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Increasing potential wildfire energy flux from climate-driven mortality and fuel aridity

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Abstract

Moisture stored in live and dead vegetation acts as a regulator on fire behaviour and area burned. Climate change is altering the distribution of live and dead fuels in forests through drought and insect-induced mortality and simultaneously making dead fuels more flammable because of decreasing fuel moisture. These system changes, both of which are driven by increasing temperature, have the potential to increase the heat flux from combustion, contributing to an increased risk of fires in affected areas becoming plume-dominated. In the southern Sierra Nevada of California and the Rocky Mountains in Colorado, drought and insect outbreaks have increased tree mortality rates, increasing the proportion of biomass that is in dead versus live fuel pools. We sought to determine the contribution that high rates of mortality could have on potential changes in energy release (energy release component and fire radiant energy) for mixed-conifer forests in the southern Sierra Nevada and lodgepole pine forests in the Colorado Rocky Mountains, the site of two large wildfires during the 2020 fire season. We found substantial increases in dead fuels and substantial decreases in fuel moisture during 2020, which increased the potential fire radiative energy. Our results demonstrate that climate-driven tree mortality and increasing temperatures that lead to lower fuel moisture are increasing the amount of energy stored in biomass that is available for combustion.

1. Introduction and Methods

1.1. Introduction

Fuel moisture content (FMC) helps regulate the amount of fuel available for combustion during wildfire (Brown and Davis 1973, Rothermel 1972). Climate warming is increasing atmospheric water demand and early season temperature increases are causing forest fuel FMC to decrease earlier in the fire season (Abatzoglou and Williams 2016, Westerling 2016). Ecosystem drying from increased warming is also increasing rates of tree mortality globally, which has the potential to increase the proportion of biomass within a forest that is more responsive to temperature effects on FMC (Allen et al. 2015, Goodwin et al. 2021).

Drought and insect-induced mortality events increase the total biomass in the dead fuel pool (Goodwin et al. 2020). The primary fuel for wildfire ignition and spread, fine fuels (litter, 1-, 10-, 100-hour), are available to burn for the duration of fire season in dry conifer forests (Rothermel 1972). While fire season length has increased with increasing temperature, it has not influenced the proportion of these quick drying fuels that are available to burn. However, large fuels (1000-hour +) dry out over longer time scales and are typically unavailable to burn during a sizable fraction of the fire season. Climate change may be increasing the availability of these larger fuels because of the increasing aridity that results from increasing temperature (Abatzoglou and Williams 2016).

Two large fire events during the 2020 fire season, the Creek Fire in the southern Sierra Nevada and the Cameron Peak Fire in the Colorado Rocky Mountains, burned through forests that had been heavily impacted by drought and insect-mortality (Meddens and Hicke 2014, Pile et al. 2019). The 153,738 ha Creek Fire began September 4, 2020 and burned through an area where severe drought from 2012-2016 had caused as much as 90% overstory tree mortality. The 84,443 ha Cameron Peak Fire began August 13, 2020 and burned through an area that had extensive mortality from a bark beetle outbreak that peaked from 2007-2009. Here we use forest inventory data from these two fire footprints to estimate the potential increase in fire radiative energy (FRE) as a function of mortality, temperature, and fuel moisture.

1.2. Methods

We used US Forest Service Forest Inventory and Analysis (FIA) plot data to estimate increases in dead tree basal area before and after drought/insect mortality in the forest types in which these fires burned. Our selection procedure for plots that were measured both before and after disturbance and included the target tree species resulted in a sample size of 118 plots in the Sierra Nevada and 173 plots in the Rocky Mountains. We used changes in dead biomass following drought/insect mortality to calculate changes in fuel availability and FRE.

To quantify changes in 1000-hour FMC and ERC over the past three decades, we used daily maximum temperature, 1000-hour fuel moisture, and ERC data from GRIDMET (Abatzoglou 2013). We also used 1000-hour fuel moisture data for the southern Sierra Nevada from the Wildland Fire Assessment System (WFAS) and temperature data from the Remote Automatic Weather Station (RAWS) Climate Archive to develop monthly fuel moisture and temperature averages for 1998-2002, 2012-2016, and 2020. For the Colorado Rocky Mountains, we used 1000-hr and lodgepole pine (*Pinus contorta v. contorta)* fuel moisture data from WFAS and corresponding RAWS temperature data for 2006-2010 and 2016-2020. We converted FMC to water content to calculate FRE and biomass consumed using the equations outlined in Smith et al. (2013).

2. Results and Discussion

2.1. Results

Drought and insect mortality within these forest types caused a substantial increase in dead basal area when we compared pre/post-drought inventory data (Figure 1). Hotter temperatures during the 2020 fire season decreased 1000-hour fuel moisture and increased energy release component (ERC) over previous seasonal averages (Figure 2). In both the Creek Fire and Cameron Peak Fire footprints, the proportion of 1000-hour fuels available to burn because they fell below the 30% moisture threshold increased during the 2020 fire season, with approximately greater than 80% of the fuel available by the start of the Creek Fire in July in the Sierra Nevada. Similarly, data from the Cameron Peak Fire in the Colorado Rocky Mountains indicate that a 5% reduction in fuel moisture increases dead fuel availability by 7%.

2.2. Discussion

Our results indicate that as climate change interacts with agents of tree mortality such as insects and drought, the amount of dead tree biomass will substantially increase and hotter temperatures can make that biomass more available to burn. Globally, tree mortality is increasing, and this suggests that as ecosystems come into alignment with changing climatic conditions, we can expect an increase in the amount of dead fuel, which is more responsive to changes in temperature and precipitation (Allen et al. 2015, Goodwin et al. 2020). Understanding how this additional stored energy will influence fire behaviour and ecosystem effects are important areas of investigation that requires further investment.

3. References

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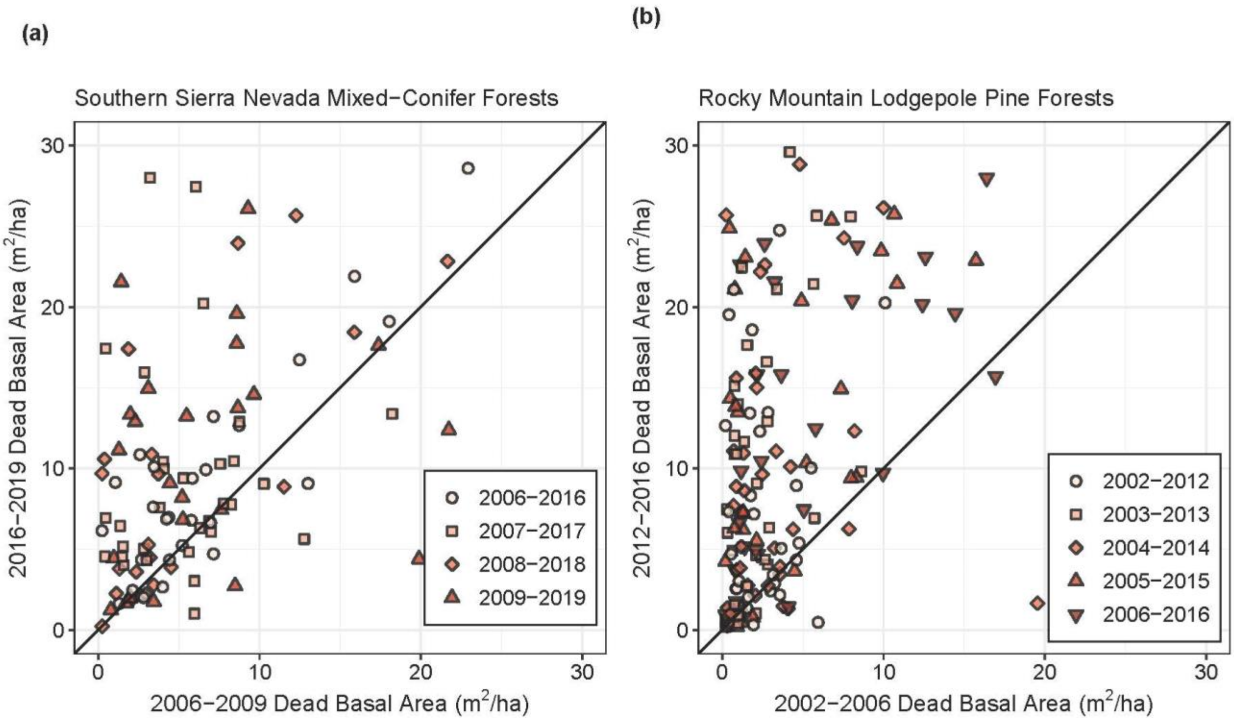

Figure 1: Increases in dead tree basal area ($m^2\ ha^{-1}$) following disturbance events. The 1:1 trend line represents no change in dead tree basal area before and after the disturbance. Plots with the same color/symbol are grouped by 10-year measurement period. Points represent FIA plots measured: A.) Before and after the 2012-2016 California drought. Points represent mixed-conifer FIA plots in the southern Sierra Nevada. B.) Before and after peak Mountain Pine Beetle mortality in the Colorado Rocky Mountains (2007-2009). Points represent lodgepole -pine FIA plots in Colorado. Figure from Goodwin et al. (2021)

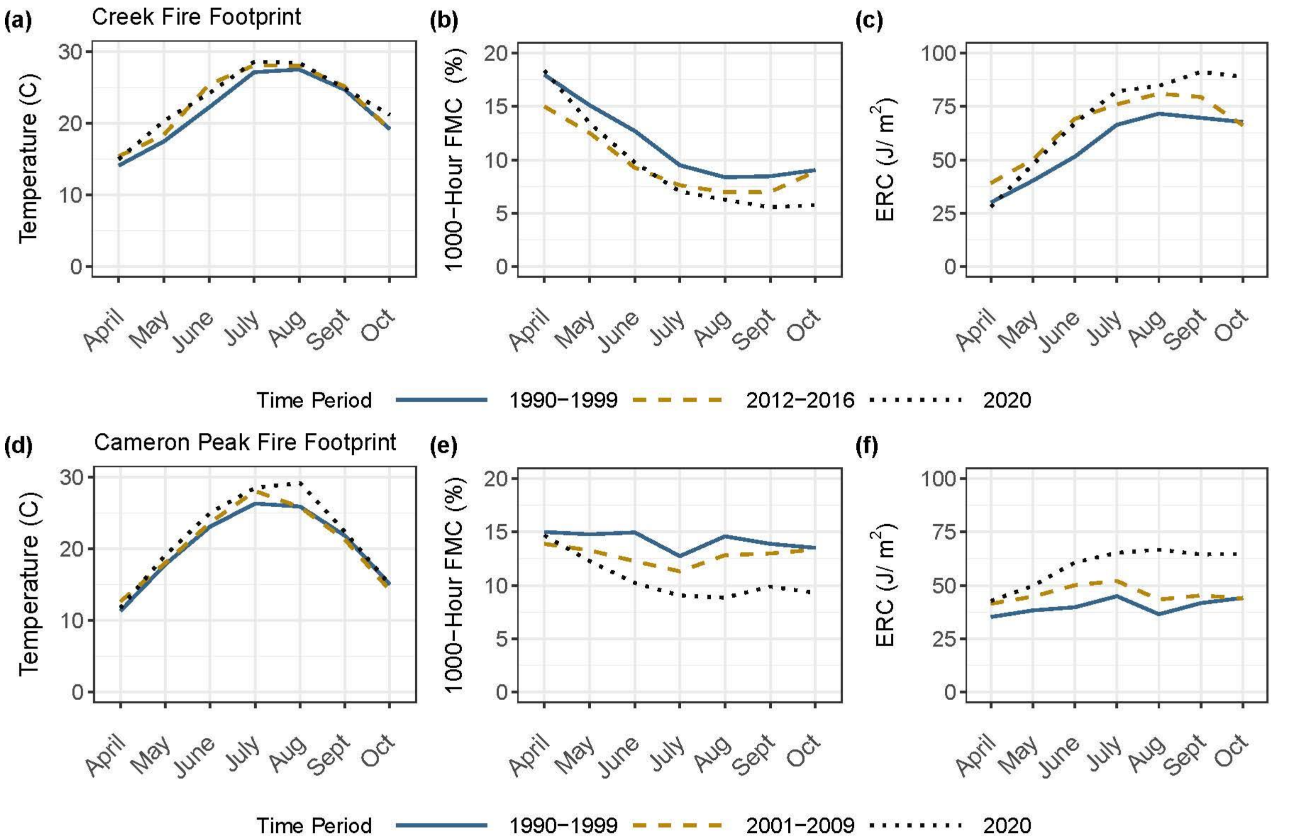

Figure 2: Average monthly temperature maximums (C), average 1000-hr fuel moisture content (FMC), and average energy release component (ERC) for the footprints of the Creek Fire (a-c) and Cameron Peak Fire (d-f) based on GRIDMET data. Time series for each site include 1990-1999, 2012-2016 or 2001-2009 (the respective drought periods for each site) and 2020. Figure from Goodwin et al. (2021).