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# Effects of small-scale forest treatments on reducing wildfire burn severity

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## ABSTRACT

**Background.** Intensive fire suppression and climate change have escalated wildfire intensity in fire-adapted forests. Although the consequences of fire suppression policies are well documented, fuel reduction treatment effectiveness – particularly across varying treatment sizes – remains debated. **Aims.** We evaluated a recent large wildfire in New Mexico, USA, to determine whether small fuel treatments reduced burn severity. **Methods.** Using paired plot analysis, we compared burn severity between treated and untreated sites. We used multiple regression analysis to evaluate how treatment effectiveness related to treatment size, topography, and time since treatment. **Key results.** Treated sites had significantly lower burn severity than untreated sites. Treatment effectiveness did not vary with treatment size, regardless of slope, aspect, and time since treatment (≤9 years). **Conclusions.** Small fuel treatments (≤4 ha) effectively reduced burn severity. **Implications.** Because treated boundary areas can still experience high burn severity, these findings provide a baseline to evaluate treatment size effects under site-specific conditions and inform future size guidelines.

**Keywords:** burn severity, fire behavior, fire management, forest treatment, fuel reduction, Southwest USA, treatment size, wildfire.

## Background

Decades of intensive fire suppression, coupled with a rapidly changing climate, have led to an increase in catastrophic wildfires in forests that were otherwise adapted to frequent fires (Parks *et al.* 2016; Hessburg *et al.* 2021; Kreider *et al.* 2024). In response, emphasis is being placed on treating overgrown forests, whether to restore forested landscapes or to protect critical resources and communities in the wildland–urban interface (WUI). Burn severity (effects on above- and below-ground organic matter; Keeley 2009) is a function of multiple factors, including weather, topography, and fuels, with fuels being the primary factor human actions can modify. Fuel treatments seek to reduce burn severity and fire intensity by decreasing the amount of fuel available to burn, typically through the reduction of tree and shrub canopy cover and surface fuels, including dead and downed material (Agee and Skinner 2005). Treatments may also include only the 'rearrangement' of fuels within a treated area (i.e. chipping, lop and scattering) without removing any of the treated material (Fallon *et al.* 2025). However, the effects of fuel reduction or rearrangement on burn severity are variable due to the confounding influence of topography and weather (Prichard *et al.* 2020). A broad range of studies have found that fuel treatments have been effective in reducing wildfire severity compared to untreated sites (Lydersen *et al.* 2017; Dodge *et al.* 2019; Cansler *et al.* 2022; Brodie *et al.* 2024; Davis *et al.* 2024), in addition to commercial timber harvest (Lyons-Tinsley and Peterson 2012). Fuel treatments can also influence long-term vegetation changes in the overstory and understory fuel layers across different stages of succession, which can, in turn, affect future fire behavior (Stevens-Rumann *et al.* 2013). Surface fuel accumulation and changes over time due to differences in climate and other factors also can influence long-term fire behavior and severity (Collins *et al.* 2011, 2013; Prichard and Kennedy 2014).

Despite the well-documented effects of forest treatments on fire behavior, it is unclear if the effects of treatments differ systematically with treatment unit size. An extensive literature review of studies assessing fuel treatment effectiveness found very few that reported on the effects of treatment size, and most of those studies used simulated fire (Ott *et al.* 2023). Further confounding our limited understanding of the influence that forest treatments have on wildfire behavior are the interacting effects of different forest types, environmental conditions at the time of the fire, pre- and post-fire stand data, and other factors (Beverly *et al.* 2020; McKinney *et al.* 2022). For studies that have reported treatment unit size effects, results are varied. In some cases, treatments greater than 200 ha were more effective in reducing burn severity than smaller treatments (Prichard and Kennedy 2014). Urza *et al.* (2023) did not discuss specific treatment sizes but also found that larger treatments were more effective at reducing fire effects than smaller treatments, in part, due to the fire's momentum overwhelming smaller treatments. McKinney *et al.* (2022) identified strong correlations between the total overall treated area (the cumulative amount of different treatments over a larger area) and wildfire size. They also found strong correlations between the number of treated sites within an area (treatment density) and the area affected by fire outside of treated sites. However, their analysis did not include effects related to individual treatment sizes on burn severity. An alternative way to evaluate the effects of treatment size is to evaluate the reduction in burn severity as a function of distance from the treatment edge. Although informative, the distance at which burn severity effectively decreases from a treatment edge can vary considerably, from almost immediately upon entering a treated area to more than 300 m, depending on fuel conditions, treatment type, topography, and other factors (Kennedy and Johnson 2014; Johnson *et al.* 2019). Significant reductions in burn severity in a treated WUI were reported by Safford *et al.* (2009), with fire effects decreasing with increasing distance from the edge of treatment. Although treatment unit sizes were not analyzed for their effects, burn severity decreased almost immediately as the fire entered the treated area.

Strategically placing fuel treatments can optimize the benefits of a given amount of fuel treatments across a landscape (Karimi *et al.* 2024). In simulations, changing treatments' placement can significantly impact fire behavior (Finney *et al.* 2006; Tubbesing *et al.* 2019), and the importance of treatment placement may outweigh the effects of treatment type (e.g. prescribed fire vs mechanical thinning, Loudermilk *et al.* 2014). Studies have also reported a point of diminishing returns after 10–20% of a landscape has been treated, supporting the need for strategic placement of treatments to optimize effectiveness across a given landscape when resources for implementing treatments are more limited (Finney *et al.* 2006; Ager *et al.* 2010). Understanding the relationship between treatment size and treatment effectiveness is a critical parameter for strategically placing treatments. For instance, if there is no reduction in effectiveness for small treatments, treatments may be micro-targeted around areas of greatest concern or areas likely to burn at the highest severity, allowing more of these areas to be treated (Supplementary material: Appendix A). The importance of treatment size to an optimal treatment strategy may also depend on forest structure. For instance, small treatments may be more effective in multi-age forest mosaics, while larger treatments may be more appropriate in more homogeneous landscapes (Duncan *et al.* 2015; Ott *et al.* 2023).

Although some work has been done to identify effective treatment sizes, few studies have compared burn severities between different-sized treatments following a high-intensity large fire. Federal and state agencies, as well as private landowners, may have limited funds to perform treatments on smaller properties, and although difficult to interpret, a comparison of burn severities between different-sized treatments following fire could be useful in these cases if accounting for adjacent untreated fuels, topography, and other factors.

The 2022 Hermit's Peak-Calf Canyon Fire (HP-CC Fire) in northeast New Mexico, USA, provided an opportunity to analyze the effectiveness of forest treatments of different sizes implemented prior to the fire. We aimed to understand how treatment size and other covariates altered the effectiveness of vegetation treatments. We considered a fuel treatment to be effective if it caused a reduction in burn severity relative to a nearby untreated site. We hypothesized that 1) burn severity in treated sites would be lower than adjacent untreated sites, and 2) decreases in burn severity relative to untreated sites would be greater in larger treated sites than smaller treated sites.

## Methods

### Study area

The HP-CC Fire occurred during spring-summer 2022 within the Sangre de Cristo Mountains in northeast New Mexico (Fig. 1). The Hermit's Peak Fire was initially planned as the Las Dispensas Prescribed Fire but quickly grew out of control due to extremely dry conditions and high winds. The Calf Canyon Fire ignited several days later from previous burn piles near the Hermit's Peak Fire, which merged with the Hermit's Peak Fire, eventually burning over 138,000 ha (USFS 2022) with approximately 44% experiencing moderate to high severity burn (Fig. 1). The HP-CC Fire burned in diverse terrain, primarily within ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), mixed conifer, and spruce (*Picea* spp.)-fir (*Pseudotsuga menziesii* [Mirb.] Franco, *Abies* spp., and *Pinus* spp.) forest types at elevations ranging from approximately 2130 m to over 3050 m.

## Data

We identified 48 treated sites throughout the HP-CC Fire burned area using the New Mexico Vegetation Treatment Geodatabase (Withnall *et al.* 2024) and only included projects completed between 2013–2019 in our analyses (Fig. 1). The treatment descriptions vary considerably but included common types (thinning, slash piles, chipping, removal, etc.). After reclassifying the treatments based on the classifications of Fallon *et al.* (2025), we found that 40 of the 48 treatments were mechanical treatments that 'rearranged' but did not remove fuels (Supplementary Appendix B). As such, we did not have a sufficient sample size to explore differences among treatment types. We used burn severity data provided by Monitoring Trends in Burn Severity (MTBS), an interagency program in the United States that measured burn severity as the difference normalized burn ratio dNBR (U.S. Geological Survey, USDA Forest Service 2021). Burn severity rating classes are provided in Supplementary Appendix C, and we used the class breaks provided by MTBS for this particular burn severity dataset. Briefly, dNBR is used to represent the change in photosynthetic biomass and charred material from the pre-fire to post-fire period based on changes in near-infrared and shortwave-infrared portions of the electromagnetic spectrum (Key and Benson 2006). For the HP-CC Fire, the pre-fire image was taken on 13 September 2020 and the post-fire image was taken on 6 September 2023, both using the Landsat 8 Satellite. These data were supplemented with topographic data from LandFire (LANDFIRE 2022). All data layers (i.e. burn severity, topographic) were used at 30 x 30-m cell resolution. Mean values for each treated and untreated site used in the analyses were based on the average of individual cell values within each site.

## Assignment of paired control sites

We analyzed 48 treatment sites ranging in size from approximately 0.3 to 4 ha and excluded sites that received multiple treatments within at least the previous 20 years. We created a paired untreated polygon for each treated site using the identical size and shape configurations of the treated sites using *ArcMap* (v10.5). We placed the untreated site polygon a minimum of 50 m from any treated sites, regardless of whether the treated site was used in our analyses. In three instances we used a smaller distance because of other constraints on the landscape. The untreated site polygons were also a maximum of approximately 120 m from their paired treated sites to ensure environmental conditions and fire behavior were as similar as possible between the treated site and its paired site (e.g. wind speed and direction, temperature, fuel moisture). We confirmed forest type descriptions for each paired site using the New Mexico landcover data produced from the GAP National Terrestrial Ecosystems data set (U.S. Geological Survey (USGS) Gap Analysis Project (GAP) 2016, Supplementary Appendix D). Additionally, we used the following criteria in the placement of the paired untreated site polygons: 1) the polygon had to be in an untreated forest stand as verified using the treatment database and satellite imagery, 2) it had to represent an area similar in slope (°), aspect, and elevation to the treated site as closely as possible, and 3) it had to be located nearby similar features as the treated site that could potentially influence fire behavior (proximity to roads, open areas, etc.). We validated the similarity of topographic variables between paired treated and untreated sites using paired *t*-tests (Supplementary Appendix E). To reduce potential bias in the selection of the untreated sites within higher burn severity areas based on visible fire damage to trees, we initially placed the paired polygon in an area based on slope and aspect without the landscape imagery visible. Once the paired untreated site was selected, we used the landscape imagery to verify placement within a suitable area based on the criteria above. If the untreated site was placed in an unsuitable area (e.g. a waterbody, non-forested area), it was moved to the nearest suitable area. One person visually verified thinning treatments reported for each site using satellite imagery taken in May and June 2022 (ESRI 2023).

We evaluated whether our procedure for hand selecting the paired untreated plots introduced bias, and how consistent the results were by evaluating burn severity in randomly placed validation plots throughout the untreated areas of the burn scar. Briefly, after establishing validation plots, we identified paired controls following the same protocol described above. Then, we compared the mean bias of burn severity in the validation vs control plots, the mean absolute bias, and the root mean squared error. We found that mean bias was 0.76, mean absolute difference was 60.9, and the root mean squared error was 82, which are reasonable given the range of the data. A detailed description of this analysis is provided in Supplementary Appendix F.

## Data transformation and statistics

Prior to analysis, we transformed the aspect data into two linear variables, northness (cos(degree aspect($\pi$/180)) and eastness (sin(degree aspect($\pi$/180)) to be used in the regression analysis (Amatulli *et al.* 2018). The transformations resulted in values ranging from 1 (due north) to $-1$ (due south) for northness with values near 0 indicating east or west-facing slopes. Values ranged from 1 (due east) to $-1$ (due west) for eastness with 0 indicating north or south-facing slopes.

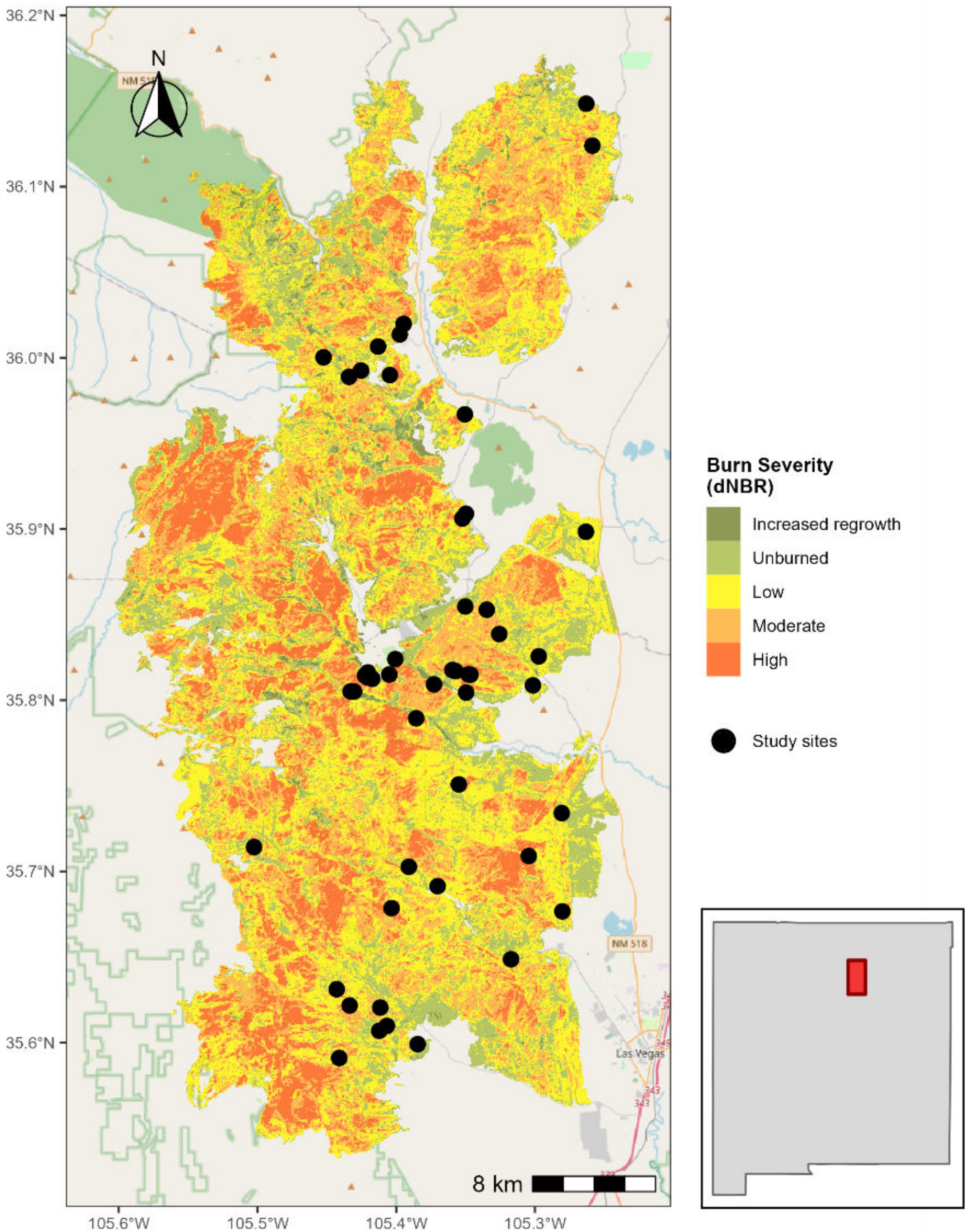


**Fig. 1.** HP-CC Fire, 2022 boundary map. Treatment sites selected for analyses and shown in black and colors represent burn severity as dNBR.

We used a paired *t*-test ($\alpha = 0.05$) to evaluate whether the treated sites burned at a lower severity than their paired untreated sites and used Cohen's *d* as a measure of effect size. We first evaluated whether differences in burn severity between paired sites violated the assumption of normality using a Shapiro-Wilk test and histograms of burn severity differences between treated and untreated sites. The treated and untreated sites differed in burn severity, which was normally distributed ($W = 0.972$, $P = 0.291$), thus meeting the assumptions of a paired *t*-test.

In order to evaluate the drivers of treatment effectiveness, we used multiple regression based on the differences in burn severity between untreated and treated sites (ΔdNBR, untreated mean − treated mean). We considered the effectiveness of a treatment to be the reduction in burn severity caused by the treatment, which yield positive values for ΔdNBR. We investigated the effects of treatment size, slope, aspect (northness, eastness), and years since treatment on ΔdNBR and used the *F*-statistic and $R^2$ value ($\alpha = 0.05$) to evaluate model fit and significance. We evaluated multiple regression assumptions (normally distributed model residuals, linear relationships between dependent and independent variables, lack of multicollinearity with independent variables) and found that assumptions were generally met. We used *R* version 4.3.1 for all statistical analysis (R Core Team 2023).

## Results

### Treated vs untreated site burn severity

The dNBR of treated sites was significantly lower than untreated sites ($t_{(47)} = -6.37$, $P < 0.0001$, Fig. 2) with a mean dNBR of treated sites of 119 (s.d. = 93.1) vs 221 (s.d. = 127) in untreated sites. The vegetation treatments reduced dNBR with a moderate effect size (Cohen's $d = -0.92$), and comparing treated and untreated dNBR values revealed most treated values were lower than their paired untreated values (Fig. 3*a*). Furthermore, this effect was persistent when we examined only the sites with areas less than 1 ha ($t_{(19)} = -3.66$, $P = 0.0016$). Among the treated sites, 15% of the dNBR values fell in the unburned range, 67% fell in the low severity range, and the remaining 18% fell in the moderate severity category. Among the untreated sites 2% of the dNBR values fell within in unburned range, 41% burned at low severity, 50% fell into the moderate severity category, and the remaining 7% burned at high severity (refer to Supplementary Appendix C).

### Treatment size, time since treatment, topography, and burn severity

In our analysis of potential drivers of treatment effectiveness, we did not find any significant relationships between ΔdNBR and treatment size, slope, aspect (northness or eastness), or time since treatment (Table 1, Fig. 3). The relationship between ΔdNBR and treatment size had a relatively large 95% confidence interval ranging from −30.63 and 29.13 suggesting inconclusive evidence of differences in dNBR between different size treatments. Confidence intervals for most other measured variables were also generally large and the effects were not significant. Variance inflation factors were generally low, suggesting multicollinearity is not the cause of the wide confidence intervals on our estimates of effects sizes (Table 1).

## Discussion

This study examined fuel treatment effectiveness following a large wildfire in a montane forested landscape. We were particularly interested in whether burn severity differed between treatment units of different sizes and between treated forest stands and untreated stands. Treated sites in our study area experienced significantly lower burn severity compared to adjacent untreated sites, corroborating other studies (Fulé *et al.* 2012; Cochrane *et al.* 2013; Kalies and Yocom Kent 2016; Cansler *et al.* 2022; Davis *et al.* 2024). Our results also suggest that small treatments may have been effective at reducing burn severity in our study area. Treatment effectiveness was similar across treated sites with sizes ranging 0.3 to 4 ha. However, the large confidence intervals on our estimates do not rule out meaningful effects of treatment size on effectiveness. The non-significant overall model suggests a more complex relationship may exist that is not fully identified here, possibly due to low replication across topographic conditions. The effectiveness of small treatments merits further investigation. Aspect-related differences in burn severity may be driven by fuel types and loading (Coop 2023). Dillon *et al.* (2011) found that north-facing slopes in the southwest USA tended to experience higher burn severity due to typically higher fuel loads while Koontz *et al.* (2020) reported higher burn severity on southwest facing slopes of coniferous forests. Understanding the relationship between aspect and burn severity across different treatment sizes can help guide treatment placement in different landscapes.

Few studies have reported treatment effects on burn severity based on treatment sizes but for those that do, many suggest larger treatments have greater effects on reducing fire intensity. Fallon *et al.* (2025) found that larger treatments were more effective at modifying fire behavior than smaller treatments but, depending on treatment type, even small treatments were effective at modifying fire as discussed below. Burn severity has been observed to decrease with increasing distance from the edge of a treated site. However, those distances have varied considerably from immediately when a fire enters a

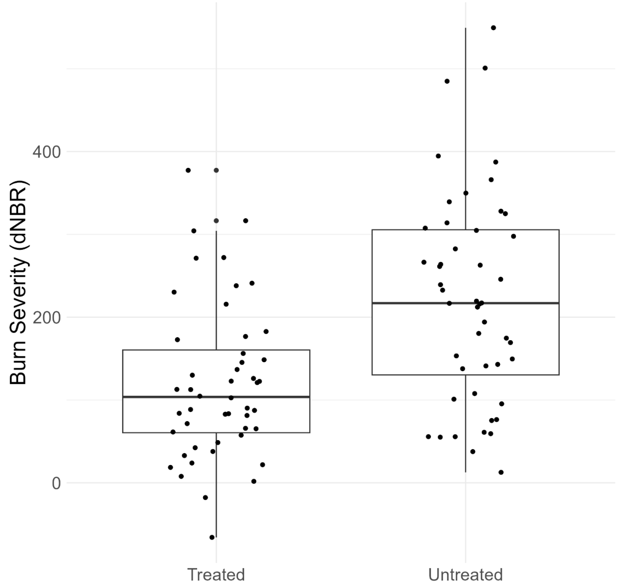


**Fig. 2.** Boxplots of burn severity (dNBR) for treated and untreated sites, HP-CC Fire, 2022.

treatment to as much as 600 m before significant reductions in fire activity. Much of the variability has been attributed to local fuel conditions, topography, and fire behavior in adjacent untreated stands as the fire entered the treated areas (Kennedy and Johnson 2014; Johnson *et al.* 2019; Johnson and Kennedy 2019). In some cases, immediate drops in active crown fire as fire moved into a treated area have been reported with significant decreases in fire activity 50 m from the edge of the treated/untreated area (Symons *et al.* 2008). Other studies have also reported substantial decreases in burn severity within 40–70 m of treatment unit edges (Safford *et al.* 2012). In one case, a substantial decrease in fire activity was observed between 25–40 m (Safford *et al.* 2009). If the minimum distance to significant reductions in fire activity reported in most previous studies was at least 40 m, and as much as 600 m, from a treatment edge, then the majority of the smaller treatment units in our study area should have experienced reduced effectiveness. Despite these findings, our results suggest that treatments as small as about 0.3 ha were effective at reducing fire activity during the HP-CC Fire. It should be noted, however, that the overall burn severity for the untreated sites was mostly moderate, suggesting that these areas did not experience extreme fire weather. It is possible that in areas that experienced more severe fire weather, these small treated sites may have been either more or less effective in reducing burn severity.

The diverse goals of fuel treatments, in addition to the complex interaction of fuel treatments with local conditions such as topography and vegetation types, precludes the creation of a single standard for fuel treatment size (Kennedy and Johnson 2014). Further adding to the complexity of interactions affecting fire behavior is that treatment type can strongly influence fire behavior. Most of the treatment sites in our study were classified as 'rearrange' following the criteria of Fallon *et al.* (2025) whereby fuels were treated and left on site rather than burned or removed. Fallon *et al.* (2025) reported that, regardless of treatment type, over 60% of all treatments influenced fire behavior. However, contrary to our findings, they found that treatments that only rearranged fuels, such as the majority of treatments we analyzed, did not significantly modify fire behavior in smaller treatments – while treatments that removed fuel were more effective. It's possible the treatment database did not report post-treatment removal of material by local residents or property owners used for firewood or small-diameter products (fence posts, etc.) which would have then classified these sites as 'removal' by Fallon *et al.* (2025). Almost all of the treatments we analyzed occurred on private property (46 out of 48 treatments). Additionally, simple categorization of treatments such as rearranging fuels in our study masks some heterogeneity among treatments that scatter, chipped, or piled slash. It is also possible that the methods we used to detect these effects are more precise than the methods used by Fallon *et al.* (2025). Future studies that can adequately measure and describe both fire behavior and post-processing of treated materials on small treatments prior to fire could address this issue. Treatment size recommendations that have been discussed by researchers have been generally based on fire effects observed within a treated area's perimeter as previously discussed. Safford *et al.* (2012) recommended a minimum of 400–500 m width for fuel treatments to effectively slow or stop active crown fire under extreme conditions but Safford *et al.* (2009) suggested that in their study area, a 50 m width could be sufficient to reduce a crown fire to a surface fire if surface fuels are reduced. This highlights that the size of a fuel treatment could be different depending if the goal is to stop a fire, or to reduce crown fire. Recommendations for treatment unit widths have been presented based on the measurement of fire effects within treated areas, albeit, wide-ranging. As presented in several of the studies discussed here, a reduction in crown fire activity occurred almost immediately or nearly so, upon fire entering a treated area. This is similar to our results which demonstrate that smaller treatments in our study area appeared to be effective in reducing burn severity. If the goal of fuel treatments is to reduce patches of extreme burn severity across the landscape, small treatments targeted at areas of highest risk may be most effective (see Supplementary Appendix A). Understanding the rational for treatment site selection among different treatment initiatives would also be useful to forest practitioners. The New Mexico Vegetation Treatment Geodatabase

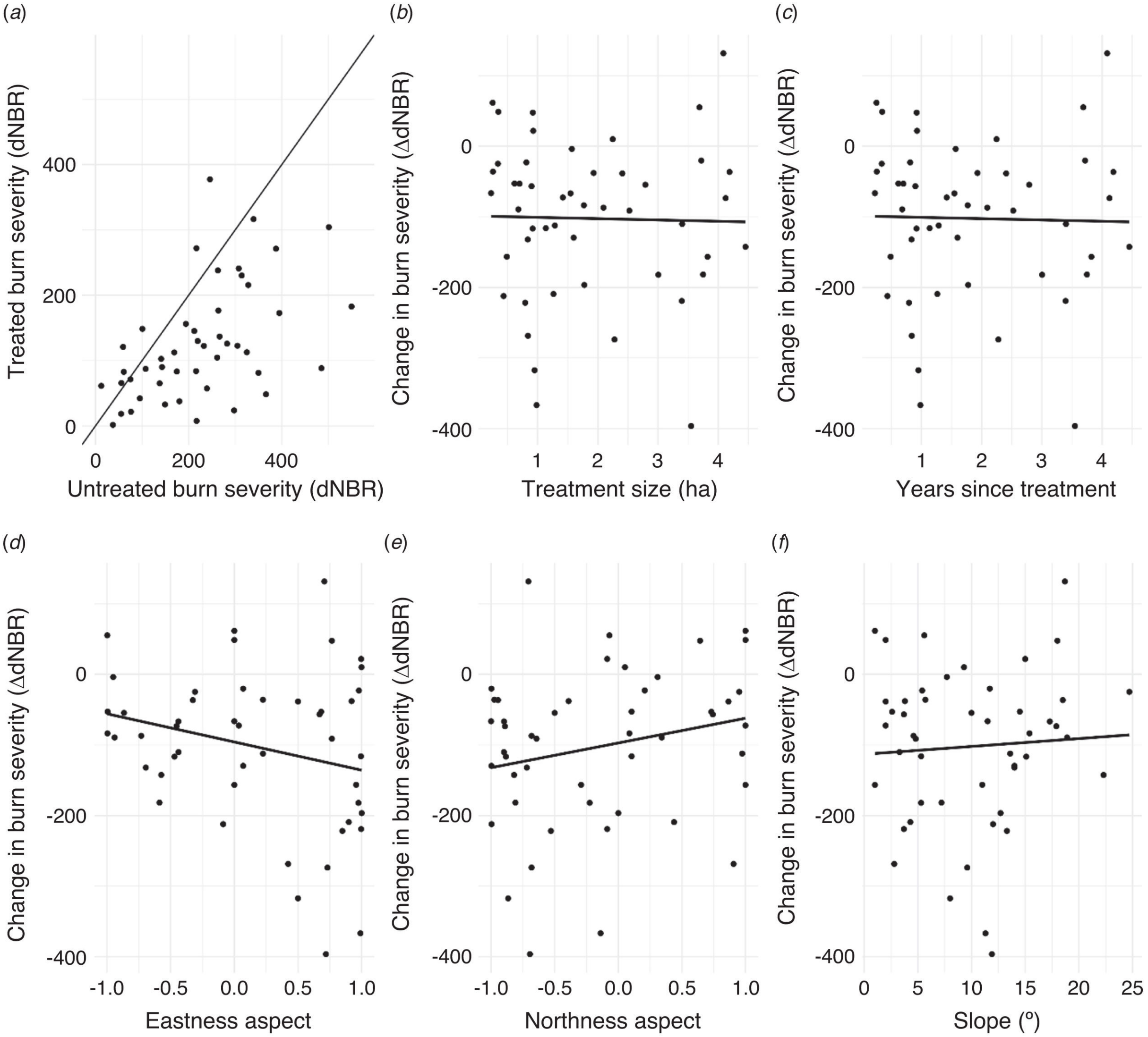


**Fig. 3.** Scatter plots representing (*a*) the relationship between untreated burn severity and treated burn severity in paired plots, and and (*b*–*f*) the change in burn severity (ΔdNBR) across environmental and management covariates: (*b*) treatment size, (*c*) years since treatment, (*d*) eastness, (*e*) northness, and (*f*) slope. All data are from treatments and their paired controls that burned in the HP-CC Fire, 2022. In panel (*a*), the line represents a 1:1 line and in panels (*b*–*f*) the lines represent lines of best fit.



is a compilation of treatments implemented by multiple agencies with different treatment goals and the specific rational for treatment site selection (topography, fuel loading, etc.) is not provided. The New Mexico Forestry Division was listed as a partner in most of the treatments and they often partner with private landowners to conduct WUI treatments (NMFD 2020). Although unverified, it's possible the primary criteria for selecting those sites pertained to fuel loading. Careful consideration of fuel treatment goals (Vorster *et al.* 2024), along with minimum fuel treatment sizes must be considered when planning treatments across a landscape.

We included topography (slope, aspect) and time since treatment in our analysis due to their potential influence on fire behavior. Safford *et al.* (2012) found that burn severity increased in treated units on steeper slopes. We found no correlation between slope and burn severity in treated units but less than 20% of the treatment units we analyzed had slopes greater than 15%, potentially masking the influence of slope over larger ranges. We also found no significant relationship between burn severity and years since treatment suggesting that treatments remained effective at maintaining low burn severity for at least nine years after treatment, similar to what has been reported in other

**Table 1.** Results of significance tests for the burn severity regression model. Variance inflation factors are provided to test for collinearity. Results are based on differences between treated and untreated sites, HP-CC Fire.

| Full burn severity model | | | | | |
|---|---|---|---|---|---|
| **Coefficients** | **Estimate** | **95% CI** | ***t* value** | ***Pr*(>\|*t*\|)** | **VIF** |
| Intercept | −48.6 | (−278.4, 181.2) | −0.427 | 0.672 | * |
| Hectares | −1.39 | (−32.73, 29.84) | −0.09 | 0.929 | 1.42 |
| Meanslope | 1.43 | (−4.31, 7.19) | 0.504 | 0.504 | 1.23 |
| Northness | 43.72 | (−10.10, 97.54) | 1.639 | 0.109 | 1.45 |
| Eastness | −43.81 | (−92.10, 97.54) | −1.810 | 0.077 | 1.08 |
| Trtinterval | −7.34 | (−32.73, 18.05) | −0.583 | 0.563 | 1.26 |

Asterisk denotes VIF not available for Intercept.
Residual s.e.: 108.9 on 43 degrees of freedom.
Multiple $R$-squared: 0.144, Adjusted $R$-squared: 0.042.
$F$-statistic: 1.415 on 5 and 42 d.f., $P$-value: 0.239.
CI, confidence interval; *Pr*, probability; VIF, variance inflation factor.



studies (Prichard and Kennedy 2014; Dodge *et al.* 2019; Cansler *et al.* 2022; Brodie *et al.* 2024; Davis *et al.* 2024).

The lack of concrete recommendations for treatment size to reduce fire intensity to a manageable level is, in part, a reflection of the high variability of factors affecting fire behavior at both the landscape and stand scales (Kennedy and Johnson 2014; Johnson *et al.* 2019; Johnson and Kennedy 2019). These include differing micro-climatic conditions, surface fuel conditions, species composition, canopy cover, and other factors. As a result, applying specific treatment unit sizes to effectively reduce burn severity in a particular area should be based on assessments of fire behavior in similarly treated areas. However, to develop such treatment size recommendations would require, most likely, prohibitively controlled field studies of multiple fuel and topographic conditions, forest types, weather scenarios, fuel moisture conditions, fire intensities, and other potentially influential variables. An adaptive management approach based on observational and controlled studies could provide general guides that are refined over time. Efforts are, in fact, being made to develop frameworks that evaluate treatment effectiveness at the stand and landscape level (Hood *et al.* 2022). Including an analysis of burn severity post-fire across different pre-fire treatment sizes, such as our study, could strengthen these types of frameworks. We recognize our comparison of treated vs untreated stands represents an observational analysis rather than a controlled experimental study and that the overall sample size of treatments used in our analyses may have been too small to detect significant relationships.

We did not collect field data on different burn severity measures such as bole and crown scorching or tree mortality and relied on burn severity measures based on remote sensed dNBR. The lack of direct field measurements of stand characteristics limits an analysis of pre-fire stand conditions in both treated and untreated areas with respect to canopy base height, canopy bulk density, canopy cover, surface fuel loading, and other fuel conditions that can influence burn severity. Given the severity of the fire and private land access issues severely limiting field measurements, the focus of this study was on comparing burn severity among a range of different-sized treatments using remotely sensed data with canopy burn severity verified using satellite imagery. It is possible that the 50 m minimum distance we used from a treated unit to its paired untreated site may not have been sufficient to ensure treated areas did not affect fire behavior in our paired untreated sites. Given the heterogeneous topography in our study area, we believed controlling for topography, site conditions, and weather conditions was a priority. A lack of field measurements on stand characteristics can limit the interpretation that varying fuel conditions have on fire intensity but our results provide insights into the relationship between treatment size and burn severity following high-intensity wildfire.

This study analyzed treatments from an abnormally intense and widespread fire event, driven by extremely dry conditions and critically windy conditions. Additional fires could be similarly analyzed to determine if these results remain consistent under potentially different environmental and fuel conditions. Stand treatments implemented before past fires could be analyzed to determine their effectiveness in moderating burn severity under different climate conditions leading up to and during the fire. Environmental changes in the southwest USA since 2000 have been significant with increasing temperatures, reduced snowpack, and prolonged intense droughts (Dunbar *et al.* 2022). We focused on analyzing treatment-level effects on burn severity rather than landscape-level effects. Evaluating the area of influence outside treated sites is necessary to assess treatment effectiveness across landscapes (McKinney *et al.* 2022). Further investigations into the area of influence for a range of treatment sizes can also help identify the optimal treatment size for reducing overall fire intensity and severity across landscapes. Lastly, understanding relationships between past fires and stand treatments can provide insight into current and future outlooks for fire behavior and the role treatment size, location, and time since treatment plays in moderating fire intensity and severity.

## Conclusions

We analyzed forest treatments within a recent large wildfire in the southwest USA and found that relatively small treatments were effective at moderating fire behavior compared to untreated stands. Our findings support previous studies that have reported a reduction in burn severity in treated areas but studies have also shown that treated forest stands can experience high severity near treatment boundaries. Although previous work has focused on measuring treatment effects on fire behavior, few studies have provided specific size recommendations due to interactive effects of weather, forest type, topography and other factors. Our findings suggest that smaller treatments can be effective at reducing burn severity but further research of treatment size effects under diverse weather, fuel, and other site-specific conditions is necessary before minimum size recommendations can be developed.

### Supplementary material

Supplementary material can be accessed from the article page online.

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**Data availability.** The datasets used and analyzed in this study are available from the corresponding author on reasonable request.

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