ENVIRONMENTAL RESEARCH
LETTERS

PERSPECTIVE • OPEN ACCESS

Severity patterns of the 2021 Dixie Fire exemplify the need to increase low-severity fire treatments in California's forests

To cite this article: Alan H Taylor *et al* 2022 *Environ. Res. Lett.* **17** 071002

IOP Publishing Environ. Res. Lett. 17 (2022) 071002 https://doi.org/10.1088/1748-9326/ac7735

ENVIRONMENTAL RESEARCH
LETTERS

RECEIVED
26 March 2022

REVISED
23 May 2022

ACCEPTED FOR PUBLICATION
8 June 2022

PUBLISHED
21 June 2022

PERSPECTIVE

Severity patterns of the 2021 Dixie Fire exemplify the need to increase low-severity fire treatments in California's forests

Alan H Taylor[1,4,*], **Lucas B Harris**[3,4] and **Carl N Skinner**[2]

[1] Department of Geography and Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, PA 16802, United States of America
[2] USDA Forest Service Pacific Southwest Research Station, Redding, CA, 96002, United States of America
[3] Current address: Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT 05405, United States of America.
[4] A H T and L B H contributed equally to this work.
[*] Author to whom any correspondence should be addressed.

E-mail: aht1@psu.edu

The extent and severity of fires in the American West has been increasing since the mid-1980s increasing risks to lives, property, carbon sequestration, biodiversity, and other ecosystem services. The increase in wildfire extent has steepened over the last decade with an unprecedented fire season in 2020 that burned over 2.5 million in the western US with 38% of that burning in California [1]. California has experienced a string of record setting fire seasons since 2018, including the largest recorded wildfire to date, the 374 000 ha Dixie Fire that started 13 July 2021. The cost and socio-ecological impacts of these recent California wildfires is staggering. Since 2018 over 27 000 homes and commercial buildings have been destroyed and fire suppression costs have ballooned. Suppression costs for an individual wildfire exceeded the $500 million mark for the first time with the 2021 Dixie ($637 million), and Beckwourth Complex ($572 million) fires (www.nifc.gov/fire-information/statistics). Suppression costs of $100 million for fires were rare a decade ago. Socio-ecological impacts far exceed suppression costs. Estimated economic impacts from the 2018 California wildfires that include property values, health costs from air pollution, and indirect loss from broader economic disruption puts their cost at $148.5 billion [2].

Plume-driven Mega fires like the Dixie Fire are likely to become more common in California and across the western US. Key factors pushing this increase include high fuel accumulation from a more than a century of fire exclusion, forest management that removed fire resistant trees, abundant human ignitions, and the inability of fire fighters to suppress fires when weather conditions are extreme. Climate change amplifies these conditions by increasing fuel aridity, fire season length, and extreme fire weather. Over the last half century, California has experienced an eight-fold increase in forest area burned that is strongly tied to an increase in atmospheric aridity [3]. The combination of climate change and high fuel loads has increased the probability of severe fire effects in settlements adjacent to wildlands, and in remote forest settings where severe fire can trigger ecological transformations such as vegetation type change [3, 4]. Reducing severe fire effects and avoiding ecological transformations is a central concern of public forest land management [5].

Scaled up funding by State (S.B. 901, S.B. 63) and Federal (H.R. 3684) law makers should increase the workforce and infrastructure needed to expand fuel treatments which can reduce area burned at high fire severity and help suppression forces more easily contain fire. Yet, legal, operational, and cost constraints limit typical mechanical thinning treatments to particular locations and other approaches are needed to break up fuel continuity across large landscapes [6]. Controlled burning using prescribed fire (intentional ignition) or managed fire (unintentional ignition) under moderate weather conditions also reduces fuels, and severe fire effects, and can increase resilience to fire that burn in fuel-rich landscapes.

Mounting evidence from landscapes with active fire regimes and mosaics of overlapping fires shows that burns exhibit a strong ecological memory that causes fire severity patterns to follow severity patterns of past fires [7]. In this context, low-severity prescribed fire or managed fire can be considered a fuel treatment which accomplishes fire hazard reduction. Yet, the strength of this ecological memory may be diminished in large plume-driven wildfires burning under extreme weather. The 2021 Dixie Fire burned during the hottest summer ever recorded in California, and 2021 was preceded by 2 years with below average

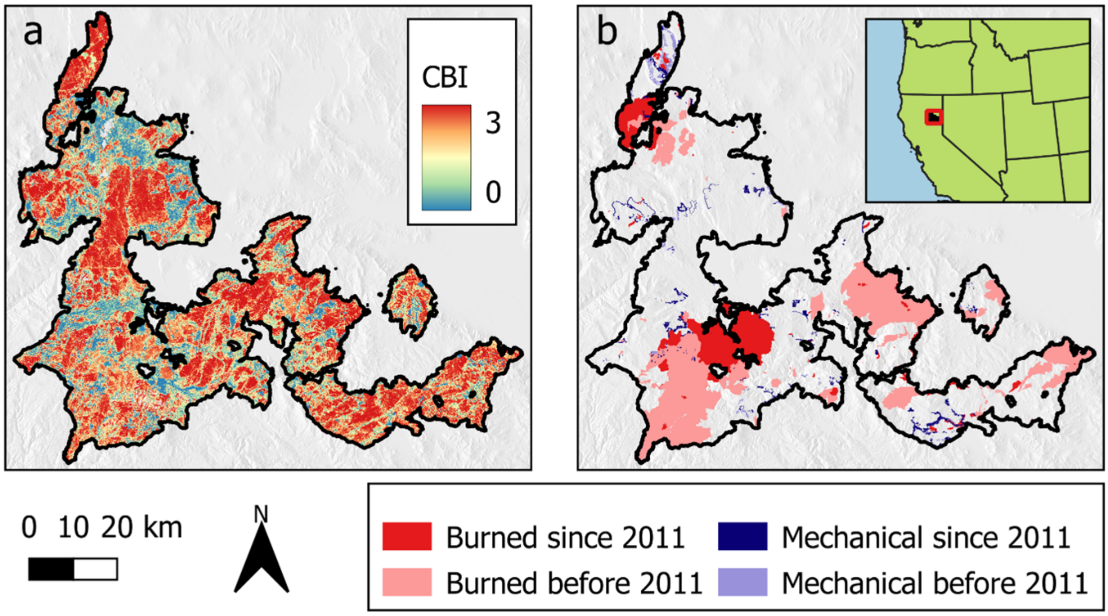

Figure 1. Fire severity (CBI) of the 2021 Dixie Fire and areas burned since 1984 or mechanically treated. Areas in gray did not burn or are untreated based on our analysis criteria. The inset shows the location of the fire within northern California, USA.

(<50%) precipitation and early spring snowmelt (https://wrcc.dri.edu/my/climate/tracker/CA). These climatic conditions created extraordinarily dry conditions known to contribute to rapid fire spread and extreme fire behavior.

Insights into the strength of ecological memory and the effectiveness of management aimed at reducing fire severity can be gained by evaluating how the spatial patterns of severity are affected by fuel treatments. Here we use the Dixie Fire as a test case for assessing whether fuel treatments and previous fires moderate or amplify fire effects in a wildfire burning under extreme conditions.

For this purpose, we created maps of the composite burn index (CBI) for the Dixie Fire (figure 1). CBI is an integrated measure of fire effects on vegetation where high values (>2.25) indicate total or near-total mortality of vegetation (high severity) and low values (<1.25) indicate minimal fire effects (low severity) with intermediate values representing moderate severity effects. To calculate CBI we first calculated the relative differenced normalized burn ratio (RdNBR) [8] using composites of pixel-level median values from Landsat 8 imagery from 19 September to 15 November 2020 and 2021 for pre-fire ($n = 6$) and post-fire ($n = 7$) images. Fire spread was minimal after September 19 and containment occurred on 25 October. CBI was then calculated from RdNBR using an extensive field calibration of fire effects on vegetation with Landsat imagery in northern California adjusted for use of immediate post-fire imagery [9].

Previous fire and mechanical fuel treatments within the Dixie Fire footprint were identified with state (Fire Resource and Assessment Program, FRAP, https://frap.fire.ca.gov/frap-projects/fire-perimeters/) and federal (Monitoring Trends in Burn Severigy, MTBS, www.mtbs.gov/; Forest Activity Tracking System, FACTS, www.mtbs.gov/) geospatial data bases, and most recent burn or treatment year was recorded. Areas burned by the Dixie Fire were then split into nine categories by treatment type (none, burn, mechanical only) and whether areas were treated since 1984 (>10 years prior) or 2011 (⩽10 years prior), and by CBI class (low, moderate, high) of the most recent fire. Prescribed fire, managed fire and wildfire were combined for this analysis in order to focus on fire severity and time-since-fire effects and only treatments identified as thinning or fuel reduction activities were considered mechanical treatments. To determine CBI class of the most recent fire, we calculated RdNBR [8] and CBI [10] following established methods. A 10 year time threshold was selected because fuel limitation on fire severity in mountain forest landscapes in California tends to diminish 10 years after treatment [7, 11].

Factors beyond fuel conditions can influence fire severity, particularly weather. To evaluate weather effects on Dixie Fire severity we created a daily fire progression map from archived fire perimeters (https://ftp.wildfire.gov/) to associate mean daily CBI ($n = 44$) with mean daily gridded weather (Gridded Surface Meteorological Data, GridMET) [12]: temperature, relative humidity, vapor pressure deficit, wind speed and two fire weather indices the energy release component (ERC) and the burning index (BI). ERC incorporates live and dead fuel moisture over past days to weeks and measures potential fire intensity, whereas BI incorporates windspeed and represents potential flame length.

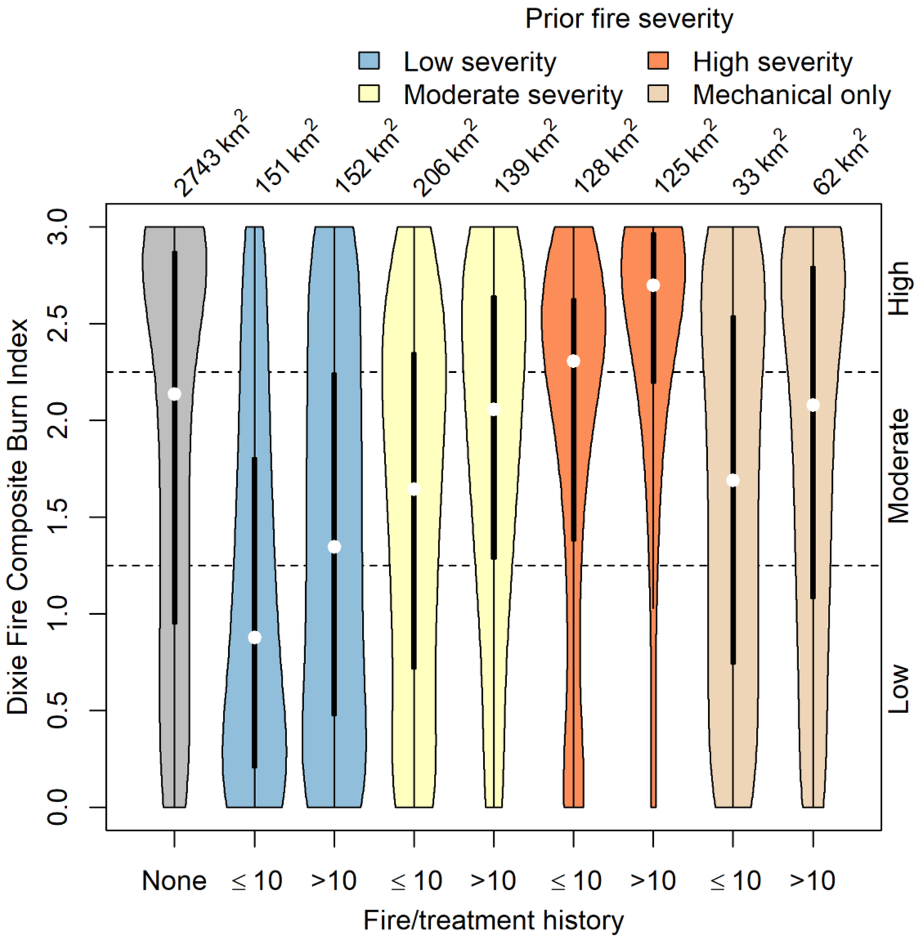

Figure 2. The severity of the Dixie Fire in areas unburned and untreated since 1984 ('none') compared with areas burned at different fire severity classes or with mechanical fuel treatments from 2011 to 2020 ('⩽10') and 1984–2010 ('>10'). The violin plot displays the median, interquartile range and distribution of the CBI within each category. The area of each category is shown above.

The Dixie Fire burned mainly federal land (89%) with a range of fuel treatment histories (figure 1). Weather did influence fire severity; there was a moderately strong relationship of daily mean CBI and ERC (Spearman rank correlation coefficient (r_s) = 0.63, $p < 0.01$) and maximum relative humidity ($r_s = -0.63$, $p < 0.01$) and ERC and maximum relative humidity were also correlated ($r_s = -0.80$, $p < 0.01$). However, Dixie Fire severity also varied strikingly by severity of the most recent fire (figure 2). Areas burned at low severity in a past fire tended to burn at lower severity again in the Dixie Fire, particularly if the fire occurred within the past 10 years. Conversely, areas burned at high severity in the past burned at higher severity in the Dixie Fire and higher than areas with no prior fire or fuel treatments. Although fire severity was moderated in areas that had burned ⩽10 years earlier, prior fire severity influenced Dixie Fire severity more strongly than time since fire (figure 2). Frequency of prior fires had little influence of Dixie Fire severity; areas burned once (911 km^2) or more (224 km^2) had similar median CBI (1.98 vs 1.79).

A strong ecological memory of past fires was evident in the Dixie Fire footprint even with antecedent drought, record breaking heat, and plume-driven fire weather. The durability of initial fire effects demonstrates the strength of self-reinforcing processes on fire severity patterns as landscapes experience overlapping fires and transition to include an active fire regime. Initial low-severity fire effects played forward and were highly effective at moderating severity of a subsequent wildfire. Mechanical fuel treatments alone, without burning, showed only limited ability to dampen the severity of the Dixie fire, and only if the treatment had occurred within the past 10 years. This limited influence of mechanical treatments on wildfire severity is noteworthy and is likely related to the generally small and dispersed nature of treatments [13], the extreme climate and weather conditions that drove spread and severity of the Dixie Fire, and inconsistent follow up with prescribed fire after mechanical treatment to consume surface fuels and makes treatments more effective. Mechanical treatments followed by prescribed fire have been observed to reduce fire severity in other large California wildfires [13]. Areas previously burned at high-severity within the Dixie Fire also played forward and tended to reburn at high severity again. In fact, the areas previously burned at high severity fared even worse than areas that had never been burned or treated. The fact that reburn fire severity patterns tend to follow past fire severity is well-established in pine and mixed-conifer forests of the western US [7, 11, 14, 15]. Likewise, areas burned by low severity fire have been shown to reduce subsequent fire severity even under extreme weather [16]. However, the Dixie Fire is a particularly dramatic example of the significant potential of low severity fire to blunt undesirable fire effects in successive fires in an era of increasing large and severe wildfires burning under extreme conditions.

The self-reinforcing high severity reburn pattern points to the critical need to proactively treat long-unburned areas so they do not burn severely in wildfires and trap landscapes in a self-reinforcing loop of forest loss driven by repeated high-severity fire. High severity fire in the western US has increased eight-fold since 1985 [17] and has been a main driver of a forest cover loss in California of 5.5% [18]. Changing self-reinforcing behavior in severely burned areas is difficult. Areas of forest canopy loss are often dominated by fire-dependent shrublands or grasslands, with an accumulations of woody fuel from the initial fire, and are maintained by reburns. Severely burned areas reforested by planting tree seedlings are also susceptible to high severity reburns due to the high fuel loads and homogeneity of conditions in dense young developing forest. The 209 000 ha of high severity burn in the 2021 Dixie Fire will remain a long term management challenge.

The Venado Declaration (www.documentcloud.org/documents/21100767-venado-declaration) calls for a paradigm shift in forest and fire management in California by expanding the workforce and infrastructure needed to increase the tempo and scale of treatments to reduce the effects of large and severe wildfires. Integration of fire and forest management and expanded use of prescribed and managed fire are necessary conditions for success. Current treatment rates are an order of magnitude lower than historical rates of fuel reduction from pre-fire exclusion fire regimes [13, 19]. Moreover, annual area burned by wildfires is *ca*. Three-fold greater than areas treated mechanically and by managed fire [13]. The strong ecological memory of past fire severity in the Dixie Fire footprint illustrates the significant potential to use areas of low and moderate severity wildfire as initial treatments to scale up and blunt future potential of high severity fire. An increased focus of fire and forest management on further developing large areas of low and moderate severity burned areas through treatments that include use of prescribed fire and managed fire would promote desirable self-reinforcing behavior and increase the resilience of landscapes to wildfires burning under extreme conditions.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

This work used information on fire effects that was funded by grants from the NPS Pacific West Region, and the US Forest Service Pacific Southwest Research Station.

Author contributions

Alan H Taylor: conceptualization, formal analysis, funding acquisition, writing original draft; Lucas B Harris conceptualization methodology, formal analysis, writing original draft; Carl N Skinner: conceptualization, formal analysis writing original draft.

Conflict of interest

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

ORCID iD

Lucas B Harris https://orcid.org/0000-0002-1416-5645

References

[1] Higuera P E and Abatzoglou J T 2021 Record setting climate enabled the extraordinary 2020 fire season in the western United States *Glob. Change Biol.* **27** 1–2

[2] Wang D *et al* 2021 Economic footprint of California wildfires in 2018 *Nat. Sustain.* **4** 252–60

[3] Williams A P, Abatzoglou J T, Gershunov A, Guzman-Morales J, Bishop D A, Balch J K and Lettenmaier D P 2019 Observed impacts of anthropogenic climate change on wildfire in California *Earth's Future* **7** 892–910

[4] Coop J D *et al* 2020 Wildfire-driven forest conversion in western North American landscapes *BioScience* **70** 659–73

[5] Hessburg P F *et al* 2019 Climate, environment, and disturbance history govern resilience of western North American forests *Front. Ecol. Evol.* **7** 239

[6] North M, Brough A, Long J, Collins B, Bowden P, Yasuda D, Miller J and Sugihara N 2015 Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada *J. For.* **113** 40–48

[7] Taylor A H, Harris L B and Drury S A 2021 Drivers of fire severity shift as landscapes transition to an active fire regime, Klamath Mountains, USA *Ecosphere* **12** e03734

[8] Miller J D, Knapp E E, Key C H, Skinner C N, Isbell C J, Creasy R M and Sherlock J W 2009 Calibration and validation of the relative differenced normalized burn ratio (RdNBR) to three measures of fire severity in the Sierra

Nevada and Klamath Mountains, California, USA *Remote Sens. Environ.* **113** 645–56

[9] Miller J D and Quayle B 2015 Calibration and validation of immediate post-fire satellite-derived data to three severity metrics *Fire Ecol.* **11** 12–30

[10] Parks S A *et al* 2019 Giving ecological meaning to satellite-derived fire severity metrics across North American forests *Remote Sens.* **11** 1735

[11] Harris L and Taylor A H 2017 Previous burns and topography limit and reinforce fire severity in a large wildfire *Ecosphere* **8** e02019

[12] Abatzoglou J T 2013 Development of gridded surface meteorological data for ecological applications and modelling *Int. J. Climatol.* **33** 121–31

[13] North M P *et al* 2021 Pyrosilviculture needed for landscape resilience of dry western United States forests *J. For.* **119** 520–44

[14] Harvey B J, Donato D C and Turner M G 2016 Burn me twice, shame on who? Interactions between successive forest fires across a temperate mountain region *Ecology* **97** 2272–82

[15] Parks S A, Miller C, Nelson C R and Holden Z A 2014 Previous fires moderate burn severity of subsequent wildland fires in two large western US wilderness areas *Ecosystems* **17** 29–42

[16] Prichard S J, Povak N A, Kennedy M C and Peterson D W 2020 Fuel treatment effectiveness in the context of landform, vegetation, and large, wind-driven wildfires *Ecol. Appl.* **30** e02104

[17] Parks S A and Abatzoglou J T 2020 Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017 *Geophys. Res. Lett.* **47** e2020GL089858

[18] Wang J A, Randerson J T, Goulden M L, Knight C and Battles J B 2021 Remote sensing reveals multi-decadal losses of tree cover in California driven by increasing fire disturbance and climate stress *bioRxiv Preprint*

[19] Stephens S L, Martin R E and Clinton N E 2007 Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands *For. Ecol. Manage.* **251** 205–16