the states that spent the least, including Wyoming (0.07 billion USD), Montana (0.09 billion USD), and Idaho (0.16 billion USD), experienced increases in human ignitions in undeveloped lands. These differences in expenditure by state are also generally reflected in other activities that can influence wildfire activity, such as spending on *Natural Resources* (e.g., forestry and fire protection) (Figure S14 in Supporting Information S1) and *Protective Inspection and Regulation* of hazardous activities (Figure S15 in Supporting Information S1). These expenditure results indicate that California and Arizona spent more on fire protection than most other states, and during the study period, this was associated with a decrease in human ignitions. In contrast, states such as Wyoming, where expenditures have been comparatively low, experienced an increase in human ignitions, likely due to the growing influence of human ignition potential associated with population growth. Note that these expenditures may not fully capture the total spending by states, as the annual survey of local government finance statistics, which these data are based on, is collected from a sample of government agencies (United States Census Bureau, n.d.). However, the data set provides complete spatiotemporal information at the state level across the WUS, using consistent definitions, concepts, and procedures established by the U.S. Census Bureau.

4. Discussion and Conclusions

Our results show a decreasing trend in annual fire frequency during 1992–2020 in the western United States (WUS), driven by declines in both human- and natural-caused ignitions. Spatial patterns at the state level, pyrome level, and at the 9 km grid scale highlight this trend, with statistically significant decreases observed in states such as California, and increases in states like Wyoming. These trends are consistent across different fire size classes. Importantly, spatial patterns in total fire frequency trends appear to be primarily controlled by human ignitions. Understanding the drivers behind human-caused fire frequency trends is complex, as they result from multiple interacting factors operating at different timescales (Harrison et al., 2025). Based on our results and previous literature, we hypothesize three main drivers that have influenced the fire frequency distribution and its trend during the study period. Anthropogenic warming has increased ignition potential (Wilson & Yebra, 2023), which may contribute to rising fire frequency in some regions. However, other anthropogenic factors related to human demographic dynamics also play a role. In ignition-limited areas, increased population and activity can lead to more human-caused ignitions. In contrast, technological advancements, increased land fragmentation, fire prevention and protection investments, and regulations and awareness can reduce ignition frequency (Bistinas et al., 2014; Bowman et al., 2011; Harrison et al., 2025; Knorr et al., 2014; Pechony & Shindell, 2009; Scott et al., 2014).

The pyric transition pattern identified in this study, where fire frequency is positively related to human activity where the human footprint is light but negatively related to human activity where the footprint is heavier, offers a useful framework for understanding how anthropogenic influence may have contributed to regional differences in fire frequency trends across the WUS in recent decades. Our analysis of general ignition causes and land cover types suggests that in sparsely populated Wyoming, ignitions associated with agricultural burning continue to rise. In contrast, in California, policies promoting fire protection and technological interventions, combined with a high level of land fragmentation, may be driving the observed decline in human-caused ignitions (Edgeley et al., 2025; Keeley & Syphard, 2018; Prestemon et al., 2010, 2013). This divergence suggests that regions experiencing opposing fire frequency trends are in different phases of the pyric transition (Bowman et al., 2011; Scott et al., 2014). This is in line with the annual expenditures of each state and local government on fire protection, as well as related categories such as natural resources and protective inspection and regulation. Future work can expand beyond fire occurrence and land cover data sets to investigate region-specific human activities and policy changes that are shaping fire regimes. Identifying where and how these changes are happening will be essential for predicting future fire dynamics in a warming and increasingly human-dominated landscape.

In a complex adaptive systems framework, pyric phases, such as hunter-gatherer, agricultural, and industrial fire regimes, can be conceptualized as distinct basins of attraction, or alternative stable states (Bowman et al., 2011; Roos et al., 2014). Each phase represents a stable configuration of social, economic, technological, and ecological relationships that shape fire activity. Particular combinations of these interacting factors may settle into relatively stable patterns until sufficient change pushes the system into a different stable state characterized by new dominant feedbacks. The pyric transition is driven by nonlinear dynamics rather than simple, one-way growth, highlighting the entanglement of human populations, technologies, economic systems, and pyrogeographies. The industrial pyric transition, for example, marks a systemic shift in which fossil fuels replace surface biomass as the primary energy source, fundamentally transforming how humans interact with, manage, and suppress fire (Bowman et al., 2011). Although it is not a universal explanatory framework for all human–fire relationships (Roos et al., 2014), the pyric transition framework may be useful for analyzing fire regimes at a systemic level, offering a distinctive perspective on interactions among society, technology, the economy, and the landscape. In this study, we examine changes in ignition types and their associated land cover (Figures S11 and S12 in Supporting Information S1). With appropriate data, this type of comparison could be extended to other characteristics, such as levels of protection and expenditure, fire prevention efforts, and related factors.

The fire occurrence data set used in this study represents fires that were suppressed and recorded by various agencies and is thus a reflection of fire protection practices. Across the full range of fire sizes, the combination of aggressive fire suppression efforts and additional societal factors such as increased public awareness (prevention), stricter regulations, improved fire protection strategies, and landscape fragmentation reduces the number of fires (Figure 3; Edgeley et al., 2025; Prestemon et al., 2010, 2013). Aggressive fire suppression policies and management practices aimed at protecting lives and infrastructure have been prompted by rapid increases in population, expansion of the wildland–urban interface, and the recent surge in extreme wildfires (McWethy et al., 2019; Moritz et al., 2014). This situation is linked to a positive feedback loop, where increased suppression capacity supports the expansion of the wildland–urban interface, which in turn heightens fire risk and damage, leading to further investment in suppression efforts (Bowman, 2024; Moritz et al., 2014). Moreover, aggressive fire suppression strategies that aim to eliminate all fires can lead to fuel accumulation, which in turn results in more extreme and suppression-resistant fires. This outcome is known as the suppression paradox (Calkin et al., 2014; Kreider et al., 2024). This is consistent with the current picture of the continued disconnect between trends in fire frequency and those in burned area and structural damages in the WUS (Figure 1). It also reflects characteristics of a maladaptive socio-ecological system, where social and environmental relationships are dysfunctional and fail to reduce risk effectively (Bowman, 2024; Fischer et al., 2016; McWethy et al., 2019). The stability of this pyric phase (Figure 4) serves as a warning that this maladaptive state could be stable, and is likely being further reinforced by anthropogenic climate change through the strengthening of the suppression–population growth feedback (Bowman, 2024; Kreider et al., 2024; Moritz et al., 2014). To escape this maladaptive state, integrated socio-ecological systems approaches have been proposed as potential solutions (Bowman, 2024; McWethy et al., 2019; Moritz et al., 2014). Our findings highlight that the effects of management approaches to reduce undesired wildfire-related outcomes may depend on where a region is situated along the pyric transition.

Decreasing trends in natural ignitions across the WUS, including statistically significant declines in states such as Arizona and Idaho, also contribute to the overall decline in fire frequency. These results are also consistent with the decreasing trends observed in cloud-to-ground lightning stroke data for regions of Canada and the United States (Burrows et al., 2025). The underlying drivers of this decrease in natural ignitions require further investigation. Natural ignitions, primarily caused by cloud-to-ground dry lightning events, are typically associated with low precipitation amounts (e.g., less than 2.5 mm/day), enhanced mid-tropospheric moisture advection, and atmospheric instability (Abatzoglou et al., 2016; Kalashnikov et al., 2022). Precipitation over the WUS, especially during spring and summer, has decreased in recent decades (Easterling et al., 2017). It is possible that these drying trends are associated with a reduction in thunderstorms that produce dry-lightning events. These drying trends have been associated with a strengthening of the zonal sea surface temperature gradient, driven by relative warming in the western tropical Pacific and cooling in the eastern tropical Pacific (Qiu et al., 2024). While there is ongoing debate about whether these trends are part of a forced response to anthropogenic emissions (Lee et al., 2022; Watanabe et al., 2024), their potential link to declining natural ignitions warrants closer examination. It is also important to note that anthropogenic climate change may increase the number of lightning strikes in certain areas of the United States (Romps et al., 2014), further complicating the understanding of the drivers of natural ignition trends.

Several caveats are associated with the fire occurrence data set and methodology. While we screened the FPA FOD data set to remove known data artifacts, and it has been rigorously quality controlled (Short, 2014), spatiotemporal inconsistencies in reporting of wildfire incidents make it impossible to produce an uncertainty-free record of historical wildfires (Short, 2015). Although very small fires were removed during screening due to inconsistent temporal reporting (Methods), all records in the FPA FOD data set represent incidents that elicited an agency response. Therefore, it is possible that some very small fires reflect increased suppression efforts, where rising numbers of small fires may be associated with declining numbers of large fires, as ignitions are being suppressed before they can grow (Archibald, 2016; Cumming, 2005; Martell, 2001). Future work should investigate fire size distributions and suppression scenarios (Kreider et al., 2024) to identify such dynamics. Another caveat is that anthropogenic warming increases ignition potential regardless of the ignition source (Abatzoglou et al., 2017; Wilson & Yebra, 2023), and as a result, fire frequency can increase. On the other hand, the warming-driven increase in aridity has been linked to the explosive growth of burned area in the WUS, which has elicited increasing federal fire suppression costs (Fernandes et al., 2020). Therefore, it is possible that the relationship we identified between human demographic change (through controlling ignitions) and fire frequency is confounded by the effects of anthropogenic warming. Fire occurrence modeling that controls for such exogenous factors could offer a more precise assessment of the relationship between demographic dynamics and ignition potential or frequency (Mann et al., 2016; Park et al., 2021). Despite these caveats, the robust decrease in annual fire frequency across the WUS, together with the demographic controls on human-caused ignitions identified here, suggest that expectations of future changes in wildfire activity should reflect an understanding that socio-demographics will modulate the effects of climate variability and change. It is important that it is understood that rapid increases in the aerial extents, severities, and costs of wildfires can occur even as changes in human activities drive significant declines in ignition frequency.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

Data used in the study are available from the links below. FPA-FOD Fire occurrence data: https://doi.org/10.2737/RDS-2013-0009.6, NLCD: https://doi.org/10.5066/P94UXNTS, Pyromes: https://doi.org/10.2737/RDS-2020-0020, GlobPOP: https://doi.org/10.5281/zenodo.11179644, Housing density: https://doi.org/10.2737/RDS-

2015-0012-4, ALFIN: https://www.census.gov/programs-surveys/gov-finances.html, CPI: https://www.bls.gov/cpi/tables/supplemental-files/, ICS-209+: https://doi.org/10.6084/m9.figshare.19858927.

Acknowledgments

We acknowledge funding from the Gordon and Betty Moore Foundation (Grants 11974 and 13283, GDM, APW), the Sustainable LA Grand Challenges program at UCLA (APW), the USGS Southwest Climate Adaptation Science Center (G24AC00611, G24AC00080, APW), the John D. and Catherine T. MacArthur Foundation (APW), and the National Science Foundation Graduate Research Fellowship Program Grant DGE-2036197 (CSJ). The findings and conclusions in this report are those of the author(s) and should not be construed to represent any official USDA or US Government determination or policy.

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