Title

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An increasing number of wildfire disasters have occurred in recent years in the United States. Here we demonstrate that cumulative primary human exposure—the population residing within the perimeters of large wildfires—was 594,850 people from 2000 to 2019 across the contiguous United States (CONUS), 82% of which occurred in the western United States. Primary population exposure increased by 125% in the CONUS in the past two decades; it was noted that there were large statistical uncertainties in the trend analysis due to the short study timeline. Population dynamics from 2000 to 2019 alone accounted for 24% of the observed increase rate in human exposure, and an increased wildfire extent drove the majority of the observed trends. In addition, we document the widespread exposure of roads (412,155 km) and transmission powerlines (14,835 km) to large wildfires in the CONUS, with a relative increase of 58% and 70% in the past two decades, respectively. Our results highlight that deliberate mitigation and adaptation efforts to help societies cope with wildfires are ever more needed.

Wildfire (hereafter called fire) activity has escalated across the United States in recent decades[1–3]. While land management and historical fire suppression have contributed to these trends[4], a warming climate is implicated as a main cause of increased fire activity in parts of the United States[5,6]. A warmer climate is conducive to the amplified concurrence of dry–hot–windy conditions that are a recipe for very large fires with notable societal and ecological impacts[7]. Furthermore, the population increase in the wildland–urban interface[8] (WUI) has contributed to the heightened societal impacts of fires in recent decades[9–11]. WUI expansion not only enhances the number of houses and populace residing in fire-prone lands but also increases the number of anthropogenic ignitions close to values at risk[12,13]. The confluence of these factors has imposed tragic losses of life, marked socioeconomic disruption, the degradation of ecosystem services and far-reaching indirect adverse impacts[14–17].

A robust analysis of the impacts of large fires on populations and infrastructure requires exploring not only the trends and drivers of increasing fire activity (that is, hazards) but also the exposure to fire hazards[18–20]. Recent studies have explored fire exposures at the regional scale[21,22] and structure loss in the western United States[17]; however, they did not examine direct human and infrastructure exposure to fire, and their trends, in the contiguous United States (CONUS). Using geospatial and statistical analyses, we quantified population and infrastructure (that is, road and powerline) exposure to large fires in the CONUS from 2000 to 2019, and trends thereof. Next, we examined the contribution of population dynamics (that is, population growth in and migration to areas impacted by fire) in overall trends in human exposure to large fires. Then, we assessed changes in population and infrastructure exposure to large fires per unit area burned from 2000 to 2019. We used annual large-fire perimeters (≥400 ha in the western United States

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and ≥200 ha in the eastern United States) from 2000 to 2019 from the Monitoring Trends in Burn Severity programme[23], the 2000–2019 annual gridded (~100 × 100 m) population data from WorldPop[24], the static road vector data from the Topologically Integrated Geographic Encoding and Referencing (TIGER) dataset[25] and the static-medium (10–70 kV) and high-voltage (>70 kV) powerline vector data from a previous study[26].

Results

Human exposure to large fires

Cumulative primary population exposure to fire—defined as the number of people residing within the perimeters of large fires—was estimated at 594,850, 488,200 and 106,650 people in the CONUS, the western United States (the 11 westernmost states in the CONUS) and the eastern United States, respectively, from 2000 to 2019 (Supplementary Data 1 and Fig. 1a,b). We note that residence within fire perimeters does not necessarily translate to direct losses (for example, property damage) as fires burn heterogeneously and include unburned islands within their perimeters[27]. However, the collocation of fires and populated areas exposes people to direct fire impacts. Furthermore, these statistics are probably an underestimation of the primary impact of fires on the population because (1) we considered only large fires in this study (constrained by fire perimeter data availability) and (2) we defined primary exposure to fire as the population residing within fire boundaries.

Notably, California accounted for 72% of the cumulative primary population exposure to fire in the CONUS from 2000 to 2019, while only accounting for 15% of the total burned area (Fig. 1d). For reference, California is home to 12% of the CONUS population (2020 statistics) and accounts for 11% of the CONUS population living in the WUI areas[8] (2010 statistics). The disproportionately larger fraction of CONUS-wide population exposure to fire in California points to the inflated co-occurrence of fires and human settlements[28]. Many of the catastrophic fires that impact populations and infrastructure in California occur coincident with offshore, downslope wind-driven fires that spread wildland fires into populated areas[9,29].

We also estimated secondary exposure—defined as populations within a 5 km buffer around, not within, large-fire perimeters. Secondary exposure probably induced secondary impacts, such as evacuations, socioeconomic disruption and emotional trauma[30,31]. Cumulative secondary exposure to fire in the CONUS, the western United States and the eastern United States from 2000 to 2019 was 36-fold, 33-fold and 47-fold larger than the primary exposure, respectively.

Human exposure trends

Primary population exposure to fire increased in the CONUS at a rate of 1,200 people per year (s.e. 1,090; s.e. has a people per year unit that is omitted for brevity) from 2000 to 2019, marking a 125% growth in two decades (Fig. 1). This trend was mainly driven by a 185% increase in the western United States (1,240 people per year, s.e. 1,120; Fig. 1a). We found a decrease in primary population exposure to fire in the eastern United States (−40 people per year, s.e. 195; Fig. 1b), indicating a 14% decline in two decades. Furthermore, the annual burned area in large fires increased with a rate of 300 $\mathrm{km}^2\,\mathrm{yr}^{-1}$ (s.e. 390), 170 $\mathrm{km}^2\,\mathrm{yr}^{-1}$ (s.e. 310) and 130 $\mathrm{km}^2\,\mathrm{yr}^{-1}$ (s.e. 140) in the CONUS, the western United States and the eastern United States, respectively, in the past two decades (Supplementary Data 1). Supplementary Fig. 1 shows trends in burned areas from 2000 to 2019.

An increasing annual primary population exposure to fire was widespread in the western United States (Fig. 1c), with the largest rate in California (1,165 people per year, s.e. 1,150) that sustained a 225% increase from 2000 to 2019. Note that the increase in population exposure to fire in California was almost identical to that of the CONUS (Fig. 1c and Supplementary Data 1). Two specific years stand out in California's observed record, with a total of 82,200 and 101,600 people exposed to primary fire impacts in 2003 and 2018, respectively (Supplementary Data 1). In California, the 2003 Cedar Fire (1,100 km^2) and the 2018 Camp Fire (620 km^2) claimed 15 and 85 lives and destroyed 2,820 and 18,804 structures, respectively, pinning them as the fourth and first most destructive fires—as measured by structure destruction—in the state's history as of April 2023. Iconic events dominate the presented statistics in this study, specifically given the limited timeline (2000–2019). California also claimed the highest rate of increase in normalized primary population exposure—normalized by state population—across the CONUS in the past two decades (Supplementary Table 1). A majority of the eastern states showed a decrease in primary population exposure to fire in the past two decades (Fig. 1c). There is, however, substantial heterogeneity in the exposure trends in the eastern United States (Fig. 1c); for example, Kansas and Oklahoma observed some of the highest rates of increase in normalized primary population exposure to fire (Supplementary Table 1).

We found increasing trends in secondary population exposure to fire in the CONUS (16,730 people per year, s.e. 24,590; Supplementary Data 1), the western United States (10,190 people per year, s.e. 23,025; Fig. 1a) and the eastern United States (6,540 people per year, s.e. 8,220; Fig. 1b), marking a 35%, 27% and 67% increase in two decades, respectively. Results for various buffer levels around large-fire perimeters are included in Supplementary Data 1. Contrasting trends in primary exposure to fire (that is, within large-fire perimeters, −40 people per year) versus this secondary exposure estimate (that is, in a 5 km buffer from but not within fire perimeters; 6,540 people per year) in the eastern United States suggest that although fire activity in the proximity of human residence increased in the past two decades, fire behaviour was more controllable in the east. This is driven by a lower baseline of fire danger and lower rates of potential fire spread, compounded by larger land fragmentation and extensive use of prescribed fires to mitigate fuel accumulation specifically in the southeast United States, compared with those in the western United States[32]. Across the CONUS, 22 states observed increasing trends in secondary exposure to fires from 2000 to 2019, with Florida claiming the largest trend (6,765 people per year, s.e. 3,965) (Supplementary Data 1). Secondary exposure to fires in California was associated with a trend of 5,880 people per year (s.e. 22,600; Fig. 1e). Supplementary Figs. 2–5 show the annual accumulated primary and secondary exposure to fires from 2000 to 2019, and trends thereof, within 1 km and 5 km buffers from the perimeters of fires.

Role of population dynamics in human exposure to large fires

We estimated the influence of recent population dynamics—population growth in and migration to fire-impacted areas (that is, within fire perimeters), including WUI growth, in 2000–2019[14]—in the observed trends. Differences between the primary population exposure to fire using a dynamic population (annual from 2000 to 2019) and a counterfactual scenario using a static population fixed at values from 2000 were used to quantify the direct influence of population dynamics on primary population exposure to fire and trends thereof in 2000–2019. We estimated that population dynamics accounted for the primary exposure of 41,050 people to fire cumulatively from 2000 to 2019 in the CONUS. This amounts to 7% of cumulative primary population exposures to fire in the CONUS in the past two decades, and the remaining 93% is attributed to the fire activity and its encroachment on human settlement in 2000 (Supplementary Data 1 and 2). We also estimated that, cumulatively from 2000 to 2019, an additional 35,740 (7%) and 5,310 (5%) people were exposed to fire (primary exposure) owing to population dynamics in the western United States and the eastern United States, respectively (Supplementary Data 1 and 2). Note that we only examined the first-order impacts of population dynamics on exposure to fires, and a variety of second-order impacts, such as changes in fire ignitions, land fragmentation and fire suppression, which can have increasing or decreasing effects on fire extent, was not explored herein.

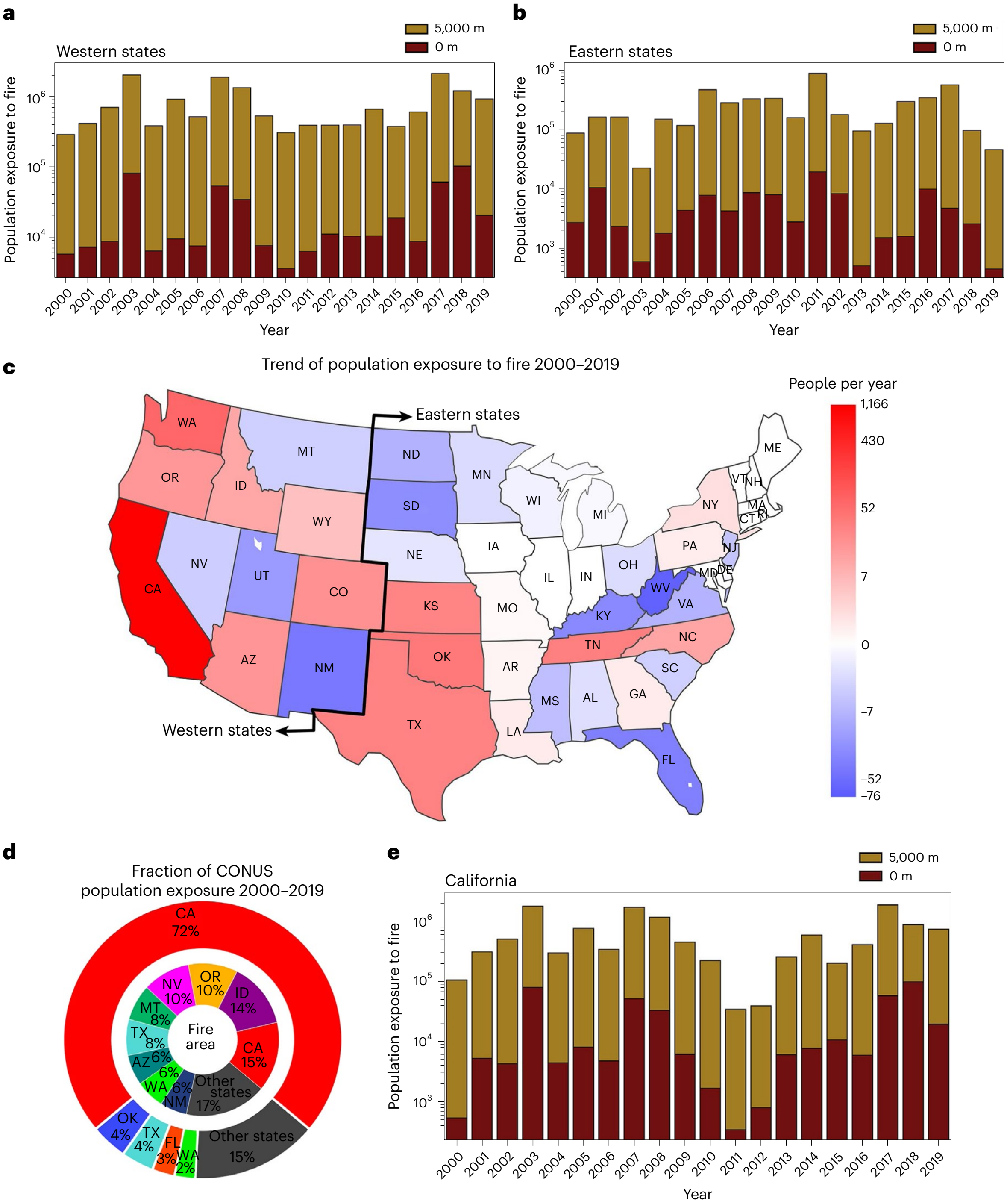

Fig. 1 | Population exposure to large fires from 2000 to 2019. a,**b**, Time series of primary (within fire perimeters; dark-red colour) and secondary (within a 5 km buffer from, but not within, fire perimeters; dark-gold colour) exposure to large fires in the western United States (**a**) and the eastern United States (**b**). **c**, Trends in primary exposure in individual states. **d**, Fraction of cumulative primary population exposure to large fires and large fire area in the CONUS. **e**, Time series of primary and secondary exposure to large fires in California. Note the log scale on the *y* axis in **a**, **b** and **e**.

We found that population dynamics contributed to a 285 people per year (s.e. 95), 270 people per year (s.e. 100) and 15 people per year (s.e. 20) increase in primary population exposure to fire across the CONUS, the western United States and the eastern United States, respectively (Fig. 2a,b and Supplementary Data 1 and 2). These results, however, showed that only a small fraction of observed trends in the CONUS and the western United States (24% and 22%, respectively) can be attributed to population dynamics in the past two decades, while a majority of the observed trends are due to the increasing extent of fires from 2000 to 2019 and their encroachment on human settlements based on population distribution in 2000. Here too, California claimed the highest rate with a 240 people per year (s.e. 100) increase in primary population exposure to large fires attributable to population dynamics, which accounts for 21% of the observed increase from 2000 to 2019 (Fig. 2c). Furthermore, Supplementary Data 6–9 show the contribution of population dynamics to accumulated primary and secondary (that is, within 1 km and 5 km buffers around fire perimeters) population exposure to fires.

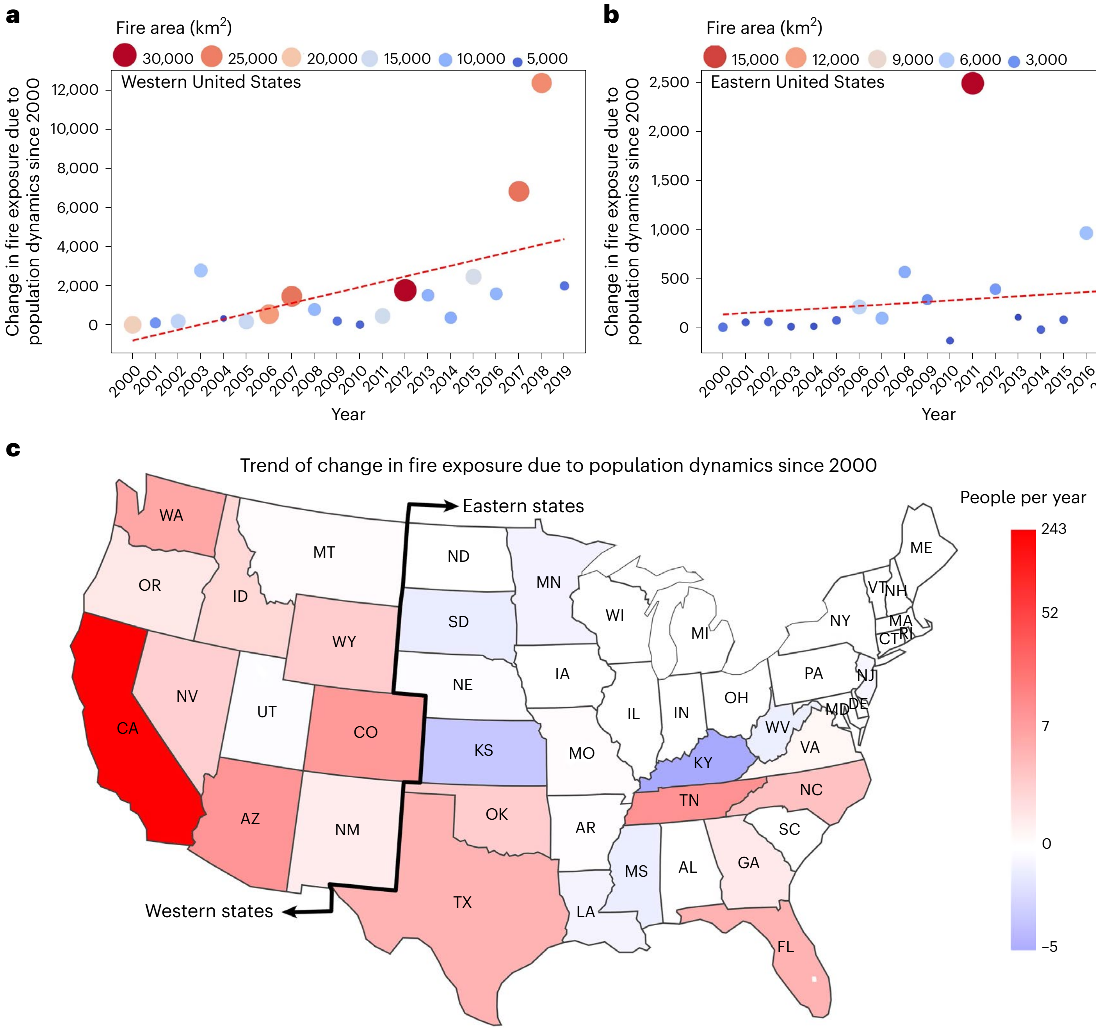

Fig. 2 | Contribution of population dynamics to primary population exposure to large fires from 2000 to 2019. a,**b**, Time series of differences between annual primary human exposure to fire captured in dynamic population data and that with a constant 2000 population level in the western United States (**a**) and the eastern United States (**b**). Dashed lines display trend. **c**, Trends in individual states. Population dynamics include migration to and population growth in fire-impacted areas.

Road and powerline exposure to large fires

Cumulative road exposure to fire—defined as the length of road occurred in the perimeter of large fires—from 2000 to 2019 in the CONUS, the western United States and the eastern United States was 412,155 km, 306,820 km and 105,335 km, which constituted 3.3%, 9.0% and 1.2% of all roads in each region, respectively (Supplementary Data 3). Cumulative powerline (medium and high voltage; ≥10 kV) exposure to fire—defined as the length of powerline occurred within the perimeter of large fires—from 2000 to 2019 in the CONUS, the western United States and the eastern United States was 14,835 km, 4,230 km and 10,605 km, which accounted for 1.2%, 5.0% and 0.4% of the total powerline in each region, respectively (Supplementary Data 4). California accounted for the largest fraction of the CONUS's cumulative road and powerline exposure to fire (18% and 24%, respectively) in the past two decades (Fig. 3e,f).

Increasing road and powerline exposure to large fires

Road exposure to fire increased in the CONUS at a rate of 485 km yr^{-1} (s.e. 400) from 2000 to 2019, corresponding to a 58% growth in two decades (Fig. 3a). Similar trends were observed both in the western United States (285 km yr^{-1}, s.e. 285; Supplementary Data 3) and the eastern United States (200 km yr^{-1}, s.e. 205; Supplementary Data 3), a 43% and 113% growth in 20 years, respectively. Here roads are static and trends are only due to changing large-fire activity. Across the CONUS, 25 states observed increased road exposure to fire, with the largest rates in California (130 km yr^{-1}, s.e. 100) (Fig. 3c).

Powerline exposure increased at a rate of 20 km yr^{-1} (s.e. 15) in the CONUS, a growth of 70% in the past 20 years (Fig. 3b). In the western United States and the eastern United States, this trend was 14 km yr^{-1} (s.e. 10) and 7 km yr^{-1} (s.e. 10), a 65% and an 85% growth, respectively (Supplementary Data 4). Similar to road data, powerline data are static. Across the CONUS, 17 states observed an increase in powerline exposure to fire in the past two decades, with the largest rates occurring in Washington (5 km yr^{-1}, s.e. 2) and California (5 km yr^{-1}, s.e. 5) (Fig. 3d).

Exposure per unit burned area increased

We found an increase in primary population exposure per unit burned area in large fires, suggesting that fires have increasingly collocated with human settlements in the past two decades. In the CONUS, we found that an additional 220 people were exposed per 1,000 km^2 of fire in two decades (Supplementary Data 1). This increase was more apparent in the western United States, and California in particular, exposing an additional 705 people and 3,950 people per 1,000 km^2 of fires in two decades, respectively (Supplementary Data 1). Arizona, Wyoming,

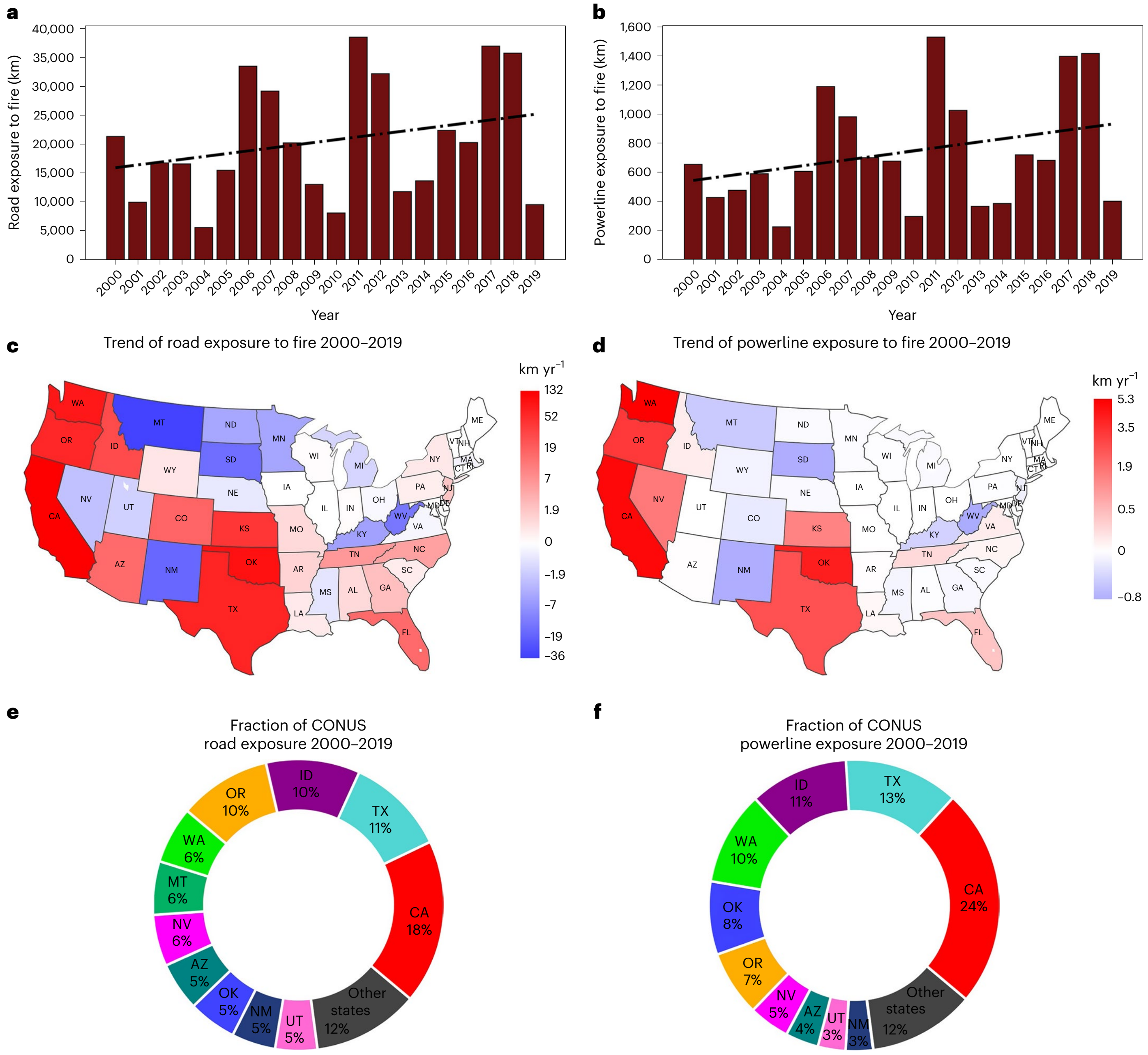

Fig. 3 | Road and powerline exposure to large fires from 2000 to 2019. a,**b**, Time series of road (**a**) and powerline (**b**) exposure in the CONUS. Dashed lines display trend. **c**,**d**, Trends of road (**c**) and powerline (**d**) exposure in individual states. **e**,**f**, Fraction of cumulative road (**e**) and powerline (**f**) exposure from 2000 to 2019 in the CONUS that occurred in each state.

Washington and Montana also stand out in the western United States with an additional 700, 650, 300 and 265 primary population exposures per 1,000 km^2 of fires in two decades, respectively (Supplementary Data 1). In the eastern United States, however, the population exposure per unit area burned declined, exposing 2,930 fewer people to each 1,000 km^2 of fires from 2000 to 2019 (Supplementary Data 1). This was even more pronounced in Florida with 3,185 fewer exposures to 1,000 km^2 of fires in the past two decades.

We also found disproportionate increases in road exposure to large fires during the past two decades with an additional 165 km, 145 km and 285 km of roads per 1,000 km^2 of fire from 2000 to 2019 in the CONUS, the western United States and the eastern United States, respectively (Supplementary Data 3). Finally, our results show an increase in powerline exposure per unit burned area in the CONUS and the western United States with an additional 7 km and 8 km of powerline exposed to each 1,000 km^2 of fire from 2000 to 2019, respectively, whereas the eastern United States observed 11 km less powerline exposure per 1,000 km^2 of fire in 20 years (Supplementary Data 4).

Discussion

We document that the cumulative primary population exposure to fire was 594,850 people from 2000 to 2019 in the CONUS. California accounted for a disproportionately large fraction (72%) of cumulative population exposure in the CONUS from 2000 to 2019, while claiming only 15% of the burned area. Offshore, downslope winds that spread fires into populated areas, under extreme fire behaviour conditions that limit the efficacy of fire-suppression efforts, contributed to the disproportionately larger population exposure to fire in California. Primary human exposure to large fires increased at a rate of 1,200 people per year in the past two decades in the CONUS, marking a 125% growth from 2000 to 2019. This trend was particularly pronounced in the western United States (1,240 people per year; 185% increase in two decades), specifically California (1,165 people per year; 225% growth in 20 years). We note that these trends are associated with a large uncertainty range given the short timeline of this study and high interannual variability of fire extent and exposure. This is common to studies that use spatiotemporally resolved fire records, which are only available for a few decades[33]. Nevertheless, this analysis offers important information about spatiotemporal patterns and trends of human exposure to large fires in the CONUS.

We note that fire impact trends are dominated by iconic events that occur during extreme fire weather[34]. For example, primary exposure trends from 2000 to 2020 in the CONUS and the western United States are notably more pronounced than those from 2000 to 2019 (Supplementary Table 2) owing to the marked fire activity in 2020. Iconic fire events are mainly the result of compounding effects of dry–hot–windy conditions[35]. Climate change has systematically increased the probability of concurrence of critical fire drivers and thereby increased the probability of megafires[7]. Furthermore, background warming has synchronously increased the critical fire danger across the western United States[36], which puts pressure on the already stressed fire-suppression resources and further contributes to the increased probability of fire disasters. These factors have culminated in exceedingly more frequent iconic events in recent years[7]. In fact, three of the deadliest and three of the most destructive fires in California, at the time of this writing, have occurred in the past 6 years.

We show that 24% and 22% of observed trends in population exposure to fire from 2000 to 2019 in the CONUS and the western United States, respectively, are attributable to population dynamics (for example, WUI growth). This indicates that population increases in fire-impacted areas in the past two decades are only marginally accountable for the increase in population exposure to fire[19,37]. By contrast, we find that the increased fire extent in 2000–2019 intersected with the population footprint from 2000 is responsible for a majority of the increased exposure. This finding bears important implications for the development of fire mitigation and adaptation strategies across the United States, for example, in terms of incentive and deterrent strategies to reduce fire risks to humans.

Primary population exposure to fires is arguably smaller than population exposure to other hazards, such as heatwaves, floods and hurricanes, across the CONUS[38,39]; however, fire poses unique and challenging threats to human lives and infrastructure. For example, fire smoke is known to suffocate exposed populations even before their residences are burned or even when they are not burned at all[40]. We also note that while immediate impacts of fires on human lives and infrastructure are tremendous, indirect and derivative fire impacts on social and ecological resources can be even more immense, triggering a range of cascading impacts[41,42], such as fire impacts on municipal water supplies[43], life-threatening post-fire debris flow[44] and health implications of fire smoke[45,46]. Specifically, fire smoke impacted millions of people across the CONUS on an annual basis in recent years, prompting metropolitan areas such as San Francisco and Seattle to experience some of the worst air qualities globally observed. This extends the fire impacts to thousands of kilometres from the fire itself. Fires also directly and indirectly disrupt supply chains[47]. For example, it was estimated that the 2018 California fires caused a total damage of roughly US$148.2 billion, 59% of which was in the form of indirect losses with cascading impacts in markets outside of California[47].

We also reveal the growth in infrastructure exposure to fire in the CONUS from 2000 to 2019. Road exposure to fire increased at a rate of 485 km yr^{-1} from 2000 to 2019 in the CONUS, a 58% increase in two decades. Roads provide a variety of societal services that are disrupted when they are exposed to fire, with long-lasting impacts that can cascade to other regions, systems and sectors through the supply chain[48]. Roads also serve as evacuation routes for the impacted population, and fire-induced road closures can lead to population entrapment in the fire perimeter and/or congestion in alternative routes. Furthermore, road networks have not been improved commensurate with the housing growth in the past several decades in the CONUS, causing an increase in the minimum evacuation times[49], which, alongside increasingly extreme fire weather conditions that promote rapid fire growth[1], leads to escalating fire risks to human lives. For example, in the 2018 Camp Fire—the deadliest fire in California's history as of writing—14 people lost their lives when flames engulfed their cars as they were fleeing the fire[40]. We also show that powerline exposure to fire increased at a rate of 20 km yr^{-1} from 2000 to 2019 in the CONUS, marking a 70% growth in two decades. Our statistics refer to electricity transmission lines—as opposed to distribution lines—which extend the impacted population and areas far beyond the immediate fire perimeters. We expect the length of electricity distribution lines impacted by fires to be several-fold longer than those of the transmission lines reported here. The exposure of powerlines to fire is associated with a wide range of implications that disrupt the functionality of dependent utilities, facilities and services[50]. Loss of electricity can, for example, disrupt the communication, water and transportation sectors. These findings warrant a proactive approach to increasing the resilience of fire-prone areas to ensure services are not halted during and after fires.

Our results also showed an increasing population and infrastructure exposure per unit burned area due to the enhanced collocation of fires and human settlements and infrastructure. This finding challenges the sufficiency of the current paradigm that communicates fire statistics in the scientific literature and to the public in terms of burned areas[51]. We argue that an impact-based communication of fire statistics is required to prompt adequate mitigation and adaptation efforts at all levels from federal investment to individual behaviour change. Importantly, exacerbating impacts necessitate not only further resources to mitigate risks in all phases of fire disasters but also a more comprehensive attention to the needs of impacted populations and first responders.

We posit that an era of fire events unprecedented in the context of contemporary population and infrastructure warrants reimagining the relationship between socio-ecological systems and fire[52]. This entails the co-evolution of human and ecological systems with preparation and planning for the periods before, during and after fires. This may require reimagining our urban planning and zoning codes[53], and adopting marked changes to our landscaping requirements and practices, for example, safe zones around structures[54,55]. The herein-revealed trends of collocating fires with communities show a grave need for a greater focus on programmes such as FireWise that provide resources to protect homes and neighbourhoods against inevitable wildland fires that spread into the WUI areas. Land management practices, including prescribed fire and managing non-threatening fires to reduce fuel density to sustainable levels, would also contribute to reduced fire risks.

Infrastructure systems can be improved to avoid exogenous fire ignitions, and road networks can be enhanced for improved, effective and equitable evacuation[20]. The potential need for fire shelters—similar to tornado, heat and clean-air shelters—can be assessed for remote communities where effective evacuation may be compromised. Additional public education efforts could reduce human ignitions of fires and prepare communities for future fires[56]. Institutions can be strengthened and resources made available to the most vulnerable populations that are at an increased risk of fire impacts[57]. Furthermore, fire mitigation, suppression and recovery resources could be increased and reinforced[53]. Finally, and importantly, moving beyond 'basic resilience', which is rebuilding impacted social and ecological systems to their pre-fire state, to 'adaptive and transformative resilience', which entails transforming systems to embrace fire as a core process[57], would help societies cope with future fire events.

Methods

We used annual large-fire-perimeter polygons (that is, shapefiles) between 2000 and 2019 from the Monitoring Trends in Burn Severity (MTBS)[23] programme. This timeline is selected to be compatible with the available dynamic annual population data (discussed later). MTBS fire perimeters are generated using the differenced normalized burn ratio from post- and pre-fire spectral reflectance in the near-infrared and shortwave infrared bands from Landsat 4, 5, 7 and 8 (ref. 23). MTBS provides the perimeters of large fires, defined as larger than 400 ha in the western United States and larger than 200 ha in the eastern United States, from 1984 to the present, with a few years' latency. We focused on exposure to 'wildfires' by removing the fires that were categorized as 'Prescribed Fire' under 'Incid_Type' or were marked as 'Unknown' under 'Incid_Type' AND 'Unnamed' under 'Incid_Name' in the Burned Areas Boundaries Dataset of MTBS. Unknown and unnamed fires mostly collocate with agricultural lands, pasture lands and grasslands (used for grazing) in which fire is commonly used as a land management tool. Here we adopted the MTBS's definition of a wildfire as "An unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out".

We used WorldPop Global Project Population Data with an ~100 × 100 m resolution that provides annual population distribution from 2000 forward[24]. WorldPop uses one of the most sophisticated weighting schemes among available gridded population products to disaggregate the total population available for administrative units (for example, US Census) to ~100 × 100 m grids. In doing so, WorldPop uses a random-forest model with geospatially refined layers of roads, land cover, built structures, cities or urban areas, nighttime lights, infrastructure, environmental data, protected areas and water bodies[58]. WorldPop offers state-of-the-art accuracy and the highest spatial resolution currently available (Supplementary Figs. 10 and 11). We deemed this dataset proper for the current study following recommendations[58], acknowledging its potential uncertainties. To estimate human exposure to fire, we cropped the population raster based on the fire perimeter layer and summed the populations exposed to fire in each state in each year. In addition, we used vector road data from the TIGER: US Census Roads dataset[25] and medium- (10–70 kV) and high-voltage (>70 kV) powerline vector data from a previous study.[26] TIGER road data provide the shapefiles of roads including "primary roads, secondary roads, local neighbourhood roads, rural roads, city streets, vehicular trails (4WD), ramps, service drives, walkways, stairways, alleys, and private roads". We considered both large and small or access roads in our analysis, as fires can impact all road types, precluding them from providing a variety of services and blocking evacuation routes. To estimate road and powerline exposure to fire, we cropped the vector data of roads and powerlines found within the perimeters of fires in each year and estimated the total annual length of road and powerline exposure to fire separately in each state. Note that human population and fire perimeter data are dynamic at an annual scale from 2000 to 2019, but road and powerline data are static for the entire study period.

We repeated our analysis of human, road and powerline exposure to fires from 2000 to 2019 for 0.5 km, 1 km, 2.5 km and 5 km buffer zones around the perimeters of fires in each year. The buffer zones provide a rough estimate of the secondary impacts of fires.

We considered a counterfactual scenario in which the population distribution is fixed at the level of year 2000 but dynamic annual fire perimeter data are used for exposure assessment. The difference between exposure assessment with a dynamic annual population and this counterfactual scenario determines the contribution of population dynamics to observed trends in human exposure to fires in each state, the western United States, the eastern United States and the CONUS. The western United States is defined as the 11 states in the west of the CONUS. Population dynamics is defined as population growth and migration and includes growth in the WUI.

Finally, we included population exposure to fires for 2020 and 2021, as fire perimeters for these two years became available during the revision of this paper. This analysis is presented in Supplementary Table 2, but the inclusion of these two years did not change the findings reported in this paper.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The fire-burned-area data are available through the Monitoring Trends in Burn Severity programme at https://www.mtbs.gov/index.php/direct-download. The gridded population dataset (WorldPop) is available at https://developers.google.com/earth-engine/datasets/catalog/WorldPop_GP_100m_pop#description. The road shapefiles are available through TIGER: US Census Roads at https://developers.google.com/earth-engine/datasets/catalog/TIGER_2016_Roads#description. Finally, the electricity power grid data are available at https://zenodo.org/record/3538890#.Yg6cFN_MKHs.

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Author contributions

M.S., A.M.R. and J.T.A. conceived the study and wrote the first draft of the paper. A.M.R. conducted all analyses. A.M.R., J.T.A., J.K., M.R.A., A.A., N.H., N.J.N. and M.S. contributed to the study design, results assessment and interpretation, and the writing of the paper.

Competing interests

The authors declare no competing interests.

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Research sample	We used annual large fire perimeters (≥400 ha in the Western U.S. and ≥200 ha in the Eastern U.S.) during 2000 to 2019 from the Monitoring Trends in Burn Severity program (Eidenshink et al. 2007), the 2000-2019 annual gridded (~100x100 m) population data from WorldPop (Sorichetta et al. 2015), static road vector data from the Topologically Integrated Geographic Encoding and Referencing (TIGER) dataset (US Census Bureau, 2017), and static medium (10-70 kV) and high (>70 kV) voltage powerline vector data from Arderne et al. (2020).
Sampling strategy	Sample size was dictated by data availability.
Data collection	A majority of the data used in this study were collected by the US governmental agencies and have gone through necessary quality checks. Other data (population and grid network) were peer-reviewed before publication and sharing.
Timing and spatial scale	Temporal coverage of this study was 2000-2019 given the availability of data. Temporal scale is considered as annual, given this is the only scale viable for multi-decadal exposure analysis and this is the scale that burned area was available. Smallest spatial scale is set at state level, and the study covers the entire contiguous United States.
Data exclusions	None.
Reproducibility	No experimental findings presented.
Randomization	Not relevant.
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