FINAL PROJECT REPORT

SECTION 1. ADMINISTRATIVE INFORMATION:

- **Principal investigator (PI):** Camille Stevens-Rumann
- **Phone number and email of PI:** 602-509-5077, c.stevens-rumann@colostate.edu
- **Institution: Colorado State University**

- **Project title:** ***Understanding extreme wildfire events to manage for fire-resistant and resilient landscapes***
- **Date: December 15, 2025**
- **Project Period: September 1, 2022-August 31, 2025**
- **Actual project cost: $335,748.04**

SECTION 2. PUBLIC SUMMARY:

Increasing wildfire activity in the western United States (US) poses profound risks for human communities and forests. Recent fire years are characterized not only by expanding area burned but also explosive fire growth. Extreme single-day fire spread events such as these are poorly understood but disproportionately responsible for wildfire impacts: just the top 1% of fire spread events account for 20% of annual area burned. Extreme events are linked to warmer and drier conditions and are projected to become more frequent under future climate. Because extreme fire spread events defy suppression and can overcome traditional fuels reductions treatments, they may demand new approaches to management. Accordingly, the purpose of our research was to improve our scientific understanding of the drivers and outcomes of extreme events, and how these might be moderated by different kinds of landscapes and potential land management interventions.

Our research showed how the climatic drivers that cause extreme events, and extremes themselves vary across different regions within North America. Climatic conditions can set the stage for ignition and influence vegetation and fuels, but finer-scale mechanisms likely drive variation in daily spread. We also found that extreme fire spread events produced not only much larger area burned, but this area is characterized by increased fire severity and larger, more homogenous patches of high severity fire. These postfire landscape outcomes may overcome the resilience of most of the forest tree species in our southwestern US study region. However, we also examined how variation in forest type can change fire growth patterns. Notably, we quantified how aspen forest types can impede fire spread and serve as barriers to continued fire growth. Management interventions that promote aspen may thus increase forest resistance and resilience to wildfire. We also found that there are management actions that can reduce fire severity even in extreme burning days. These findings can help managers design and implement activities that may dampen fire behavior and produce more resilient landscapes. We also worked with land managers in the Upper Gunnison Basin, Colorado, to help develop models that are informing a project that will use stand-replacing prescribed fire to increase aspen patches and produce landscape mosaics to reduce the likelihood of extreme and severe fire in the future.

SECTION 3. PROJECT SUMMARY:

Our objective was to gain new understanding into the drivers of extreme fire spread events and work with land management partners to develop strategies to reduce growing risks to human and ecological communities. Extreme fire spread events defy suppression, overcome small-scale fuels treatments, and account for a disproportionate share of wildfire impacts. For example, in 2020, our data show that multiple fires grew >100,000 acres (achieving "megafire" status) within a single day. Yet, under a 2C warming scenario, we project the number of extreme fire spread events to double, and fire seasons like 2020 to represent a new normal. In this project, we explored the drivers and outcomes of extreme events to improve our understanding and inform mitigation strategies within a research-management co-production framework.

First, we developed and utilize a novel dataset of day-of-burning maps, climate and weather grids, and spatial data on vegetation, fuels, and topography to assess drivers of extreme fire spread events across western North American ecosystems. Our research showed that extreme fire climatic drivers varied by regions across North America, but climatic conditions can set the stage for ignition and influence vegetation and fuels. However, finer-scale mechanisms likely drive variation in daily spread (Balik et al. 2024).

Second, we contrasted patterns of fire spread in different vegetation types and management treatments in the southwestern US, focusing in particular on differences between conifer and aspen. We found that the presence of aspen contributed to smaller fire spread and were barriers to continued fire growth (Harris et al. 2025). Though unsurprising, our quantification of the influence of aspen in contrast to other cover types, including recent prior burns and undisturbed conifer forest, supports management decision making and informs the use of treatments and fire incident management to improve landscape resilience.

Third we examined how extreme fire spread events influenced burn severity and how management actions influenced burn severity. During these extreme fire spread days, burn severity increased, indicating lasting ecological effects of these days of extreme fire growth (McFarland et al. 2025). However, management actions can reduce this severity even in extreme burning days (Hettema et al. 2026), providing hope for the potential for management actions to mitigating some of the last ecological impacts of these extreme fires. We also developed fire behavior models to inform a project led by the Bureau of Land Management (BLM) to use stand-replacing prescribed fire in the Powderhorn Wilderness to create landscape mosaics that can reduce the likelihood of extreme and severe wildfires. Finally, working with partners, we discussed key issues and brainstormed solutions across the western US and internationally through workshops, special sessions and webinars.

Findings were broadly shared with research and natural resource management communities via scientific publications, presentations, a webinar hosted by Fire Science Exchange Networks, and multiple public media engagements. A two-day workshop at the Rocky Mountain Biological Lab (RMBL) explored management opportunities and barriers to the use of aspen on mitigating extreme fire spread events and featured a field trip to a recent wildfire site where aspen forest patches acted to impede fire progression. We worked closely and directly with agency partners (BLM) to develop actionable science products that are being incorporated into burn plans for public lands in the Upper Gunnison Basin.

SECTION 4. REPORT BODY (Please Include the Following Sections):

Purpose and Objectives:
Our overarching study objective was to **gain new knowledge into the causes and consequences of extreme fire spread events** and work with land managers to **apply this understanding to reduce risks** posed by undesirable and unmanageable wildfire. Our project addressed three key study objectives to meet information needs. We were able to complete all objectives, and we expanded upon most of them.

1) ***Understanding drivers of extreme fire spread events across western US forest ecosystems***: We developed and analyzed a novel, satellite-derived dataset quantifying daily fire spread, and information on vegetation type, fuels, topography, climate, and weather, to elucidate the factors that promote or impede exceptional fire growth. We were able to expand this to North America with the help of key partners in the US Forest Service (USFS)and Canadian Forest Service, resulting in two manuscripts (Balik et al. 2024, Balik et al. *in revision*). Additionally, during this analysis several additional research needs emerged including understanding the ecological impact of extreme fire spread events and how management actions alter these ecological outcomes, which we address with two additional papers (MacFarland et al. 2025, Hettema et al. *in revision*).

2) ***Contrasting fire spread in conifer and aspen in the upper Colorado River basin***: We analyzed daily fire spread, severity, and vegetation type (i.e. conifer vs. aspen), and we tested whether and under what conditions low-flammability landscape patches (early-seral post-fire vegetation and aspen stands) limited extreme fire spread events. We were able to expand upon this to address this objective across Arizona, Utah, Colorado and New Mexico (Harris et al. 2025). We facilitated a scientist-manager workshop on climate adaptation, data stewardship and the use of aspen in forest management.

3) ***Models and maps to inform stand-replacing prescribed fire as a management tool for resistant and resilient forest landscape mosaics in the Upper Gunnison Basin:*** We worked with partners in the BLM Gunnison Field Office to help design treatments and model fire impacts in the North Powderhorn project area (Phillips, unpublished thesis, 2023). This project proposes to use stand-replacing prescribed fire to reduce dead and down conifer fuels and increase aspen regeneration, expanding aspen patches and other early-seral vegetation in mosaics that reduce the continuity of conifer canopy fuels.

Organization and Approach:
This project was a collaborative effort between Colorado State University (CSU), Western Colorado University (WCU), the USFS, and other partners. This project expanded upon an initial research project led by Western Colorado University (Coop et al. 2022). With the leadership of a post-doctoral fellow, we were able to incorporate multiple students at both CSU and WCU. Each component of the resulting work was incorporated into part of a Master's thesis, and we have 3 student led peer-reviewed papers in addition to papers led by the post doc.

Broadly, for objectives 1 and 2, we started with remotely sensed daily progression of 9,636 wildfires ≥400 ha to characterize ecoregional patterns of fire growth, extreme single-day events, duration, and seasonality. To explore occurrence, extent, and impacts of single-day extremes among ecoregions, we considered complementary ecoregional and continental extreme thresholds (Ecoregional or Continental Mean Daily Area Burned + 2SD; Balik et al. 2014). Ecoregional spread rates were regressed against Actual Evapotranspiration(AET) and Climatic Water Deficit (CWD) to explore climatic influence on spread. This larger dataset was then reduced to the southwestern US incorporating 623 fires comprising 4,267 single-day events within forested ecoregions to examine burn severity and further reduced to 314 fires occurring between 2001 and 2020 to analyze the influence of aspen on fire spread. Finally, a smaller subset of fires were used to look at the influence of treatments on burn severity in these extreme spread events in just Colorado and New Mexico, using a total 63 wildfires.

For objective 3, we worked closely with a range of partners and collaborators to a) host a workshop session on “Fire for aspen, and aspen for fire”, and with the BLM Gunnison Field Office to b) develop models and maps for use in a prescribed fire project (planned for 2026 or 2027), the North Powderhorn project.

Project Results, Analysis and Findings:
To address drivers of extreme fire spread events, we examined drivers within different ecoregions, establishing thresholds for extreme fire spread that are geographically specific and allow for more nuanced understanding of “extreme” within different landscapes. Ecoregional daily area burned varied greatly across US and Canada. In the southwestern US, this threshold was 16,262 ha/day in the North American Desert ecoregion, and 5,364 ha/day in the Temperate Sierras ecoregion, which included the sky islands of Arizona. Ecoregions with shorter fire durations had greater daily area burned, suggesting some regions are dominated by fast-growing short-duration fires, while others are slow-growing long-duration fires elsewhere. Although climatic conditions can predispose landscapes to wildfire occurrence, finer-scale mechanisms drive variation in daily spread, such as vegetation, topography and wind. Daily fire progression offers valuable insights into the regional and seasonal distributions of extreme single-day spread events, and how these events shape net fire effects. (Figure 1; Balik et al. 2024).

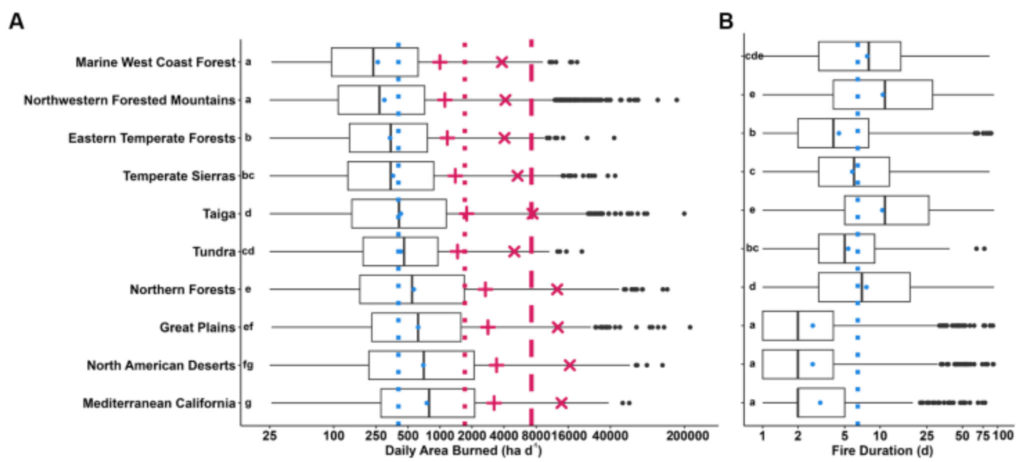

Figure 1: (A) Ecoregional daily area burned (ha day^{-1}) by fire spread events, and (B) fire duration (days). In both panels, values were log10 transformed and axis labels were backtransformed to original scale. Boxplot hinges correspond to the first and third quartiles, bolded center lines represent medians, whiskers represent 1.5 x interquartile range, and black circular points indicate outlier spread events. Blue circular points represent ecoregional geometric mean daily area burned or fire duration. Blue dotted vertical lines indicate continental geometric mean daily area burned (406 ha d^{-1}) and continental mean fire duration (6.5 days). Black letters in plot spaces to the immediate right of Y axis indicate Tukey’s HSD groupings (e.g., Marine West Coast Forest and Northwestern Forested Mountains have the same mean daily area burned; from one-way ANOVA test of Daily Area Burned:$F(9, 66{,}308) = 317.6$, $p < 0.001$; Fire Duration one-way ANOVA: $F(9, 9{,}626) = 290.8$, $p < 0.001$). In (A), red “+” points represent ecoregional “large” fire spread thresholds (i.e., ecoregional geometric mean + 1SD; Table 2), and red dotted vertical line indicates continental “large” spread threshold (i.e., continental geometric mean + 1SD; 1,704 ha d^{-1}). Red “X” points represent ecoregional “extreme” spread thresholds (i.e., ecoregional geometric mean + 2SD; Table 2), and red dashed vertical line indicates continental “extreme” spread threshold (i.e., continental geometric mean + 1SD; 7,173 ha d^{-1}). *From Balik et al. 2024.*

The spread of these wildfires was mitigated by vegetation type, most prominently recent wildfires or otherwise disturbed landscapes and certain ecosystem types like aspen dominance, wetlands, and shrub lands were most like to be on the perimeter of fires, indicating these are good places of control during large wildfire events (Figure 2, Harris et al. 2025). Fire weather conditions are a dominant driver of increased fire growth rates, however even during days of extreme fire spread, differences between aspens and conifers persisted.

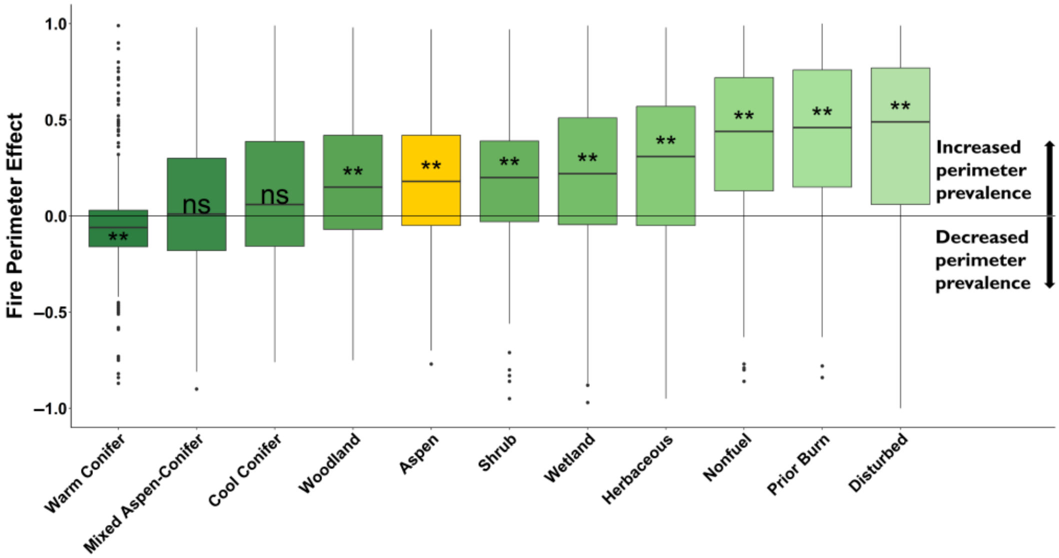

Figure 2. Box plot of fire perimeter effect (FPE) for each cover type across all fire events, depicting the median and distribution of FPE values (**$p < 0.001$; *$p < 0.05$; ns, $p < 0.1$). *From Harris et al. 2025.*

During these extreme spread days burn severity was higher across the southwestern US (Figure 3, MacFarland et al. 2025) and treatment impact on burn severity declined but was still sometimes successful (Figure 4, Hettema et al. *in revision)*. This demonstrates that not only are these days of extreme spread burning a large proportion of our landscape, ~1/3rd of area burned in the southwest in the last 20 years (Balik et al. 2024), but these fires have lasting ecological effects with large high severity patches with few trees that survived the fire.

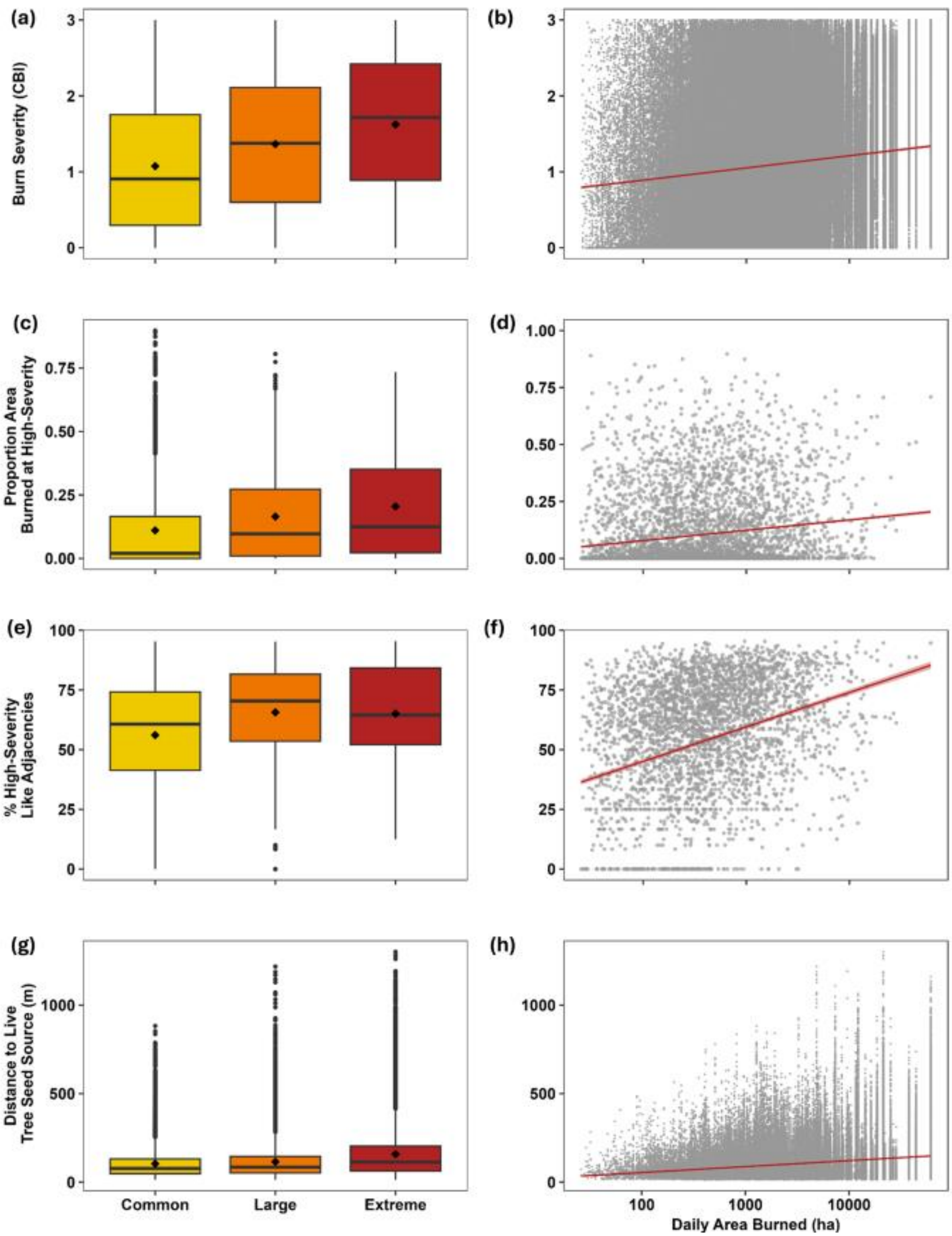

Figure 3. Burn severity (a,b), proportion of area burned at high severity (c,d), high severity patch homogeneity (e,f) and distance to tree seed source (g,h) as a function fire spread rate class and daily are burned. *From MacFarland et al. 2025*

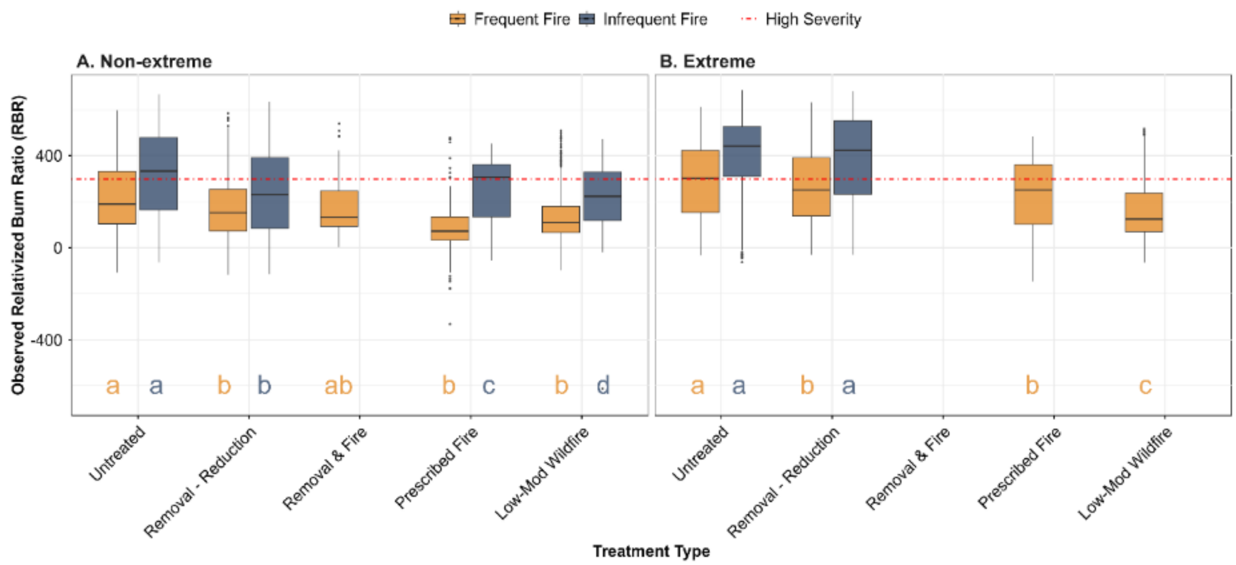

Figure 4. Observed burn severity differences across treatment types for (A) non-extreme and (B) extreme conditions by historically frequent and infrequent fire forests. Frequent fire forests include ponderosa pine, mixed-conifer, and aspen – mixed-conifer. Infrequent fire forests include lodgepole pine and spruce-fir. Frequent fire group (orange) and infrequent fire group (blue) indicate significant differences among treatment groups ($p < 0.05$, Dunn's Test). Groups that share a letter are not significantly different. Groups with missing bars had insufficient sample sizes. The red dashed line represents the relativized burn ratio (RBR) threshold for high severity (> 298, Parks et al., 2014a). *From Hettema et al. in revision.*

Conclusions and Recommendations

This work has numerous management implications. First, drivers of extreme fire spread vary geographically with many fine scale drivers beyond climate and weather. This demonstrates that modifying fuels may be more effective in some regions and increasing specificity of high fire danger warnings may be warranted. Second, aspen stands and other vegetation types can act as a fuelbreak, indicating interventions that shift conifer to aspen cover could lessen the risk of fire for nearby values of importance (e.g., communities, infrastructure) but still support forest ecosystem function. Additionally, fire-catalyzed shifts from conifer to aspen forest types in some landscapes may produce a negative feedback that dampens future fire activity.

There is much to still be understood about extreme fire spread and where or how we may change wildfire outcomes on extreme burning days. The SWCASC grant has led directly to a range of additional, "next-step" research projects being conducted by the PIs. These include examining how forest heterogeneity may mitigate wildfire outcomes, assessing the effectiveness of fuels treatments in halting wildfire or reducing burn severity under fire weather extremes, collaborative planning for novel, aspen-enhancement silvicultural projects in the Upper Gunnison Basin, forest climate adaptation research, and other initiatives. Fundamentally, however, there remain large knowledge gaps for future research. Thematically, these revolve around 1) improving our understanding of how variation in forest vegetation composition and structure may change under future climate, and how these changes will influence future fire activity under more extreme fire weather conditions, and 2) the capacity of land management to shape vegetation at a scale that shapes outcomes.

Outreach and Products:

Papers published

1. MacFarland J, Coop, J, Balik J, Rodman K, Parks S, Stevens-Rumann CS (2025*)* Extreme fire spread events burn more severely and homogenize post-fire landscapes in the southwestern United States. *Global Change Biology* https://doi.org/10.1111/gcb.70106
2. Balik JA, Coop JD, Krawchuck MA, Naficy CA, Parisien MA, Parks SA, Stevens-Rumann CS, Whitman E (2024) Biogeographic Patterns of Daily Wildfire Spread and Extremes across North America. *Global Ecology and Biogeography* 7, 1355361 https://doi.org/10.3389/ffgc.2024.1355361
3. Harris MP, Coop JD, Balik JA, McFarland JR, Pa4ks SA, Stevens-Rumann, CS (2025). Aspen impedes wildfire spread in southwestern United States landscapes. *Ecological Applications*, 35(5), e70061. https://doi.org/10.1002/eap.70061
4. Hettema SL, Stevens-Rumann, CS, Van Dusen H, Battaglia MA, Vorster AG, Stevens J. 2026. Burn severity across forest types and burning conditions for forest treatments on the southern Rockies Front Range. *Forest Ecology and Management* 606, 123529. https://doi.org/10.1016/j.foreco.2026.123529

Papers in review

1. Balik J, Coop JD, Krawchuk MA, Naficy CE, Parisien MA, Parks SE, Stevens-Rumann CS, Whitman E (*in revision)* Weather, drought, and landscape context promote extreme fire spread events across North American ecoregions. *Fire Ecology.*

Presentations

1. Balik J, Coop J 2024. Snowpack decline kindles early fire seasons with greater area burned and more severe fire in the western US. Southwest Association for Fire Ecology Meeting, November 2024, Santa Fe, NM.
2. Coop J, Balik J, McFarland J, Parks S, Stevens-Rumann C, Krawchuk M, Naficy C, Parisien MA, Whitman E. 2024. Faster-growing wildfires burn more severely and undermine forest futures as western North America warms. Southwest Association for Fire Ecology Meeting, November 2024, Santa Fe, NM [P].
3. J McFarland, J Coop, J Balik, K Rodman, S Parks, C Stevens-Rumann. 2024. Extreme fire spread events burn more severely and homogenize post-fire landscapes in the southwestern US. Ecological Society of America Annual Meeting August 2024
4. Harris M, Balik J, Coop J, Parks S, MacFarland J, Stevens-Rumann CS. 2024. Aspen as a firebreak: influence of forest type in impeding fire spread. Building resilience to mountain wildfire by weaving indigenous and scientific ways of knowing, Calgary Canada, February 2024.
5. MacFarland J, Coop J, Balik J, Rodman K, Parks S, Stevens-Rumann CS. 2023. Burn severity and landscape outcomes of extreme fire spread events in the southwestern US. 10th International Fire Ecology and Management Congress, Monterey CA, December 2023.

6. Harris M, Balik J, Coop J, Stevens-Rumann CS. 2023. Aspen as a firebreak: influence of forest type in impeding fire spread. 10th International Fire Ecology and Management Congress, Monterey CA, December 2023.[P]
7. Hettema S, Stevens-Rumann CS, Battaglia M. 2023. Evaluating the impacts of fuel treatments on burn severity across the Front Range. 10th International Fire Ecology and Management Congress, Monterey CA, December 2023[P].

Theses

Harris, Matthew P. 2024. Aspen impedes wildfire spread in the southwestern United States. Master of Science in Ecology, Western Colorado University.

McFarland, Jessika R. 2024. Extreme fire spread events burn more severely and homogenize post-fire landscapes in the southwestern United States. Master of Science in Ecology, Western Colorado University.

Phillips, Mariah L. 2023. Fuel characterization and modeled fire behavior in spruce-beetle impacted forests of the Powderhorn area, Colorado. Master in Environmental Management, Western Colorado University.

Hettema, Sarah. 2025. Burn severity across forest types and burning conditions for forest treatments on the Front Range. Master of Forest Sciences, Colorado State University.

Media

ABC February 28, 2025

Denver7 March 13, 2025

Colorado Public Radio July 26, 2025

Steamboat Today July 29, 2025

KUNC In the NOCO July 29, 2025

Workshops and manager engagement

Co-sponsored and leveraged SWCASC funds for Co-Stewardship of Aspen Workshop, in Gothic, CO. August 28-29 2024 https://www.centerforpubliclands.org/cpl/aspen

Hosted a special session at the Association for Fire Ecology Congress in Monterey, CA December 2023 that presented the work from an international audience including Europe, Canada and the US.

"Wood You Believe It? Aspen Interactions with Fire and Wildfire Spread in the Southwestern U.S."- Webinar with the Southern Rockies Fire Science Network. https://www.frames.gov/catalog/71193