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Changing wildfire complexity highlights the need for institutional adaptation

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As wildfires grow increasingly complex, institutional adaptation—adjusting institutions to respond effectively to environmental changes—is crucial for enhancing wildfire management capabilities. However, institutional adaptation is a challenge as the connection between environmental changes and human institutions remains poorly understood. Here, by analysing trends in five incident characteristics linked to institutional complexity at national and regional levels from 1999 to 2020 in the USA, we show national trends of increasing institutional complexity of wildfire indicators associated with wildfire governance, logistics, management, resource scarcity and network coordination. Substantial regional variation was observed, with some cases exhibiting trends in opposite directions. For example, while average jurisdictional complexity showed an increase in the west, it decreased in the east. These results offer insight into the linkage between environmental change and demands for institutional adaptation and provide an empirical basis for considering potential trade-offs of different institutional adaptations in light of competing pressures.

Widespread attention is being given to the growing risk from wildfires as one of the signature threats of climate change[1]. The empirical basis for this concern is considerable, with a convergence of scholarship revealing upward trends in wildland fire severity and size[2–4], shorter durations between re-burning due to accelerated interactions between droughts and wildfire activity[5], longer fire weather seasons[6] and an increase in the global burnable area[7,8]. Recent extreme incidents, such as the 2023 Canadian and Hawaiian wildfires, are clarion calls signalling growing wildfire risk and associated demands for human adaptation. Research suggests that escalation in wildfire emissions and associated negative impacts to air quality will continue[9]. In other words, there is growing scientific consensus globally of the need for human and institutional adaptation to a changing climate, both now and into the future. And yet, knowing adaptation is needed and understanding what adaptation requires are two different things.

The growing threat of wildfire to human populations is driven by a complex array of factors rooted in a changing climate, historical land management practices and the expansion of human settlements into the wildland[2,10–12]. While the understanding of the interactions between climate, land use and wildfire has advanced, and scientists are increasingly aware of humanity's role in contributing to climate change[1,13], the ability to improve fire management outcomes remains elusive[14]. A key impediment lies in the limited attention given to the conceptual linkage between environmental changes and human institutions[15]. Wildfire management, while rooted in biophysical phenomena, is fundamentally a human activity constrained and enabled by governing institutions—both long-standing organizations and the system of rules and logics that govern their behaviour[16]. Successful adaptation requires understanding how environmental changes translate into new demands on these institutions[17]. Despite this, the state of knowledge concerning the institutional dimensions of wildfire remains nascent. Little is known about where institutional adaptation pressures are most acute or about the forces that reinforce stability and inertia in systems governing wildland fire management. While wildfires are increasingly described as more complex, far less is understood about how changes in wildfire complexity systematically alter the demands on responding institutions at national and regional levels. This study examines trends from 1999 to 2020 in the characteristics of complex wildfire incidents in the USA, focusing on incident characteristics associated with institutional complexity. Because institutions differ

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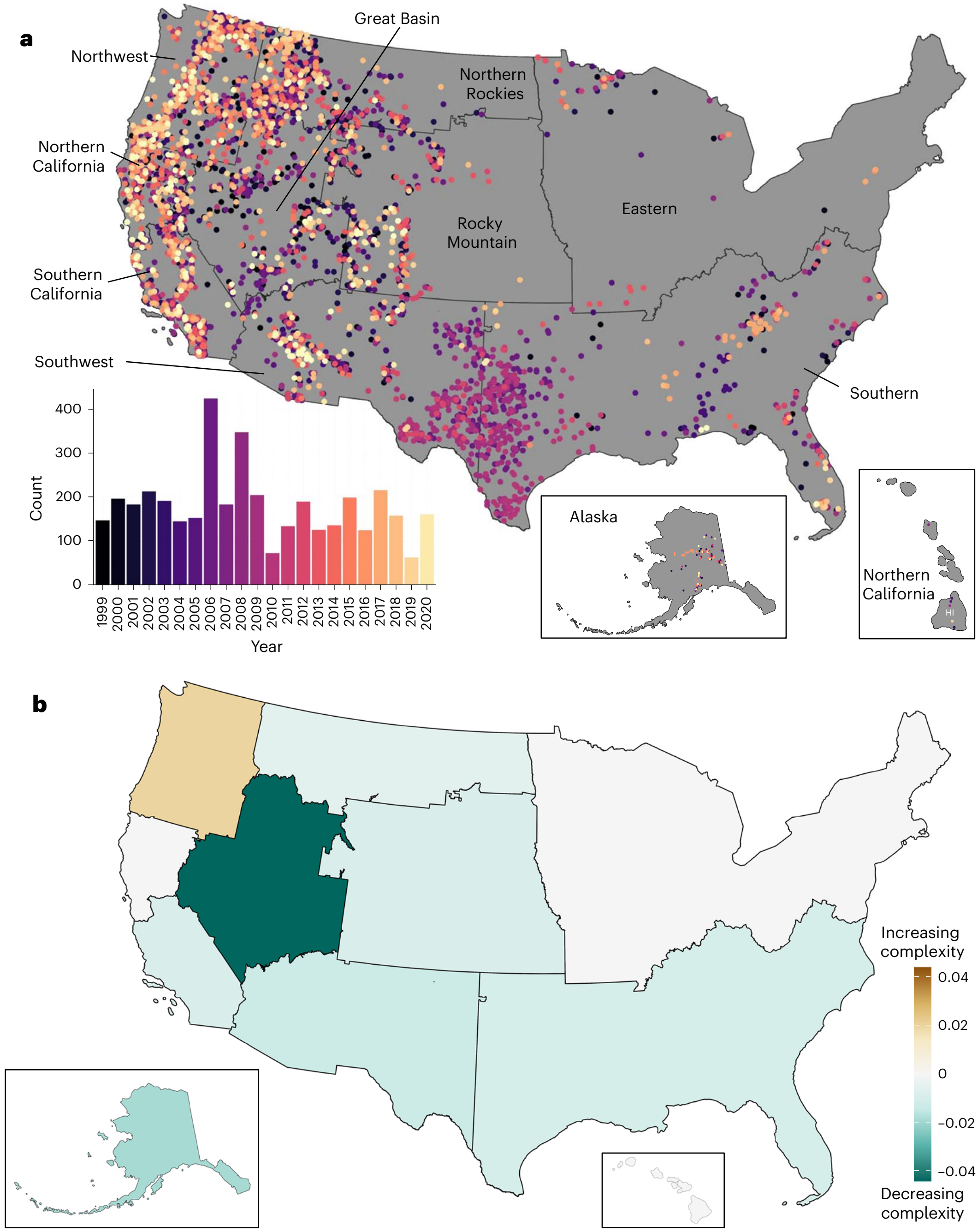

Fig. 1 | Spatiotemporal trends in the number of type 1 and 2 wildfire incidents and change in incident counts by region from 1999 to 2020. a, Locations of type 1 and 2 wildfires coloured by year. The bar chart shows annual frequency of type 1 and 2 wildfires. **b**, Degree of change in annual type 1 and 2 incident frequency 1999–2020 by region based on linear slopes normalized within region. Note: Hawaii is grouped by NWCG as part of the Northern California region.

across contexts, consideration of environment and institutional linkages must be understood within national contexts, which vary in their institutional wildfire response[18].

Institutional complexity is an important concept for advancing climate research because it conceptually links the biophysical environment and associated task environment. In this context, the task environment refers to the nature and scope of demands placed on institutions with authority and responsibility to manage some aspects of the biophysical environment. Changes in the biophysical environment can create variation in the task environment for these institutions. However, case studies reveal that the nature of this coupling is not necessarily linear nor obvious[19]. Agencies and organizations evolve over time to reflect the demands of their task environments[20]. The task environment of an agency is not exclusively a function of their physical environment but is also linked to demands in their policy and their political, economic, cultural and social environment[21,22]. The logics that guide these organizations are rooted in past experience[23]. Institutional logic refers to the tacit and explicit rules that govern thought and action within an organization and are tied to normative expectations of what 'right' looks like within larger institutional fields. Institutions are, by definition and design, stable and enduring[16]. Their very nature makes them resistant to change and oriented towards stability and incrementalism. New logics can take years, sometimes decades, to become institutionalized. In general, the older, larger and more complex an institution is, the more challenging and time intensive adaptation can be[24].

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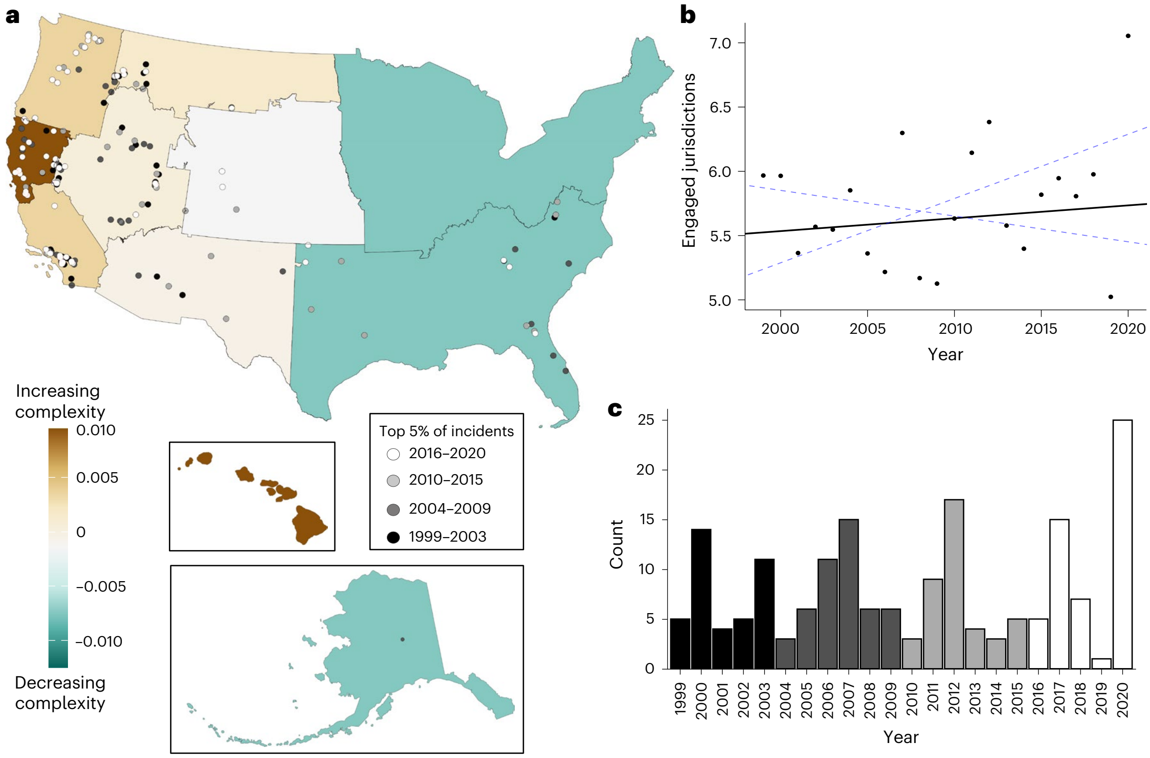

Fig. 2 | Trends in jurisdictional complexity of complex wildfires. a, Change in jurisdictional complexity 1999–2020 by region based on linear slopes normalized within region. Points reflect the locations of the top-5% most jurisdictionally complex wildfires coloured by time period (1999–2003, 2004–2009, 2010–2015 and 2016–2020). **b**, Theil–Sen linear trend (black) 90th percentile bootstrapped confidence bounds (dotted) of the annual national average for jurisdictional complexity of type 1 and 2 wildfires. The linear fit had a slope of 0.01, median absolute error of 0.28 and 90% slope confidence bounds of [0.05, −0.02]. **c**, Annual frequency of the top-5% most jurisdictionally complex wildfires, coloured by time period.

Land management and fire management are both old, highly bureaucratized and deeply professionalized institutions within the USA. Effective institutional adaptation is understood as readiness to meet the demands of the new task environment[25]. However, during times of environmental change, institutions—and their governing policies—may struggle to re-align logics to reflect the demands of the new task environment, particularly if those changes are not well understood[19,26].

In the USA, wildfire response is managed under the incident command system by incident management teams (IMTs) who are called in by affected land jurisdictions to assume operational command of fire suppression activities[27]. Several different factors can influence the institutional complexity of wildfire and their implications may vary on the basis of country context[28]. For this study, we focus on change over time in five key features of wildfire incidents in the USA: incident frequency, jurisdictional complexity, incident size, incident days as preparedness level (PL) 4 or 5 and the scale of threat to human populations. Detailed justifications for considering these features as dimensions of institutional complexity can be found in Methods.

Here we document and investigate changes in the institutional complexity of wildfire incidents in the USA from 1999 to 2020 to address the following research questions: How have these features of wildfire institutional complexity changed over the past 20 years? What aspects of institutional complexity have seen the greatest change? And do these changes vary by region? We focus on the wildfire incidents that require either a type 1 or a type 2 IMT, which are reserved to manage the most extreme wildfire incidents among the five types (types 1 to 5). Our interest in type 1 and 2 incidents is twofold. First, consequences of climate change are often observed in the extremes rather than the averages[3]. Second, national resilience in the context of wildfire should be the capability to prepare for and mitigate harm from extreme events instead of the average incident. Understanding regional variation patterns is critical because, in most cases in the USA, the initial phase of wildfire response is heavily dependent on local and regional capacity.

Prevalence of complex wildfires

Wildfire incidents in the USA are classified on the basis of the qualifications of the IMT deployed for the incident. IMT classifications range from types 5 to 1 based on team size and qualifications. Type 1 and 2 IMTs are the largest, most elite teams and are reserved to manage incidents of the greatest complexity and national consequence (www.nifc.gov/resources/firefighters/incident-management-teams, accessed 15 June 2023). First, we consider change over time in the total number of incidents involving type 1 or 2 IMTs from 1999 to 2020 (Fig. 1a). The number of incidents is an aspect of institutional complexity as the national cache of qualified personnel to staff type 1 and 2 IMTs is decreasing[29], leading to the potential situation of more deployments of fewer IMTs. While type 1 and 2 incidents are consistently concentrated in the western USA, all US regions have experienced type 1 and 2 wildfires (Fig. 1a).

Nationally, on average, the linear trend associated with the prevalence of type 1 and 2 incidents has decreased slightly in number since 1999, by 2%; this is due to very active fire years in 2006 and 2008 (Fig. 1a). The key exception to this is the Pacific Northwest (Fig. 1b), which has seen, on average, a 2% per year linear increase in type 1 and 2 incidents since 1999. This suggests that increased regional pressure on type 1 and 2 resources is possible, but these pressures vary greatly from year to year and region to region.

Jurisdictional complexity

Second, we investigate trends in the changing jurisdictional complexity of complex wildfire incidents. Authority for managing wildfire in the USA is fragmented across a mosaic of local, state, federal and

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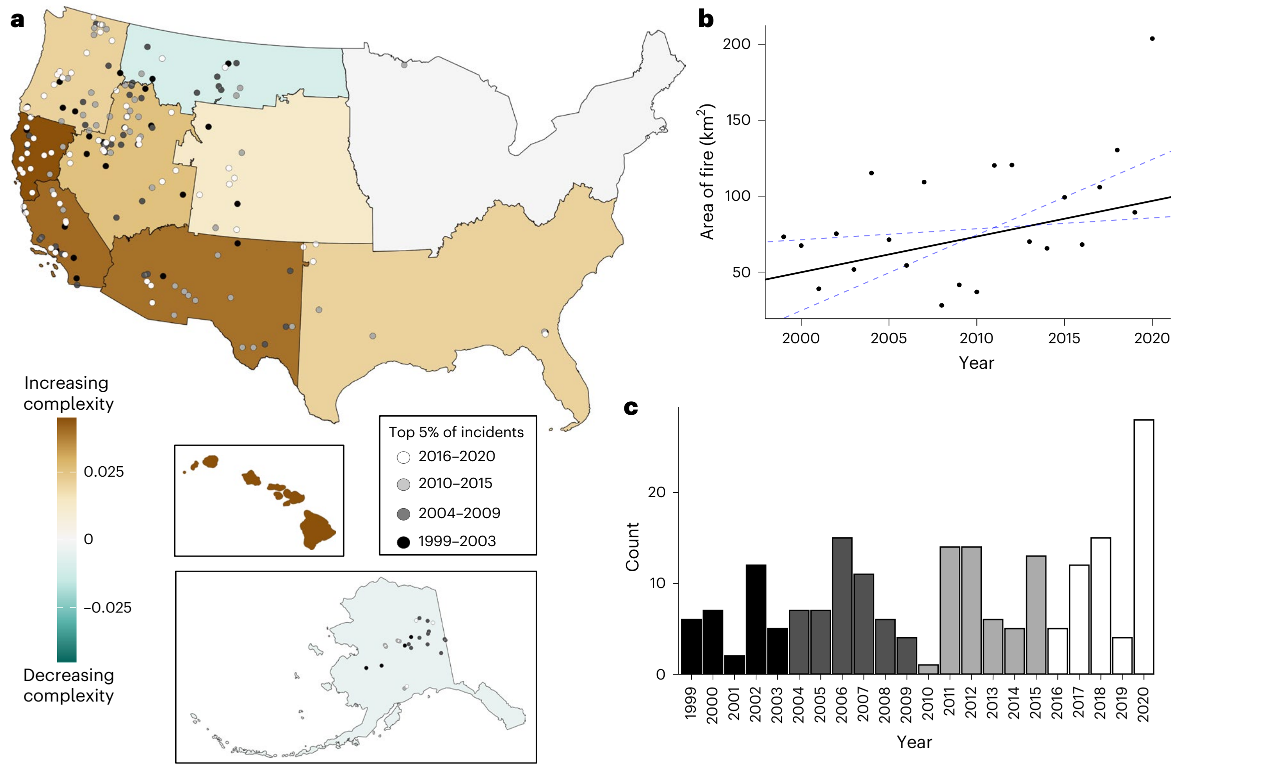

Fig. 3 | Trends in the average size of type 1 and 2 wildfire incidents. a, Change in average size of incidents 1999–2020 by region based on linear slopes normalized within region. Points reflect the locations of the top-5% largest wildfires coloured by time period (1999–2003, 2004–2009, 2010–2015 and 2016–2020). **b**, Theil–Sen linear trend (black) and 90th percentile bootstrapped confidence bounds (dotted) of the national annual average for size of type 1 and 2 wildfires. The linear fit had a slope of 2.35, median absolute error of 25.72 and 90th percentile slope confidence bounds of [4.98, 0.72]. **c**, Annual frequency of the top-5% largest wildfires, coloured by time period.

tribal jurisdictions. Jurisdictional complexity reflects the number of discrete land jurisdictions affected by, and engaged on, a wildfire incident as well as the extent to which affected jurisdictions span several levels of government[28]. As jurisdictional complexity increases, the governance complexity of the incident intensifies as each jurisdiction may have differing priorities and no single jurisdiction has singular authority over the incident. Evidence suggests that the average jurisdictional complexity of wildfires has increased slightly (Fig. 2). Thirty per cent of the most jurisdictionally complex incidents during the study period occurred since 2016. However, as shown in Fig. 2, the trends differ from east to west. For example, in Northern California, the average wildfire in 2020 was 24% more jurisdictionally complex when compared with the average wildfire in 1999, whereas the southern region showed a 13% linear decrease in the average type 1 or 2 jurisdictional complexity. Standardization is based on the cumulative average fire size within the Geographic Area Coordinating Center (GACC). Slopes represent average percentage change in size within GACC by year. It is noteworthy that the Theil–Sen estimator used in calculating these trends subdues the impact of outlier incidents. For example, even though the region overall showed a decrease in complexity, two of the three most jurisdictionally complex incidents in the dataset occurred in the southern region (Supplementary Information).

Size of complex wildfires

Larger wildfires require larger fire organizations with more fire-fighters and equipment spread out across a larger area, which increases the management complexity of the incident. Results confirm that nationally, on average, type 1 and 2 wildfire incidents are increasing in size annually by 2.13 km^2 (Fig. 3). This means an increasingly greater distance of fire perimeter must be managed and coordinated. Nearly one-third of the largest incidents in the study period have occurred since 2016. All regions but three have experienced an upward trend in fire size. California and the southwest region showed the strongest relative change, where the average incident size within each of these regions in 2020 is approximately 90% larger than it was in 1999.

Incident days at PL 4 or 5

The national PL is an index in the USA managed by the National Multi-Agency Coordinating Group (NMAC) based on national resource availability (www.nifc.gov/sites/default/files/2020-09/National_Preparedness_Levels.pdf). This index ranges from 1 to 5. Higher PL levels indicate that many or most fire response resources have been deployed and there is a scarcity of resources that can be allocated to any given incident. When a complex incident occurs during times when the nation is at PL 4 or 5, incident commanders may not have access to the fire-fighters and equipment they need and will need to calibrate their strategy on the basis of what can be accomplished with the resources that are available. Nationally, analysis suggests a slight increase in the average number of incident days at PL 4 or 5 per year over the past 22 years, although substantial annual variation was observed (Fig. 4). Of the incidents with the greatest number of incidents days at PL 4 or 5, 30% have occurred since 2016. Regional analysis reveals that this trend is driven by changes in the western USA. In these regions, wildfires are increasingly managed under conditions of resource shortages. For example, the average complex wildfire incident in Northern California in 2020 has seen, on average, a 75% increase in days at PL 4 or 5 since 1999. Interestingly, while the southern region has increasingly larger fires, the average type 1 or 2 incident is not experiencing more days at PL 4 or 5. This may suggest that regions with peak wildfire activity occurring off-cycle from the peaks in the west may benefit from increased availability of national resources.

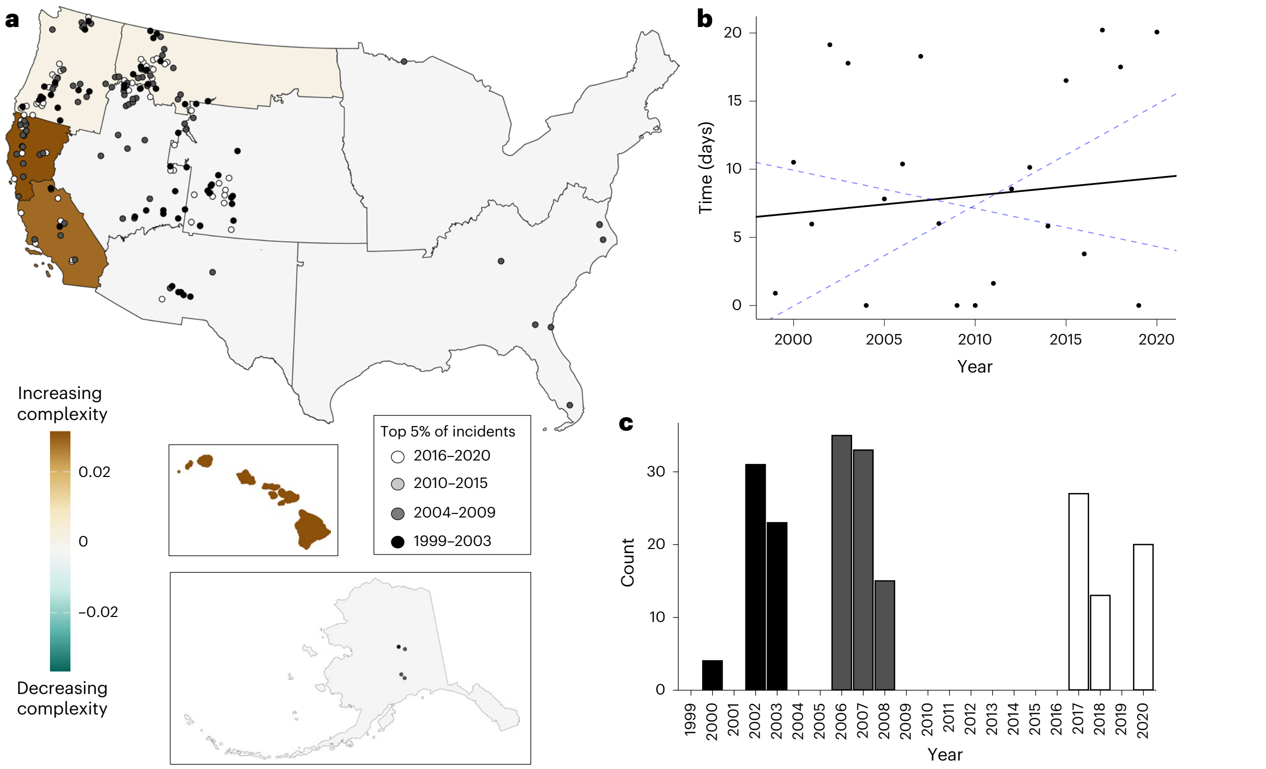

Fig. 4 | Trends in the number of incident days at national PL 4 or 5. a, Change in average number of incident days at PL 4 or 5 from 1999 to 2020 by region based on linear slopes normalized within region. Points reflect the locations of the top-5% of incidents with the most days at PL 4 or 5, coloured by time period (1999–2003, 2004–2009, 2010–2015 and 2016–2020). **b**, Theil–Sen linear trend (black) and 90th percentile bootstrapped confidence bounds (dotted) for incident days at PL 4 or 5. The linear fit had a slope of 0.13, median absolute error of 4.46 and 90th percentile slope confidence bounds of [0.75, −0.28]. **c**, Annual frequency of the top-5% most institutionally complex wildfires in terms of number of days at PL 4 or 5, coloured by time period.

Structures threatened, damaged or destroyed

The findings indicate that complex wildfire incidents are becoming more threatening over time. On average, nationally, a complex wildfire in the USA is threatening, damaging or destroying approximately 38 more structures every year (Fig. 5). Of those wildfires representing the top-5% in terms of the number of structures threatened, damaged or destroyed, nearly half the most threatening wildfires between 1999 and 2020 have occurred since 2016. Findings further indicate that wildfires are increasingly threatening, damaging and destroying more structures in just about every region (Fig. 5). However, the southwest has seen the greatest relative change over time, with the average incident in 2020 being 220% more threatening or destructive than the average incident in 1999. In California, the linear average type 1 or 2 incident is 112% more threatening or destructive. This trend is driven by spikes in threatened, damaged or destroyed structures from key incidents between 2015 and 2020. A previous study[29] cautioned that incident data on structures threatened, damaged and destroyed may represent the information available at the time and should be viewed as estimates.

Discussion

Changes in fire regimes, driven by changes in climate, invasive species, land use and land management, are affecting the nature of wildfire and its consequences for human settlements[2,15,30]. Effective adaptation will require, in part, an understanding of how these changes translate to changes in the task environment for the institutions that are responsible for mitigating the consequences of wildfire to communities. This study documents changes in key areas of institutional complexity for complex wildfire incidents in the USA. Findings indicate a national picture of an increasingly complex task environment for organizations and agencies responsible for managing these incidents; one that is likely to require the management and support of larger and more complex fire organizations and strain historical wildfire governance systems with a growing portfolio of competing jurisdictional priorities and interests that must be reconciled[31]. While this portfolio of potentially competing interests is expanding for IMTs, the west is experiencing more incident days when there are limited national resources to respond. Finally, the scale of threat to human settlements for the average type 1 and 2 wildfire incident has increased over the past 22 years. In addition to being a significant concern to local communities, this escalation of risk further exacerbates the complexity of incident response as it requires tighter coordination between wildfire management and emergency management operations, which are governed by different actors operating at different scales[27].

These findings contribute to the understanding of the nature of the demands for institutional adaptation, raising important empirical and practical questions about the extent to which, and ways in which, existing institutions at local, state, tribal and federal levels are adapting to these new demands, providing an empirical basis to consider potential trade-offs in adaptive action. One example of this is a recent policy development in the USA to create complex IMTs[32]. These teams combine the previous two highest qualified categories of IMTs (type 1 and 2) into a single level of qualification and allow for greater ad hoc integration of type 1 or 2 individuals from other teams into key team-member roles. The intent of this institutional adaptation is, in part, to increase the number and availability of IMTs that can be deployed to complex incidents formerly requiring type 1 IMTs[32]. This adaptation aims to address critical resource availability challenges in staffing type 1 teams[33] while the number of incident days at PL 4 and 5 increase in some regions. What is yet unknown is whether this adaptation may be associated with trade-offs with other areas of growing institutional complexity, as team members with potentially fewer qualifications face increasingly complex wildfire governance challenges

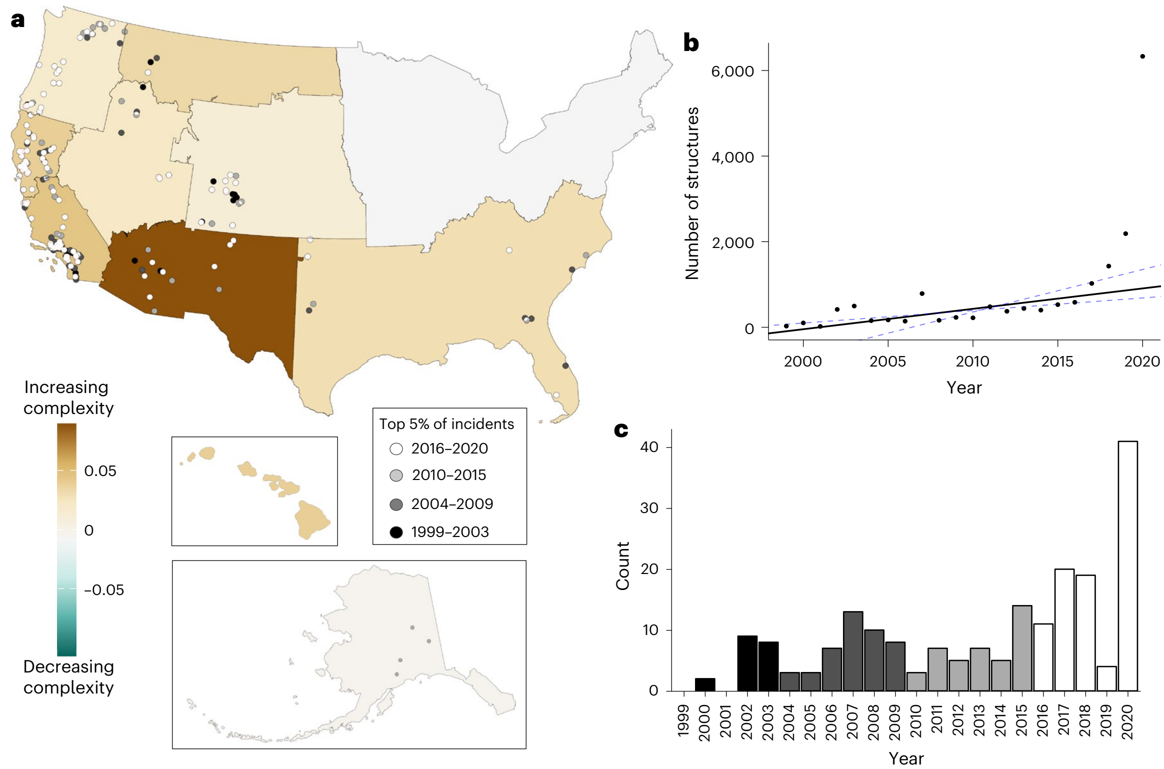

Fig. 5 | Change in average number of structures threatened, damaged or destroyed. a, Change in average number of structures threatened, damaged or destroyed by region based on linear slopes normalized within region. Points reflect the locations of the top-5% most complex wildfires in terms of the number of structures threatened, damaged or destroyed coloured by time period (1999–2003, 2004–2009, 2010–2015 and 2016–2020). **b**, Theil–Sen linear trend (black) and 90th percentile bootstrapped confidence bounds (dotted) of the national annual average of structures threatened. The linear fit had a slope of 47.66, median absolute error of 97.21 and 90th percentile slope confidence bounds of [99.13, 29.30]. **c**, Annual frequency of the top-5% most institutionally complex wildfires in terms of the number of structures threatened, damaged or destroyed, coloured by time period.

both across jurisdictions and in the coordination with emergency management operations. Monitoring these changes and investigating how different aspects of institutional complexity interact to affect incident outcomes over time is an important direction for future research.

Clarifying the geographies where the pressures for adaptation are most acute is also critical to advancing a programme of study about the institutional adaptation of wildfire. Findings reveal regional variation not just in the magnitude of change but, importantly, in the direction of change. Implications of the risk profile by region are different based on directionality of change. Regions that have limited recent experience with complex wildfires may be particularly vulnerable to extreme events, such as the case of the 2016 Gatlinburg and 2023 Lahaina wildfires[34]. Hawaii is administratively grouped with Northern California GACC. Regional analysis shown here may mask within-GACC variation. On the other end of the spectrum, the magnitude and scope of increasing complexity in the west has been comparatively greater relative to other regions. The institutions in these regions have had to adapt in more substantial ways to managing larger and more jurisdictionally complex fire organizations, requiring more complex coordination with emergency operations to protect human settlements, and under more frequent conditions of resource scarcity. Future research should look to these regions as potential front runners of innovation in the management of this new task environment. The institutional innovations and adaptations that are proving effective in managing in this more complex task environment may hold valuable lessons for the rest of the nation as it prepares for the coming decades. Future research should also consider how national changes may have variable impacts across regions in consideration of these divergent task environments.

Wildfire has been recognized as a growing global challenge, linked to changes in climate[35]. However, little is known about how changes in biophysical characteristics of wildfire may have differing consequences in different societal and national contexts. The present study can speak only to changes in institutional complexity within the US context; however, this study raises important questions for future research about how these trends may vary across countries and globally. Research suggests that trends in the biophysical characteristics of fire are variable across country context[28,36,37]. Wildfire climatology is likely to be associated with different institutional demands for adaptation across different country contexts. Further, countries vary in their institutional systems for managing wildfire[38]. For example, it is possible that similar changes in biophysical environments could have very different consequences based on different institutional characteristics of wildfire response across countries.

Findings must take into account potential data limitations. Under extreme fire years, raw counts of team assignments may mask or under-represent institutional complexity as there are finite numbers of type 1 and 2 teams available to be assigned. As indicated by our analysis of changes in incident days at national PL 4 or 5, western regions are experiencing, on average, a growing number of incident days when national response resources are scarce due to the level of fire activity. This may necessitate IMTs assigned to manage multiple fires as part of the same incident (referred to as complexing; 29). It should also be noted that data carry across the pandemic of 2020, which had an impact on the availability of wildfire personnel[39].

Last, findings from this study illustrate the need to give greater empirical attention to the coupling between changes in the biophysical aspects of climate change and needs for institutional adaptation in response to corresponding changes in the task environment. Our study examines large-scale trends aggregated by incident by year. However, temporal variation in institutional complexity is also present within incidents over time and different patterns, such as the number of days when structures are threatened, may also signal increases in institutional complexity. Further, institutional complexities associated with changes in fire funding and policy, insurance, an ageing workforce and Covid 19 offer fertile, policy-relevant directions for future research. Normal accidents theory has long argued that, as systems become more complex and interdependent, risks for failures also increase[40]. Despite this, the current state of scientific knowledge concerning the coupling of environmental change and requisite institutional adaptation is comparatively nascent. Successful adaptation to a changing climate will require an integrated understanding of coupled change in the biophysical environment to the associated task environment of governing institutions.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-025-02367-1.

References

1. Kumar, A., Nagar, S. & Anand, S. in *Global Climate Change* (eds Singh, S. et al.) 1–31 (Elsevier, 2021).
2. Farkhondehmaal, F. & Ghaffarzadegan, N. A cyclical wildfire pattern as the outcome of a coupled human natural system. *Sci. Rep.* **12**, 5280 (2022).
3. Mann, D. H., Rupp, T. S., Olson, M. A. & Duffy, P. A. Is Alaska's boreal forest now crossing a major ecological threshold? *Arct. Antarct. Alp. Res.* **44**, 319–331 (2012).
4. Rupp, T. S. et al. in *Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of Alaska* (eds Zhu, Z. & McGuire, A. D.) 17–52 (US Geological Survey, 2016).
5. Whitman, E., Parisien, M. A., Thompson, D. K. & Flannigan, M. D. Short-interval wildfire and drought overwhelm boreal forest resilience. *Sci. Rep.* **9**, 18796 (2019).
6. Jolly, W. M. et al. Climate-induced variations in global wildfire danger from 1979 to 2013. *Nat. Commun.* **6**, 7537 (2015).
7. Balch, J. K. et al. Warming weakens the night-time barrier to global fire. *Nature* **602**, 442–448 (2022).
8. Senande-Rivera, M., Insua-Costa, D. & Miguez-Macho, G. Spatial and temporal expansion of global wildland fire activity in response to climate change. *Nat. Commun.* **13**, 1208 (2022).
9. Wilmot, T. Y., Mallia, D. V., Hallar, A. G. & Lin, J. C. Wildfire plumes in the Western US are reaching greater heights and injecting more aerosols aloft as wildfire activity intensifies. *Sci. Rep.* **12**, 12400 (2022).
10. Duane, A., Castellnou, M. & Brotons, L. Towards a comprehensive look at global drivers of novel extreme wildfire events. *Climatic Change* **165**, 43 (2021).
11. Pausas, J. G. & Keeley, J. E. Wildfires and global change. *Front. Ecol. Environ.* **19**, 387–395 (2021).
12. Syphard, A. D., Keeley, J. E., Pfaff, A. H. & Ferschweiler, K. Human presence diminishes the importance of climate in driving fire activity across the United States. *Proc. Natl Acad. Sci. USA* **114**, 13750–13755 (2017).
13. Crowley, T. J. Causes of climate change over the past 1000 years. *Science* **289**, 270–277 (2000).
14. Schultz, C. A., Thompson, M. P. & McCaffrey, S. M. Forest Service fire management and the elusiveness of change. *Fire Ecol.* **15**, 13 (2019).
15. Moritz, M. A. et al. Learning to coexist with wildfire. *Nature* **515**, 58–66 (2014).
16. DiMaggio, P. & Powell, W. The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. *Am. Sociol. Rev.* **48**, 147–160 (1983).
17. Essen, M., McCaffrey, S., Abrams, J. & Paveglio, T. Improving wildfire management outcomes: shifting the paradigm of wildfire from simple to complex risk. *J. Environ. Plan. Manag.* **66**, 909–927 (2023).
18. Henderson, M. et al. Fire and society: a comparative analysis of wildfire in Greece and the United States. *Hum. Ecol. Rev.* **12**, 169–182 (2005).
19. Nowell, B. & Stutler, J. Public management in an era of the unprecedented: dominant institutional logics as a barrier to organizational sensemaking. *Perspect. Public Manag. Gov.* **3**, 125–139 (2020).
20. Meyer, J. W. & Rowan, B. Institutionalized organizations: formal structure as myth and ceremony. *Am. J. Sociol.* **83**, 340–363 (1976).
21. Pennick McIver, C., Cook, P. S. & Becker, D. R. The fiscal burden of wildfires: state expenditures and funding mechanisms for wildfire suppression in the Western US and implications for federal policy. *State Local Gov. Rev.* **53**, 337–351 (2021).
22. Thompson, M. P., MacGregor, D. G., Dunn, C. J., Calkin, D. E. & Phipps, J. Rethinking the wildland fire management system. *J. For.* **116**, 382–390 (2018).
23. Schein, E. H. *Organizational Culture and Leadership* (Jossey-Bass, 1993).
24. Greenwood, R. & Hinings, C. R. Understanding radical organizational change: bringing together the old and the new institutionalism. *Acad. Manag. Rev.* **21**, 1022–1054 (1996).
25. Sarta, A., Durand, R. & Vergne, J. P. Organizational adaptation. *J. Manag.* **47**, 43–75 (2021).
26. Weick, K. E. *Sensemaking in Organizations* (Sage, 1995).
27. Nowell, B. & Steelman, T. Beyond ICS: how should we govern complex disasters in the United States? *J. Homel. Secur. Emerg. Manag.* **16**, 20180067 (2019).
28. Jones, K., Vukomanovic, J., Nowell, B. & McGovern, S. Mapping wildfire jurisdictional complexity reveals opportunities for regional co-management. *Glob. Environ. Change* **84**, 102804 (2024).
29. St. Denis, L. A. et al. All-hazards dataset mined from the US National Incident Management System 1999–2020. *Sci. Data* **10**, 112 (2023).
30. Kelly, L. T. et al. Understanding fire regimes for a better Anthropocene. *Annu. Rev. Environ. Resour.* **48**, 207–235 (2023).
31. Steelman, T., Nowell, B., Velez, A. L. & Scott, R. Pathways of representation in network governance: evidence from multi-jurisdictional disasters. *J. Public Adm. Res. Theory* **31**, 723–739 (2021).
32. Gabbert, B. Proposal for combining Type 1 and Type 2 incident management qualifications into a single level. https://wildfiretoday.com/proposal-for-combining-type-1-and-type-2-incident-management-qualifications-into-a-single-level/ (2022).
33. Black, A. E. *Incident Management Organization Succession Planning* (RMRS-GTR-297) (USDA, 2013); https://doi.org/10.2737/RMRS-GTR-297
34. Blaustein, J., Shearing, C. & Miccelli, M. Adaptive policing for a climate crisis. *Policing Soc.* https://doi.org/10.1080/10439463.2024.2362713 (2024).
35. Shi, K. & Touge, Y. Characterization of global wildfire burned area spatiotemporal patterns and underlying climatic causes. *Sci. Rep.* **12**, 644 (2022).
36. Andela, N. et al. A human-driven decline in global burned area. *Science* **356**, 1356–1362 (2017).
37. Bowman, D. M. et al. Vegetation fires in the Anthropocene. *Nat. Rev. Earth Environ.* **1**, 500–515 (2020).
38. Moore, P. F. Global wildland fire management research needs. *Curr. For. Rep.* **5**, 210–225 (2019).

https://doi.org/10.1038/s41558-025-02367-1

39. Wells, E. M. et al. Quantifying wildland fire resources deployed during the compound threat of COVID-19. *Sci. Rep.* **14**, 20039 (2024).
40. Perrow, C. *Normal Accidents: Living with High Risk Technologies* (Princeton Univ. Press, 1999).

Methods

This study examined trends over time associated with five dimensions of institutional complexity associated with wildfire incidents. All analysis was conducted on publicly available datasets. All data and code are available[41]. Justification of each dimension of institutional complexity as well as a description of the analytic approach are outlined below.

Five dimensions of wildfire incident institutional complexity

Institutional complexity was conceptualized as incident characteristics that would affect the task environment for responsible agencies and their IMTs. We analysed five wildfire incident characteristics associated with increased institutional complexity: (1) prevalence of type 1 and 2 incidents, (2) jurisdictional complexity, (3) incident size, (4) incident days at PL 4 or 5 and (5) number of structures threatened, damaged or destroyed.

First, the frequency of incidents is an important feature of institutional complexity because the extent to which demand for the most elite and qualified incident response resources is increasing will place greater burden and strain on national resources. Further, in the USA, incident response personnel are predominantly reservists who work full-time elsewhere, often in key land or fire management leadership positions. More frequent deployment of these individuals from their primary posts increases institutional complexity of incidents because it will add further strain on both these agencies and the team members, who may struggle to balance these competing demands.

Second, trends in the jurisdictional complexity of complex incidents are critical for understanding changing demands in wildfire governance. IMTs work under the authority of one or more jurisdictions who have requested their assistance. When managing an incident wholly contained within the bounds of a single jurisdiction, such as a National Forest, there is a clear principal–agent relationship between the National Forest and the IMT. However, if a fire crosses jurisdictional boundaries, the objectives of multiple jurisdictions must now be taken into consideration and balanced into a unified response strategy. Previous scholarship has demonstrated that different land jurisdictions have different missions and often perceive competing interests in the strategic management of wildfire[42,43]. For example, federal agencies such as the US Forest Service and the Bureau of Land Management have a multiple-use mandate from Congress requiring them to balance land interests associated with conservation, recreation and natural resource use. Other jurisdictions have more narrow mandates, such as a commercial timber manager whose mandate is to protect the financial interests of their shareholders. The more jurisdictions threatened or affected by a wildfire, the more institutionally complex a wildfire is to manage in terms of reconciling a more diverse array of interests and objectives[31,43].

Third, we consider changes over time in the size of incidents. Most often, incidents with more acreage are more institutionally complex, not just because they may involve more jurisdictions, but also because they generally require a larger fire organization. Larger fire organizations spread out over a larger fire perimeter result in more complex planning and logistics as well as potentially larger and more complex spans of managerial control.

Fourth, we consider trends in the number of incident days managed at national PL 4 or 5. The national PL is an index in the USA managed by the NMAC on the basis of national resource availability (www.nifc.gov/sites/default/files/2020-09/National_Preparedness_Levels.pdf). The national PL reflects the cache of IMTs, fire crews and other wildfire resources that can be called upon to respond to a wildfire incident. This index ranges from 1 to 5. At PL 1, fire activity is minimal and there are ample wildfire response resources to deploy on any incident. As the PL index increases, there is more wildfire activity and resources are increasingly committed to incidents. At PL 5, at least 80% of the US resources for managing wildfire are already committed. This means that if new incidents occur or existing incidents intensify, resources may not be available or may need to be pulled from other active incidents. In other words, at higher PL levels, IMTs may not have the resources available to protect everything; trade-offs may be necessary. Consideration of PL is an important aspect of institutional complexity because it speaks to the realities of resource constraints when managing wildfire. If more complex wildfire incidents are concentrated during the same time period, this will have greater consequences than if these incidents are spread out across a longer timeframe.

Last, we consider trends over time in the number of structures threatened, damaged or destroyed on type 1 or 2 incidents. This metric speaks to both the human cost of a wildfire and to changes in the institutional complexity of wildfire, as fire management activities must become more tightly coordinated with emergency management. Wildfire is unique in that incident responders do not attempt to direct tornados or hurricanes away from populated areas but fire-fighters do attempt to intervene to keep wildfire away from populated areas. When wildfire threatens human settlements, emergency response and structure protection operations become activated in the same geographic area as wildfire operations. There is increasing pressure on public information for coordinated and timely communication[44]. Emergency management efforts are managed by an entirely separate set of organizations and agencies, yet these activities are highly interdependent with fire operations. The institutional complexity of the incident increases as the number of different organizations and agencies responsible for these emergency support functions become engaged.

Database

The dataset used in this study reflects the population of type 1 and 2 wildfire incidents from 1999 to 2020 as identified in Federal 209 incident reports[41]. We identified relevant wildfire incidents using the all-hazards dataset of ref. 29, which compiles Federal 209 data into incident-level summaries. Federal 209 reports are daily reports required of all type 1 and 2 incidents and are submitted by the assigned IMT. The unit of analysis is a discrete incident. We included incidents if they contained at least one 209 record as a type 1 or 2 incident. Consistent with ref. 29, wildfire complexes were included as a single unique incident rather than separated by their component fire perimeters. This sampling strategy resulted in a population-level dataset of 3,974 type 1 or 2 wildfires. However, the specific number of incidents used to analyse each variable varies on the basis of data availability in the all-hazards dataset and subsequent processing.

Analysis approach. For each variable, we evaluated trends nationally, regionally and through time by integrating nine national datasets, including the all-hazards dataset[29], the monitoring trends in burn severity fire footprints spatial data[45], the National Interagency Fire Center (NIFC) PL dataset and six multiscale jurisdictional boundary datasets summarized above (for detailed description by variable, see Supplementary Information).

All analyses were performed using R statistical software (v.4.2.1)[46]. We used the START_YEAR field in the all-hazards dataset of ref. 29 to assign each wildfire to a year (1999–2020). For each variable, values for all incidents were averaged annually and trend lines fit to these averaged values. We used the Theil–Sen estimator[47] with 90th percentile bootstrapped confidence intervals from the openAir R package (v.2.18)[48] to estimate linear trends through time for each variable. Analysis code is available[49].

We relied on the GACC boundaries to delineate the regional analyses. GACCs were selected because they are a central administrative entity for coordinating incident support. GACC delineations are governed by the NIFC and the National Coordination Center. Currently, there are ten GACC regions: (1) Northwest, (2) Northern California, (3) Southern California, (4) Northern Rockies, (5) Great Basin, (6) Southwest, (7) Rocky Mountain, (8) Eastern, (9) Southern and (10) Alaska. GACC boundaries changed in 2001, so we assigned fires that occurred between 1999 and 2001 to their present GACCs for consistency through time. See https://gacc.nifc.gov/ for more information.

GACC boundaries were identified using a GACC shapefile (National GACC boundaries, 2023, see 'Data availability'). We used the point of origin (latitude and longitude) to assign wildfires to individual GACCs. Eighty-four incidents did not have a point of origin to assign to a region. The total number of incidents assigned to the 10 regions is 3,890 instead of 3,974.

Data availability

All data used in this manuscript were sourced from publicly available datasets. Source datasets and associated access links as of 25 October 2023 are given below. Permanent copies of data received by request are available for download at https://doi.org/10.5061/dryad.gxd2547z8 (ref. 41). MTBS data access: fire level geospatial data (2023, January—last revised) MTBS project (USDA Forest Service/US Geological Survey) is available at http://mtbs.gov/direct-download. National GACC boundaries (2023—last revised) NIFC is available at https://hub.arcgis.com/datasets/nifc::national-gacc-boundaries. NIFC (2022—last revised) wildland fire decision support system—jurisdictional agencies is available at https://data-nifc.opendata.arcgis.com/datasets/jurisdictional-unit-public/explore. The all-hazards dataset is found in ref. 29. US Bureau of Indian Affairs: BIA Regions, BIA Branch of Geospatial Support (2020) is available at https://onemap-bia-geospatial.hub.arcgis.com/datasets/a9be4c360a154a8faf2f75de0880847f_0/explore?location=32.969469%2C66.145772%2C3.00. US Bureau of Land Management: BLM Administrative Unit District Boundary, BLM Geospatial Gateway (2021) is available at https://www.arcgis.com/home/webmap/viewer.html?url=https%3A%2F%2Fgis.blm.gov%2Farcgis%2Frest%2Fservices%2Fadmin_boundaries%2FBLM_Natl_AdminUnit%2FMapServer&source=sd. US Census Bureau data are available at: US Census place boundaries (2019) https://www2.census.gov/geo/tiger/TIGER_RD18/LAYER/; US county boundaries (2019) https://www2.census.gov/geo/tiger/TIGER_RD18/LAYER/COUNTY/tl_rd22_us_county.zip; and US state boundaries https://www2.census.gov/geo/tiger/TIGER_RD18/LAYER/STATE/tl_rd22_us_state.zip.

Code availability

All code is available via Zenodo at https://doi.org/10.5281/zenodo.15199351 (ref. 49).

References

41. Nowell, B., Jones, K. & McGovern, S. Changing wildfire complexity highlights the need for institutional adaptation data sets. *Dryad* https://doi.org/10.5061/dryad.gxd2547z8 (2025).
42. Fleming, C. J., McCartha, E. B. & Steelman, T. A. Conflict and collaboration in wildfire management: the role of mission alignment. *Public Adm. Rev.* **75**, 445–454 (2015).
43. Nowell, B., Steelman, T., Velez, A. L. & Albrecht, K. Co-management during crisis: insights from jurisdictionally complex wildfires. *Int. J. Wildland Fire* **31**, 529–544 (2022).
44. Steelman, T. A., Nowell, B., Bayoumi, D. & McCaffrey, S. M. Understanding information exchange during disaster response: methodological insights from infocentric analysis. *Adm. Soc.* **46**, 707–743 (2014).
45. MTBS data access: fire level geospatial data. *MTBS* http://mtbs.gov/direct-download (2023).
46. R Core Team *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, 2023).
47. Ohlson, J. & Kim, S. Linear valuation without OLS: the Theil–Sen estimation approach. *Rev. Account. Stud.* **20**, 395–435 (2015).
48. Carslaw, D. C. & Ropkins, K. openair—an R package for air quality data analysis. *Environ. Model. Softw.* **27–28**, 52–61 (2012).
49. Jones, K., Nowell, B. & McGovern, S. Wildfire_Institutional_Complexity Code. *Zenodo* https://doi.org/10.5281/zenodo.15199351 (2025).

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Author contributions

B.N. led the conceptualization, design and writing of the paper. K.J. served as the lead methodologist, leading data integration, analysis and the creation of data visualizations, and authored all code and Supplementary Information. S.M. helped to identify relevant datasets and assisted with data cleaning. B.N., K.J. and S.M. collectively contributed to conceptualizing the study and refining the research question. All authors reviewed and approved the final paper.

Competing interests

The authors declare no competing interests.

Additional information

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