ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
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Extreme fire spread events and their drivers in the western US

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Keywords

Fire spread, drivers of fire spread, climate change, western US

Abstract

Wildfire activity in recent years not only have large total area burned but also large, single-day fire spread events that pose challenges to ecological systems and human communities. Our objective was to better understand the relationships between extreme single-day fire spread events, annual area burned, and fire-season climate, and predict changes under future warming. We employ a satellite-derived dataset of daily fire spread events in the western USA and gridded climate data over this region to assess relationships between extreme single-day fire spread events, annual area burned, and fire-season maximum temperature, climate moisture deficit, and vapor pressure deficit over a time period of 2002-2020. Extreme single-day fire spread events which were classified as single day of burning that burned more than >1100 ha (the top 16%), these could have been a part of multiple days of extreme fire behavior resulting in multiple extreme fire spread events or an isolated day of extreme behavior, regardless days with fire spread >1100ha on a single fire were analyzed separately. We then develop models to predict fire activity under a 2°C warming scenario. These extreme fire spread events accounted for 70% of the cumulative area burned over the period of analysis. Annual area burned was correlated with number and mean size of spread events, and those largest of these large fire spread events. In 2020, wildfires burned over 4 million ha in the US and we identified 441 extreme fire spread events, identified as >1100 ha burned in a single day. These 441 events in 2020, burned 2.2 million ha across our study area. In contrast, the average extreme events between 2002 and 2019 was 168 per year that burned 0.5 million ha. Fire season climate variables correlate strongly with the annual number of extreme events and area burned. Our models predict that the annual number of extreme fire spread events more than doubles under a 2°C warming scenario, with an attendant doubling in area burned. Exceptional fire seasons like 2020 will likely be more common, and wildfire activity under future extremes will likely exceed anything witnessed yet. Safeguarding human communities and supporting resilient ecosystems may require new lines of scientific inquiry, novel land management approaches, and accelerated climate mitigation efforts.

1. Introduction

Recent fire seasons in the western US and elsewhere have been characterized not only by high total area burned, but also periods of extremely rapid fire growth and very large single-day fire spread events. Throughout a fire season, short duration but extreme events may have outsized effects, vastly expanding the area burned in individual fires (i.e. "megafires"; Adams, 2013) and contributing disproportionately to cumulative social and ecological impacts (Duane et al., 2021). As examples, 4 million ha burned in the US in the 2020 fire season, mostly in western states (www.nifc.gov), with many states seeing record-setting fires. In Oregon and Washington, there were multiple days of individual fire growth over 10,000 ha (including one report of 40,000 ha), and a record-setting wildfire in Colorado that burned ca. 1500 ha/hr for >24 hours in October (https://inciweb.nwcg.gov/). Similarly, California reported a record-setting individual fire (the 400,000-ha August Complex) that exhibited extreme fire growth under high winds and low fuel moisture over several days in early September, contributing to record total annual area burned (1.7 million ha; www.fire.ca.gov).

Observations of very large single-day fire runs within the context of recent record-breaking fires and fire seasons raise a suite of research questions and hypotheses (Duane et al., 2021). New methods to calculate daily fire spread from satellite observations have catalyzed the development of datasets of daily fire spread over expanded spatial and temporal scales (Parks, 2014) and are leading to analyses that provide new insights into wildfire activity (Hart & Preston, 2020; Wang et al., 2017). At a foundational level, aggregate fire effects such as area burned represent the accumulation of thousands of single-day fire spread events. Growing evidence suggests that climate change will continue to expand fire activity in coming decades, but with interannual variability (e.g., El Niño Southern Oscillation, Pacific Decadal Oscillation; Crimmins, 2011; Trouet et al., 2009) likely resulting in climatic conditions and patterns in fire spread events outside of those experienced within recent observations. What constitutes an extreme under contemporary climate may change as once rare conditions (such as occurred in 2020) become more common. Thus, we might ask if climate and attendant fire activity in the western US in 2020 could be representative of future norms, and what kind of wildfire activity could occur during future extremes?

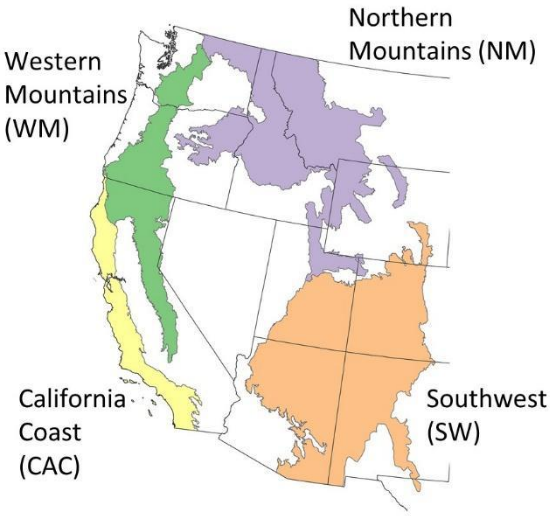

Figure 1- Western US study area, comprising four forested ecoregions.

2. Methods

Our analyses are based on measurements of daily fire spread (ha/day) for individual wildfires. Following the methods of Parks (2014), we developed spatially continuous maps depicting the day-of-burning for all fires whose centroid intersected our western US study area from 2002-2020 (Fig. 1). Briefly, this procedure interpolates VIIRS and MODIS fire detections (from https://firms.modaps.eosdis.nasa.gov/active_fire/) to map the day 1f burning within the entire area of the final fire perimeter at a 30-m resolution. This day-of-burning interpolation technique has been successfully used in several previous fire studies (e.g., Downing et al., 2021; Holsinger et al., 2016; Meigs et al., 2020; Wang et al., 2017). All day-of-burning interpolations were constrained to the final fire perimeters as obtained from national repositories; we obtained 2002-2018 fire perimeters from the Monitoring Trends in Burn Severity (MTBS) program (Picotte et al., 2020). Fire perimeters from 2019 and 2020 were downloaded from the National Interagency Fire Center (Interagency Fire Perimeter History - All Years: available at https://data-nifc.opendata.arcgis.com/datasets/); fires <400 ha were removed to match the MTBS dataset. Given minor differences between the NIFC and MTBS databases, we performed a sensitivity analysis to examine whether or not a bias correction to 2019 and 2020 NIFC fire counts and area burned would influence our findings or interpretations. We found that such a correction led to negligible increases in future projections and thus elected to use the data from NIFC without adjustments, noting that as more and better data become available, more refined future projections may become feasible. Fires with less than 10 fire detections were excluded from the analysis because of uncertainty associated with interpolating small numbers of detections. Fire detections that occurred between 12 am and 6 am were assigned to the previous day. In total, we interpolated day-of-burning for 2391 fires and 20,991 unique fire spread events ranging in size from 25 to 74,509 ha.

3. Results and Discussion

Daily fire spread followed a slightly skewed log-normal distribution, with a median value of 260 ha/day and a mean of 295 ha/day (Fig. 2). Single-day spread events >1100 ha represented the top 16% of events (1 standard deviation from the mean), and accounted for 70% of total area burned. Described another way, the top 10% of fire spread events burned 58% of the total area and just the top 1% of events burned 20% of the total area. Parameters of annual distributions of daily fire spread were closely linked to annual area burned. Number of events (P <0.001), mean event size (P <0.001), and skewness (P = 0.03) were all significant predictors of annual area burned in our best-fitting model (r^2 = 0.90, 15 d.f.). Relative contributions each term were as follows: number of events, 68%; mean event size, 29%; and skewness, 3%.

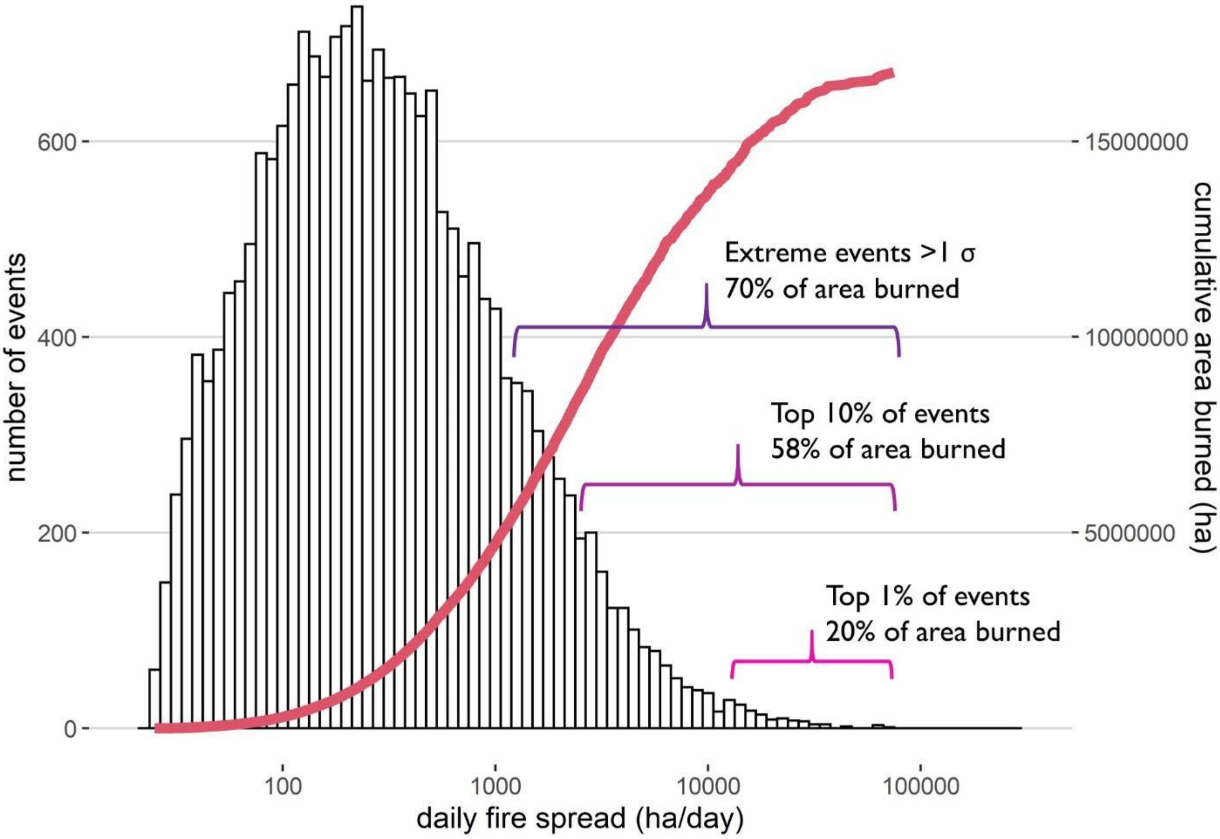

Figure 2- Distribution of daily fire spread events and the cumulative area burned during the 2002-2020 study period. Extreme events ≥1100 ha (the top 16%, 1 standard deviation) account for 70% of area burned).

A generalized linear (negative binomial) model predicting the total count of extreme fire spread events from Aridity provided robust predictions for the entire study area (P<0.001, McFadden's r^2 = 0.42); this model was then employed to predict of the annual number of extreme spread events for a 2°C above pre-industrial warming scenario in contrast to a 1986-2015 reference period, and modeled and observed activity in 2020. This model predicted a mean of 343 extreme spread events per year under the +2°C scenario, ranging from a minimum of 81 to a maximum of 815 events in extreme future years (Fig. 3). In contrast, the mean modeled number of extreme spread events in the reference period was 129, with a range of 32-302. Model predictions for the 2020 fire season climate were 324 extreme spread events; the observed number was 441.

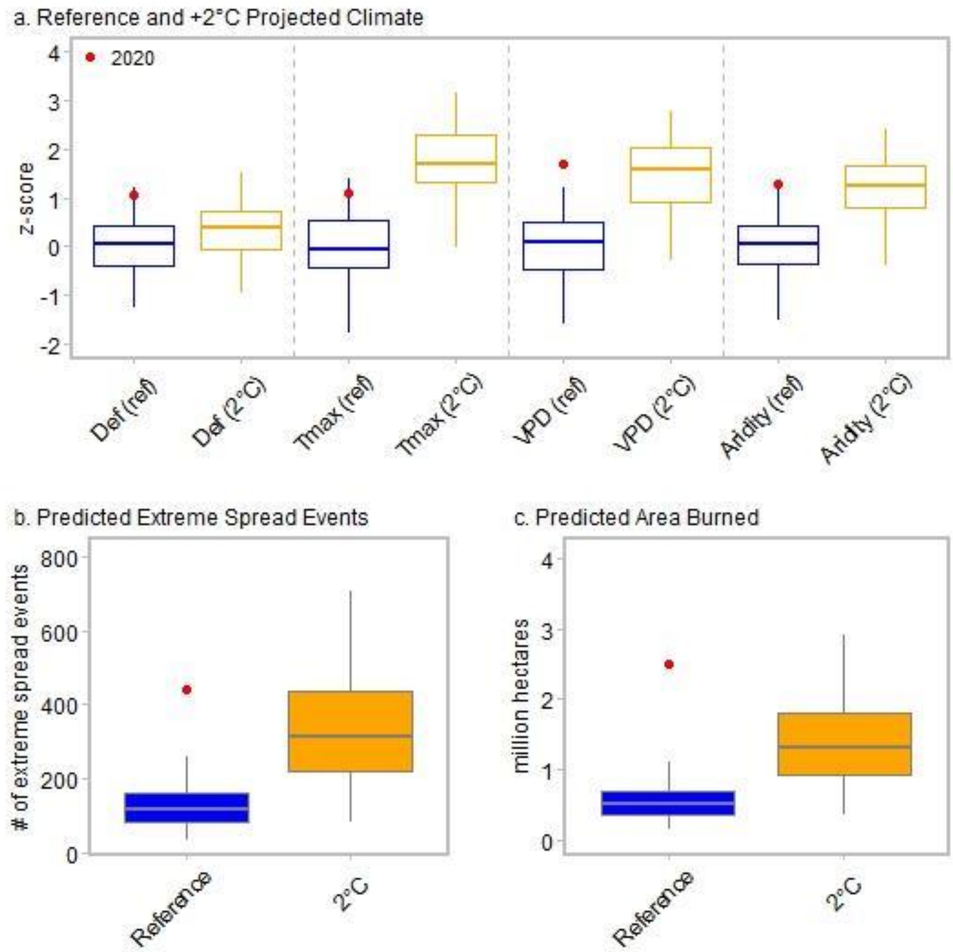

Figure 3- Reference period (1986-2015) vs. future (+2°C) projections (a) for four climate variables, Deficit, Tmax, VPD, and Aridity (defined in the text as the average of the other three variables), (b) predicted number of extreme events >1100 ha/day, and (c) annual area burned. Red dots represent observed climate and fire activity in 2020.

Better understanding the capacity for human activities to modulate the undesirable effects of extreme fire spread is also imperative. Contemporary fire management policies appear to be relatively ineffective in mitigating extreme fire spread events, which are occurring despite recent annual fire suppression expenditures of $1-3 billion in the US (data available from the National Interagency Fire Center, www.nifc.com). Explosive fire growth during extreme fire spread events can severely reduce the efficacy of fire suppression as currently practiced. Extreme burning conditions that facilitate early fire growth allow fires to escape initial attack; as these fires continue to grow, their size and potential to impact communities and other resources can subsequently overwhelm fire management resources. Given the likelihood of increasing societal and ecological exposure to extreme fire spread events, new approaches to fire management and policy may be needed (Cochrane & Bowman, 2021; Moritz et al., 2014; Smith et al., 2016). In some settings, management activities may be directed towards reducing undesirable fire effects, such as by promoting frequent but low-to-moderate severity fire to prevent anomalously severe fire and attendant ecological changes (Walker et al., 2018). In others, higher-severity prescribed fire and managed wildfire might be useful to change fuel types and reduce landscape flammability (e.g., shifts from conifer to broadleaf forest types). Enhancing community preparedness under extreme burning conditions will also be critical to safeguarding human lives and infrastructure.

Writing and conference presentation from Coop J, Parks S, Stevens-Rumann CS, Ritter S, Hoffman C (2022) Extreme fire spread events and area burned under recent and future climate in the western US. Global Ecology and Biogeography 2022: 00:1–11 https://doi.org/10.1111/geb.13496

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