ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Numerical Investigation of Crown Fuels Arrangements on Wildfire Behavior Following Fuels Treatments

Justin Paul Ziegler[1]∗; Chad M. Hoffman[1]; Russel A. Parsons[2]; Morris Johnson[3]; James Menakis[4]

[1]Department of Forest & Rangeland Stewardship, Colorado State University, Fort Collins, CO 80523, USA, {c.hoffman@colostate.edu}
[2]Fire Sciences Laboratory Forest Service, Rocky Mountain Research Station, US Forest Service, Missoula, MT, USA, {russell.a.parsons@usda.gov}
[3]Pacific Northwest Research Station, US Forest Service, Seattle, WA, USA, {morris.c.johnson@usda.gov}
[4]Washington Office Fire & Aviation Management, US Forest Service, Washington, DC, USA, {james.menakis@usda.gov}

**Corresponding author*

Keywords

Physics-based fire model; structural complexity; forest restoration; Pinus ponderosa; spatial heterogeneity

Abstract

Conventional fuels treatments often simplify forest structure by spacing residual trees and thinning from below to optimize fire hazard reduction. Conversely, restoration treatments, aimed at achieving ecological multiple objectives in addition to fire hazard reduction, purposefully retain heterogeneous forest structures. The retention of tree groups and small trees following restoration may however limit reductions in fire behavior. To quantify this potential trade-off, we performed a suite of simulations with the Wildland-urban interface Fire Dynamics Simulator to compare stand-level fire behavior between silvicultural cuttings that either emphasized or reduced forest heterogeneous structure under a range of residual basal areas, surface fuel loads, and burning conditions. These cuttings included distance-based retention, variable retention, and random cuttings, optionally with thinning from below. While all treatments reduced fire behavior, differences between cutting scenarios emerged at low levels of residual basal area. Rate of spread did increase under more severe burning conditions, and slightly increased after thinning from below or after variable retention cuttings due to higher wind speeds associated with the creation of openings. Canopy consumption was lowest when thinning from below and highest after variable retention. The differences we observed support the advantage of using fuels treatments that preferentially space residual trees and remove small trees where fire hazard reduction is of primary importance. Additionally, the effects of residual basal area, surface fuel load, and burning conditions highlight the multivariate considerations required when planning fuels treatments and assessing performance at stand scales.

1. Introduction

Mechanical fuels treatments are a primary tool in forests to reduce the likelihood of undesirable fire behavior and post fire effects at the stand scale (Reinhardt et al., 2008; Stephens et al., 2021). At a minimum, fuels treatments are oriented around four principles (Agee and Skinner, 2005): reduce surface and canopy fuel loads, increase canopy base height, and preserve larger fire-resistant trees. These principles are often implemented silviculturally by removing small trees and leaving widely spaced large trees (Larson and Churchill, 2012; Stephens et al., 2021).

There is a desire in many forests globally however to use silvicultural practices which emphasize the creation of heterogeneous forest structures (Fahey et al., 2018; Puettmann, 2011; Zenner and Hibbs, 2000; Ziegler et al., 2017). For example, dry forest stands of the western USA, for example, were composed of fine-scale (sub-ha) mixtures of openings, isolated trees and tree groups prior to EuroAmerican settlement (Clyatt et al., 2016; Larson and Churchill, 2012). In these forests, restoration treatments aim to dually achieve both ecological and fire hazard objectives. Restoration-based silvicultural practices permit variable tree spacing rather than distance-based minima (Churchill et al., 2013), and shift from a size-centric focus geared towards lifting the canopy to a free thinning approach (Addington et al., 2018; Tuten et al., 2015; Underhill et al., 2014).

https://doi.org/10.14195/978-989-26-2298-9_229

Restoration treatments are generally seen as compatible with reducing fire hazard (Addington et al., 2018; Stephens et al., 2021). The long-term persistence of heterogeneously structured forests, historically sparser than their modern counterparts, suggests these forests have been resilient (Larson and Churchill, 2012). In addition, Koontz et al. (2020) found that sparse and heterogeneous forest structures experienced low severity fire effects following wildfires. Further, fire simulation studies confirm heterogeneous restoration treatments reduce fire behavior relative to their state pre-treatment (Ziegler et al., 2017). However, it is suggested that fire behavior reduction may be hindered after restoration relative to homogenizing conventional fuels treatments, implying restoration treatments carry tradeoffs (Addington et al., 2018; Larson and Churchill, 2012; Stephens et al., 2021; Ziegler et al., 2017). These remarks cite the potential for surface-crown transitions facilitated by residual ladder fuels and local crown fire spread within tree groups (Larson and Churchill, 2012; Stephens et al., 2021). Further, the openings created by restoration treatments can increase within-stand wind speeds, exacerbating fire rate of spread and fireline intensity (Linn et al., 2013; Ziegler et al., 2017).

We conducted a systematic study of simulated fire behavior under hypothetical cutting alternatives using data measured in real-world dry forests in the intermountain West, USA. We developed five hypothetical cutting scenarios to manipulate the horizontal and/or vertical arrangements of tree crowns. We implemented cutting scenarios to various levels of residual basal areas. Then we simulated fire using a three-dimensional, physics-based fire model across a range of surface fuel loads and burning conditions. Last, we compared measures of fire behavior and severity between cutting scenarios at each level of residual basal area.

2. Materials and Methods

2.1. Design of Fire Simulations

We planned our experiment to simulate the effects of cutting scenarios on potential fire behavior and severity across a range of burning conditions. With the Wildland urban interface Fire Dynamics Simulator (WFDS) (Mell et al., 2007; Mueller et al., 2014), we simulated fire before and following virtual cuttings on five stem-mapped 4-ha sites. These sites are located within ponderosa pine (*Pinus ponderosa* Lawson)-dominated forests in Colorado and Arizona, USA (Ziegler et al., 2017). Cuttings included: random, distance-based, with or without thinning from below, and variable retention, with or without thinning from below. Each cutting operated by sequentially removing, or retaining, trees until a basal area target of either 5, 10 or 15 m^2 ha^{-1} was met. The random cutting equally sampled trees. The distance-based cutting removed trees nearest to another tree. Our variable retention cuttings used an algorithm previously described by Tinkham et al. (2017) to retain groups of trees. For each WFDS simulation, we populated three-dimensional domains with the residual trees for a given site, its respective cutting scenario at each residual basal area. Our parameterization mimicked related WFDS studies, e.g. Ziegler et al., (2021, 2020, 2017). Table 1 details the forest structure following each cutting scenario.

Table 1- Spatial and aspatial summary of forest structure following hypothetical cuttings, averaged (std. error) across five 4-ha sites.

Cutting scenario	**Trees ha^{-1}**	**QMD**	**Mean trees $group^{-1}$**	**Mean opening size (m^2)**	**Mean nearest neighbor (m)**
Pre-cutting	687 (88)	22.8 (2)	10.1 (2.2)	16 (6)	1.6 (0.1)
Residual basal area: 15 m^2 ha^{-1}					
Random	403 (56)	23 (2)	4.1 (0.6)	37 (13)	2.2 (0.2)
Distance-based	292 (46)	27 (2)	2.4 (0.4)	29 (11)	3.6 (0.4)
Variable-retention	386 (60)	23 (2)	4.3 (0.7)	62 (14.4)	2.1 (0.2)
Distance-based w/ thin-from-below	118 (23)	43 (5)	1.1 (0.0)	105 (34)	6.3 (0.7)
Variable-retention w/ thin-from-below	153 (28)	38 (4)	1.6 (0.1)	117 (29)	4.1 (0.4)
Residual basal area: 10 m^2 ha^{-1}					
Random	265 (37)	23 (2)	2.7 (0.2)	68 (19)	2.7 (0.2)
Distance-based	178 (28)	28 (3)	1.3 (0.1)	56 (19)	5.0 (0.5)
Variable-retention	269 (36)	22 (2)	3.1 (0.3)	117 (16)	2.2 (0.2)
Distance-based w/ thin-from-below	62 (12)	49 (6)	1.0 (0.0)	189 (38)	9.0 (1.0)

Variable-retention w/ thin-from-below	83 (15)	42 (5)	1.3 (0.0)	194 (30)	5.6 (0.6)
Residual basal area: 5 m^2 ha^{-1}					
Random	132 (22)	23 (2)	1.7 (0.1)	139 (28)	4.2 (0.4)
Distance-based	82 (13)	29 (2)	1.0 (0.0)	141 (26)	7.9 (0.8)
Variable-retention	144 (18)	22 (2)	2.7 (0.3)	215 (8)	2.6 (0.2)
Distance-based w/ thin-from-below	24 (5)	56 (7)	1.0 (0.0)	312 (21)	15.9 (1.9)
Variable-retention w/ thin-from-below	32 (7)	48 (6)	1.1 (0.0)	304 (22)	9.5 (1.2)

We varied additional parameters in WFDS simulations to capture a range of fire behavior outcomes from moderate to extreme. Our experimental design varied the open wind speed (5, 10, or 15 m s^{-1} at 20-m AGL), surface fuel loading, and surface fuel moisture (5%, 8%, or 11%) to generate a range of burning condition severities. Median surface fuel loads were 0.4, 0.8 or 1.2 kg m^{-2}. We distributed surface fuel loads heterogeneously to reflect the influence that canopy cover has on the composition of the surface fuelbed locally (Figure 1) (Banwell and Varner, 2014; Matonis and Binkley, 2018). First, we calculated the distances from any location to a tree, then inverted these distances, and last re-scaled these distances to fuel load using a triangular distribution with a minimum of 0.2, maximum of 3.0, and median of either 0.4, 0.8, or 1.2. Where the surface fuel load was 0.2 kg m^{-2}, we assigned a fuel bulk density of 2 kg m^{-3}. For each surface fuel load increase of 1 kg m^{-2}, we increased fuel bulk density by 6.25 kg m^{-3}.

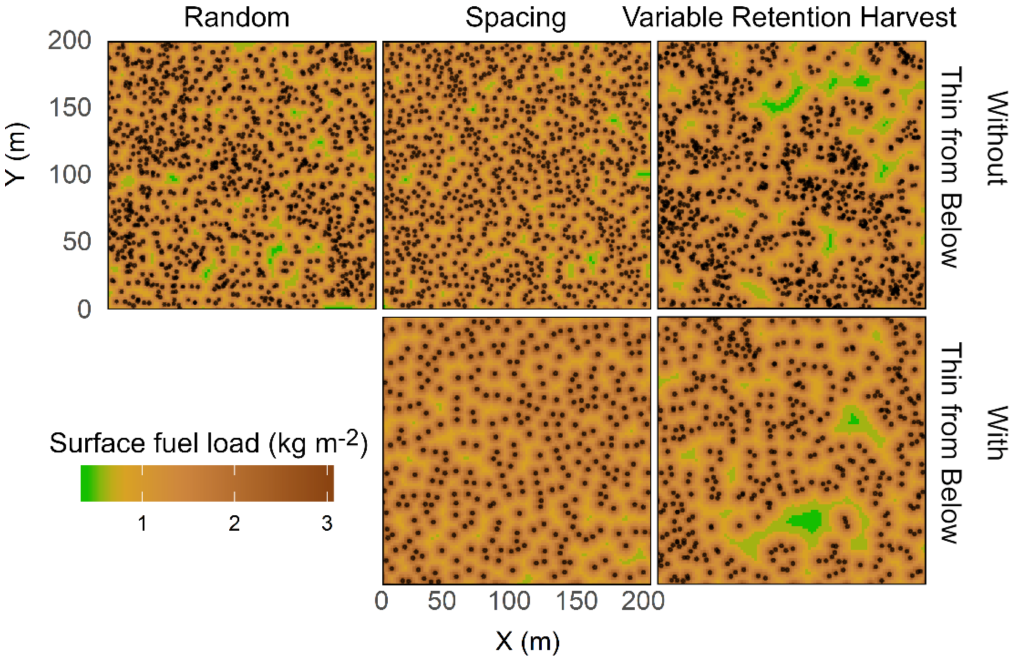

Figure 1- Example of simulated cuttings on one site, Long John, mapping the locations of residual trees (black dots) given a target basal area of 10 m^2 ha^{-1}, and the arrangement of surface fuel loads, given a spatial median of 1.2 kg $^{-2}$

2.2. Experimental Design & Analysis

We performed 200 simulations of fire behavior after cutting. We used an implementation of C-optimized Fedorov's exchange algorithm (Atkinson and Donev, 1992) as implemented by the AlgDesign v1.2.0 package (Wheeler, 2019) in R to choose a subset of simulations to run among a full factorial candidate list. We also simulated fire behavior a total of 40 times across sites pre-cutting across all variables, again using C-optimized Fedorov's exchange algorithm.

We measured mean rate of spread and logit-transformed percent canopy consumption for each WFDS simulation. First, we used linear mixed-effects regressions, with nlme v.3-1-152 (Pinheiro et al., 2021) in R, to measure the estimators for each variable, using the form (Eq. 1):

$$\{ROS, CC\} = U_{10} + SFL + SFM + BA + Cutting + BA \times Cutting + Plot, \qquad (1)$$

which includes fire rate of spread (ROS), percent canopy consumption (CC), open wind speed (U_{10}) measured at 10 m above the ground, surface fuel load (SFL), surface fuel moisture (SFM), residual basal area (BA), cutting scenario, and plot as the single random variable. Second, we then applied a subsequent analysis of deviance test to assess statistical significance of variables, using an α of 0.05 for all hypothesis tests in this study.

3. Results

Fire rate of spread (ROS) was lower after all cutting scenarios relative to pre-cutting (Dunnett's test, all *p*-values < 0.002). ROS averaged 0.67 m s^{-1} before cutting, and from 0.48 m s^{-1} to 0.53 m s^{-1} across cutting scenarios. There was a significant main effect between cuttings (Analysis of deviance, χ^2(df = 5) = 24.6, $p < .001$). Further, while there was no trend with respect to residual basal area (Analysis of deviance, χ^2(df = 1) = 3.4, $p = .064$), we found that the differences between cuttings increased with lower residual basal area (Analysis of deviance, χ^2(df = 5) = 13.9, $p = .016$; Figure 2a). At the highest basal area, pairwise comparisons tests showed that ROS was not different between cutting scenarios, averaging 0.51 m s^{-1}. But when thinning to 5 m^2 ha^{-1}, ROS decreased to 0.47 m s^{-1} within distance-based and random cuttings. Meanwhile, ROS increased to 0.54 m s^{-1} after variable retention.

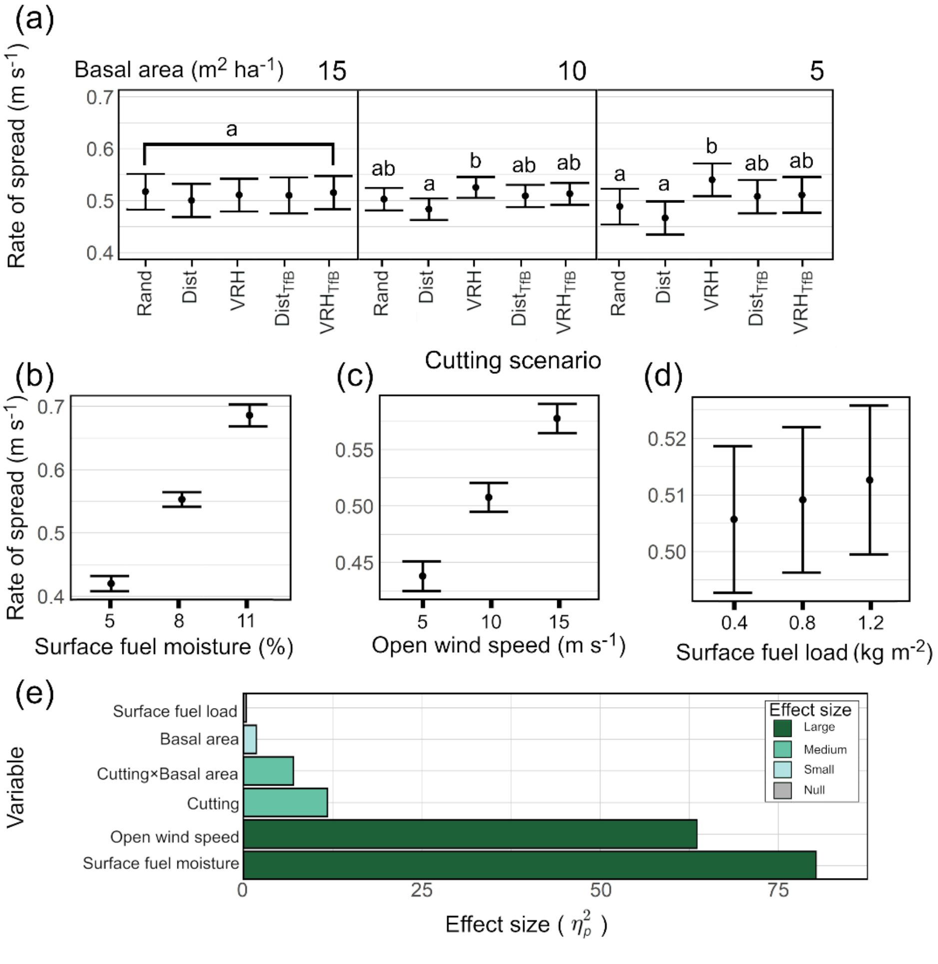

Figure 2- Marginal effects of a) cutting scenario × basal area, b) surface fuel moisture, c) open wind speed, and d) surface fuel load following mixed effects modelling on rate of spread, and e) effect size of variables. Letters indicate significant differences between cuttings using pairwise comparison procedures.

Among the other independent variables, surface fuel moisture most explained ROS (Analysis of deviance, χ^2(df = 1) = 759.9, $p < .001$; Figure 2e), with 0.42 m s^{-1} ROS at 11% surface fuel moisture to 0.69 m s^{-1} ROS at 5% surface fuel moisture (Figure 2b). Meanwhile, ROS ranged from 0.44 to 0.58 m s^{-1} as open wind speed increased from 5 to 15 m s^{-1} (Analysis of deviance, χ^2(df = 1) = 323.1, $p < .001$; Figure 2c). Surface fuel load was the only variable which did not explain variability in ROS (Analysis of deviance, χ^2(df = 1) = 0.8, $p = .381$; Figure 2d).

The percent canopy consumption (CC) averaged 73% before cuttings and significantly dropped to 43% to 54% across cuttings (Dunnett's test, all *p*-values < 0.001). CC did vary between cutting scenarios (Analysis of deviance, χ^2(df = 5) = 65.6, $p < .001$) and explained the most variance alone of any variable (Figure 3a, e). In general, we found that the cuttings including thinning from below had lower CC than those cuttings without any thinning from below; of the latter scenarios, variable retention harvests were the highest. While CC diminished with lower residual basal areas (Analysis of deviance, χ^2(df = 1) = 34.5, $p < .001$), we identified an interaction with cutting scenarios. Specifically, the spread in CC between cutting scenarios was greater with less residual basal area (Analysis of deviance, χ^2(df = 5) = 23.3, $p < .001$).

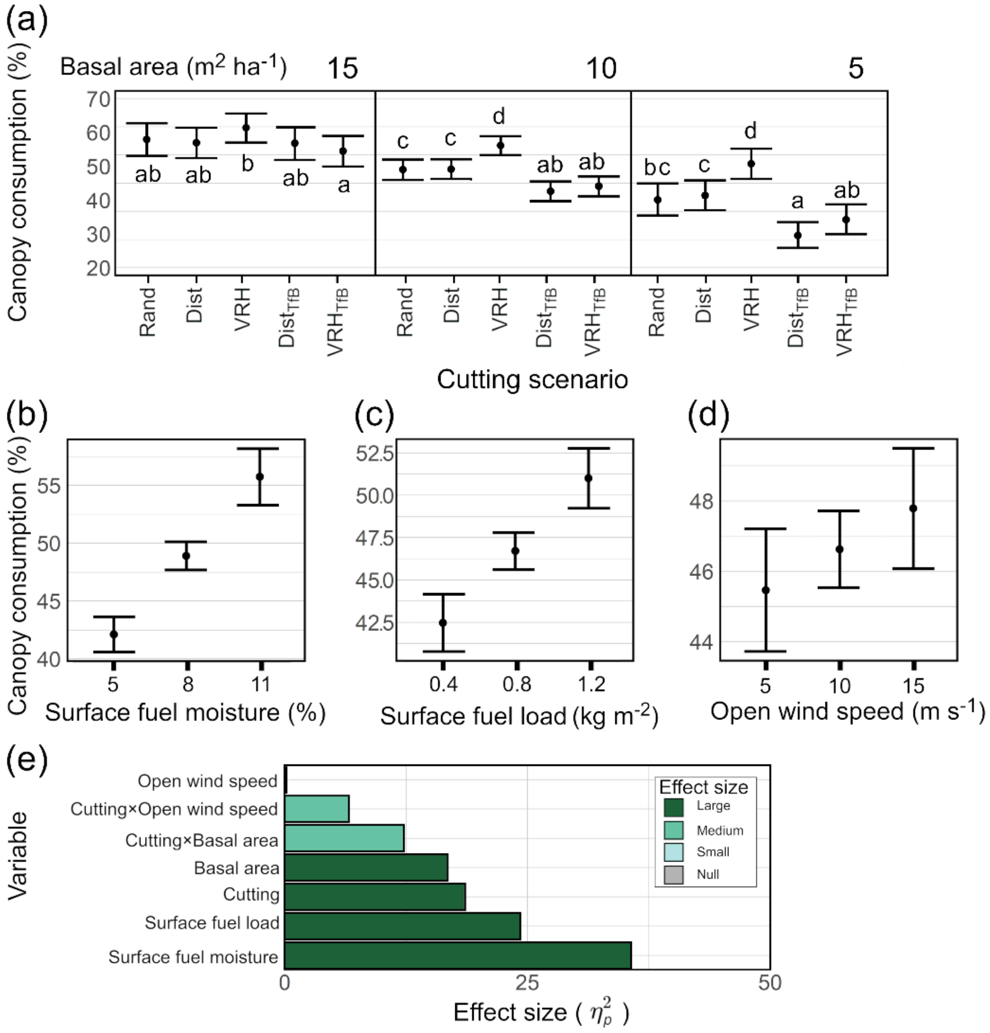

Figure 3- Marginal effects of a) cutting scenario × basal area, b) surface fuel moisture, c) surface fuel load, and d) open wind speed following mixed effects modelling on canopy consumption, and e) effect size of variables. Letters indicate significant differences between cuttings using pairwise comparison procedures.

Surface fuel moisture was the second most important variable (Analysis of deviance, χ^2(df = 1) = 95.7, $p < .001$) as CC rose from 42% to 56% while surface fuel dried (Figure 3b). As surface fuel loads increased from 0.4 to 1.2 kg m^{-2}, CC rose from 42% to 51% (Analysis of deviance, χ^2(df = 1) = 56.4, $p < .001$; Figure 3c). Open wind speed was a significant predictor of CC (Analysis of deviance, χ^2(df = 1) = 4.0, p = .045; Figure 3d), but had only a small effect size (Figure 3e).

4. Discussion

Most notably we found that all cuttings reduced fire behavior relative to pre-cutting scenarios, at all residual basal areas and burning conditions. This gives silviculturalists and fuels managers more opportunity to decide how remnant trees are arranged to realize other objectives. Where forest managers seek to maximize every potential gain in fire haz-ard reduction with few other considerations, our results validate the use of conventional fuels treatments which combine distance-based specifications with thinning from below (Addington et al., 2018; Stephens et al., 2021). We found lower rates of canopy consumption because isolated trees experience greater convective cooling (Ritter et al., 2020) and lower heat fluxes between tree crowns (Contreras et al., 2012) (Figure 4). In contrast, restoration treatments which create both vertical and horizontal heterogeneity in forest structure were less effective at reducing fire behavior; wind entrained in openings pushing fire rate of spread higher, and the retention of both small trees and grouped trees allowed for instances of group torching, resulting in higher canopy consumption (Figure 4). This affirms a trade-off between retention of heterogeneous forest structure and fire hazard reduction (Stephens et al., 2021).

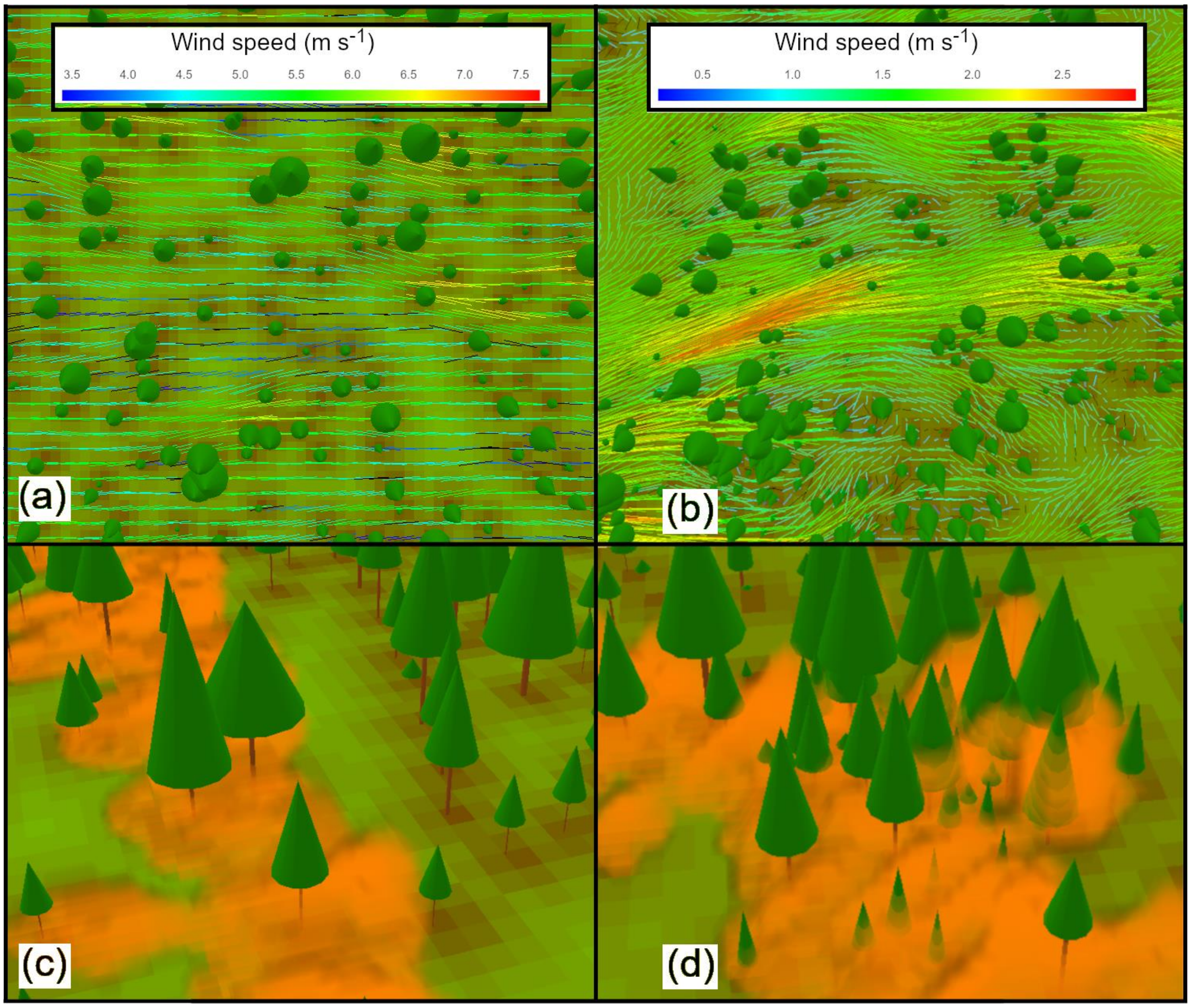

Figure 4- Demonstration of regimes of pre-fire (a) laminar flow with distance-based cuttings and (b) entrainment of wind following variable retention harvest, with wind vectors at 2 m above ground level flowing from left to right. During fire spread, (c) fire passed under large trees after distance-based cutting, while (d) groups torched after variable retention harvest.

Forest managers can close the spread between conventional fuels cuttings and forest restoration. Firstly, silviculturalists can undertake more aggressive reductions in basal area. As reported by Underhill et al. (2014) and Ziegler et al. (2017), recent implementations of restoration treatments in the forests simulated by this study have been retaining a basal area of 10 to 20 m^2 ha^{-1}. In contrast, these forests historically had an average basal area of 6.3 and density of 97 trees ha^{-1} (Battaglia et al., 2018). Forest managers have an opportunity to further reduce residual stocking and potential fire behavior without deviating outside of the range of natural variability and impairing ecosystem functioning. Secondly, some removal of small trees can increase fire behavior reduction; specifically, retaining tree groups without ladder fuels (Churchill et al., 2013) while preserving clusters of smaller, regenerating tree groups (Addington et al., 2018) can reduce the potential for surface-crown fire transition while maintaining younger cohorts of trees.

5. References

Addington, R., Aplet, G., Battaglia, M., Briggs, J., Brown, P., Cheng, A., Dickinson, Y., Feinstein, J.A., Pelz, K., Regan, C., Thinnes, J., Truex, R., Paula, J., Gannon, B., Julian, C., Underhill, J., Wolk, B., 2018. Principles and practices for the restoration of ponderosa pine and dry mixed-conifer forests of the Colorado Front Range. Gen. Tech. Report, RMRS-GTR-373, USDA For. Serv. Rocky Mt. Res. Station. Fort Collins, CO. 121. https://doi.org/10.1093/acprof:oso/9780195310139.003.0002

Agee, J.K., Skinner, C.N., 2005. Basic principles of forest fuel reduction treatments. For. Ecol. Manage. 211, 83–96. https://doi.org/10.1016/j.foreco.2005.01.034

Atkinson, A.C., Donev, A.N., 1992. Optimum Experimental Designs. Oxford University Press.

Banwell, E.M., Varner, J.M., 2014. Structure and composition of forest floor fuels in long-unburned Jeffrey pine-white fir forests of the Lake Tahoe Basin, USA. Int. J. Wildl. Fire 23, 363–372. https://doi.org/10.1071/WF13025

Battaglia, M.A., Gannon, B., Brown, P.M., Fornwalt, P.J., Cheng, A.S., Huckaby, L.S., 2018. Changes in forest structure since 1860 in ponderosa pine dominated forests in the Colorado and Wyoming Front Range, USA. For. Ecol. Manage. 422, 147–160. https://doi.org/10.1016/j.foreco.2018.04.010

Churchill, D.J., Larson, A.J., Dahlgreen, M.C., Franklin, J.F., Hessburg, P.F., Lutz, J.A., 2013. Restoring forest resilience: From reference spatial patterns to silvicultural prescriptions and monitoring. For. Ecol. Manage. 291, 442–457.

Clyatt, K.A., Crotteau, J.S., Schaedel, M.S., Wiggins, H.L., Kelley, H., Churchill, D.J., Larson, A.J., 2016. Historical spatial patterns and contemporary tree mortality in dry mixed-conifer forests. For. Ecol. Manage. 361, 23–37. https://doi.org/10.1016/j.foreco.2015.10.049

Contreras, M.A., Parsons, R.A., Chung, W., 2012. Modeling tree-level fuel connectivity to evaluate the effectiveness of thinning treatments for reducing crown fire potential. For. Ecol. Manage. 264, 134–149. https://doi.org/10.1016/j.foreco.2011.10.001

Fahey, R.T., Alveshere, B.C., Burton, J.I., D'Amato, A.W., Dickinson, Y.L., Keeton, W.S., Kern, C.C., Larson, A.J., Palik, B.J., Puettmann, K.J., Saunders, M.R., Webster, C.R., Atkins, J.W., Gough, C.M., Hardiman, B.S., 2018. Shifting conceptions of complexity in forest management and silviculture. For. Ecol. Manage. 421, 59–71. https://doi.org/10.1016/j.foreco.2018.01.011

Koontz, M.J., North, M.P., Werner, C.M., Fick, S.E., Latimer, A.M., 2020. Local forest structure variability increases resilience to wildfire in dry western U.S. coniferous forests. Ecol. Lett. 23, 483–494. https://doi.org/10.1111/ele.13447

Larson, A.J., Churchill, D., 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. For. Ecol. Manage. 267, 74–92. https://doi.org/10.1016/j.foreco.2011.11.038

Linn, R.R., Sieg, C.H., Hoffman, C.M., Winterkamp, J.L., McMillin, J.D., 2013. Modeling wind fields and fire propagation following bark beetle outbreaks in spatially-heterogeneous pinyon-juniper woodland fuel complexes. Agric. For. Meteorol. 173, 139–153. https://doi.org/10.1016/j.agrformet.2012.11.007

Matonis, M.S., Binkley, D., 2018. Not just about the trees: Key role of mosaic-meadows in restoration of ponderosa pine ecosystems. For. Ecol. Manage. 411, 120–131. https://doi.org/10.1016/j.foreco.2018.01.019

Mell, W., Jenkins, M.A., Gould, J., Cheney, P., A, W.M., B, M.A.J., C, J.G., C, P.C., 2007. A physics-based approach to modelling grassland fires. Int. J. Wildl. Fire 16, 1–22. https://doi.org/10.1071/WF06002

Mueller, E., Mell, W., Simeoni, A., 2014. Large eddy simulation of forest canopy flow for wildland fire modeling. Can. J. For. Res. 44, 1534–1544. https://doi.org/10.1139/cjfr-2014-0184

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., Team, R.C., 2021. {nlme}: Linear and Nonlinear Mixed Effects Models.

Puettmann, K.J., 2011. Approaches, silvicultural challenges and options in the context of global change: "Simple" fixes and opportunities for new management. J. For. https://doi.org/10.3928/01477447-20080901-33

Reinhardt, E.D., Keane, R.E., Calkin, D.E., Cohen, J.D., 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. For. Ecol. Manage. 256, 1997–2006. https://doi.org/10.1016/j.foreco.2008.09.016

Ritter, S.M., Hoffman, C.M., Battaglia, M.A., Stevens-Rumann, C.S., Mell, W.E., 2020. Fine-scale fire patterns mediate forest structure in frequent-fire ecosystems. Ecosphere 11, 1–17. https://doi.org/10.1002/ecs2.3177

Stephens, S.L., Battaglia, M.A., Churchill, D.J., Collins, B.M., Coppoletta, M., Hoffman, C.M., Lydersen, J.M., North, M.P., Parsons, R.A., Ritter, S.M., Stevens, J.T., 2021. Forest restoration and fuels reduction: Convergent or divergent? Bioscience 71, 85–101. https://doi.org/10.1093/biosci/biaa134

Tinkham, W.T., Dickinson, Y., Hoffman, C.M., Battaglia, M.A., Ex, S., Underhill, J., 2017. Visualization of heterogeneous forest structures following treatment in the Southern Rocky Mountains. Gen. Tech. Report, RMRS-GTR-365, USDA For. Serv. Rocky Mt. Res. Station. Fort Collins, CO.

Tuten, M.C., Sánchez Meador, A., Fulé, P.Z., 2015. Ecological restoration and fine-scale forest structure regulation in southwestern ponderosa pine forests. For. Ecol. Manage. 348, 57–67. https://doi.org/10.1016/j.foreco.2015.03.032

Underhill, J.L., Dickinson, Y., Rudney, A., Thinnes, J., 2014. Silviculture of the Colorado Front Range Landscape Restoration Initiative. J. For. 112, 484–493. https://doi.org/10.5849/jof.13-092

Wheeler, B., 2019. AlgDesign: Algorithmic Experimental Design.

Zenner, E.K., Hibbs, D.E., 2000. A new method for modeling the heterogeneity of forest structure. For. Ecol. Manage. 129, 75–87.

Ziegler, J.P., Hoffman, C., Battaglia, M., Mell, W., 2017. Spatially explicit measurements of forest structure and fire behavior following restoration treatments in dry forests. For. Ecol. Manage. 386, 1–12. https://doi.org/10.1016/j.foreco.2016.12.002

Ziegler, J.P., Hoffman, C.M., Collins, B.M., Knapp, E.E., Mell, W., 2021. Pyric tree spatial patterning interactions in historical and contemporary mixed conifer forests, California, USA. Ecol. Evol. 11, 820–834. https://doi.org/10.1002/ece3.7084

Ziegler, J.P., Hoffman, C.M., Collins, B.M., Long, J.W., Dagley, C.M., Mell, W., 2020. Simulated fire behavior and fine-scale forest structure following conifer removal in aspen-conifer forests in the Lake Tahoe Basin, USA. Fire 3, 1–16. https://doi.org/10.3390/fire3030051