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Does Private Forest Land Management Result in Higher Burn Severity from Wildfires in Timberlands of the Pacific States?

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Abstract

There are many pressing scientific questions surrounding the topic of whether forest management has resulted in higher burn severity from recent wildfires in timberlands of the Pacific states. Using burn severity maps from Landsat satellite imagery, zonal statistics in QGIS were used to summarize and compare the attributes (mean, median, variance, range) of burn severity classes within two zones for each fire: the privately managed forest area and a surrounding control (largely unmanaged forested area). We analyzed 100 individual managed forest areas across the Pacific states with a total of 800 privately owned management units. Comparison of the burned severity class by individual managed forest area showed that 42% of these timberlands burned at significantly lower severity ($p < 0.05$) than their surrounding (unmanaged) buffer zones in large wildfires between 2013 and 2022. In addition, 30% of managed forest lands were not significantly different from their unmanaged buffer zones in burn severity. Landsat normalized difference moisture index (NDMI) clearly shows recent clear-cuts, fire scars, and thinning management in every case we examined, eliminating the possibility of underestimating or overlooking timber management activities in control buffer zones. The highest burn severity did occur in landscapes where extremely high levels of pre-fire live forest biomass remained in large patches around equally large and thinned or logged forest areas. We conclude that this type of mixed-age management plan may create a potentially explosive fuel-loading status in a forest, whereby wildfire can be readily carried by high winds from dense fuel areas (not recently thinned or managed) over and around patches of low biomass stands that have been recently thinned and logged.

Keywords

Forest Management, Wildfire, Landsat, Thinning, Logging

1. Introduction

In the Pacific states of California, Oregon and Washington (USA), numerous wildfires over the past decade have caused extensive forest loss and hundreds of billions of dollars in damage to infrastructure (Hsiang et al., 2017; NOAA, 2023; Potter et al., 2024). Although fire on the land has shaped the ecology of western North America for millennia, whether ignited by lightning or by humans, wildfires have increased in size, severity, and frequency in most western forests of North America over the last three decades (Westerling, 2016; Singleton et al., 2019). One cause of this trend is that historical fire suppression has increased fuel loads in forests of the western United States (McKelvey & Johnston, 1992; Ansley & Battles, 1998). Forest ecosystems of the west have also become more structurally homogenous, making them more vulnerable to high intensity wildfire and damage by bark beetles (Fettig, 2012).

High winds and lightning storms are catalyzing large pyro-convective fire events that spread to developed areas and consume hundreds of buildings and vehicles, despite local fire-fighting efforts within and around them (Zhang et al., 2019b; MacDonald et al., 2023). Such wildfire complexes can quickly spread over large landscapes, regardless of forest structure and density, and, in some cases, burn thousands of acres in just a few days. Balch et al. (2024) reported from satellite data analysis of more than 60,000 fires across the contiguous U. S. that the daily growth rates more than doubled in the western states from 2001 to 2020. Nearly half of the U. S. experienced destructive wildfires since the year 2000 that grew more than 1,620 hectares in a single day.

Forest regrowth patterns of western forests are changing as well. A dataset of post-fire conifer regeneration from 10,230 field plots in the western region of the United States was compiled by Davis et al. (2023) and these authors reported that warmer, drier climate conditions are leading to lower tree regeneration after wildfires in the past decade, compared to the decades of the 1980s and 1990s. This study quantified the importance of fire-caused tree mortality, which limits seeds available for tree regeneration during warming, drying climate conditions. Lower elevation tree species (e.g., *Pinus ponderosa*) have already experienced a significant decline in recruitment probability between the 1981 to 2000 and the 2001 to 2020 time periods, while higher elevation species such as *P. contorta* and *P. engelmannii* were predicted to experience more declines in the coming decades following wildfires.

Tree thinning in managed timberlands is often used with the intention of reducing fire risk and lowering wildfire severity (Stone et al., 2003). Thinning of tree plantations is used to reduce the basal area (BA) of forest stands, commonly from BA levels greater than 50 $m^2\ ha^{-1}$ down to lower than 20 $m^2\ ha^{-1}$. Selective removal of trees allows the remaining ones to grow larger and healthier (lower mortality rates and higher individual tree-level growth) with less competition for resources like sunlight and water (Zhang et al., 2019a and 2019b). When fire weather is not extreme (relatively cool temperatures and low wind speeds), thinning of small diameter trees followed by prescribed fire, and in some cases, controlled burns alone, can reduce fire severity in certain forest types for a limited period of time (Kalies & Kent, 2016). In a comprehensive literature review, Schoennagel et al. (2017) concluded that fuels treatments that remove midstory and understory fuels through thinning and prescribed fire can reduce fire intensity, severity, and rate of spread and may promote adaptive resilience to more frequent fire in the western United States.

Other recent studies of note include those by Zald and Dunn (2018) who reported on the 2013 Douglas Complex Fire that burned over 19,000 ha of Oregon & California Railroad (O & C) lands in southwestern Oregon. Using Random Forest ensemble machine learning, these authors found that daily fire weather was the most important predictor of fire severity, followed by stand age, land ownership, and topographic features. Estimates of pre-fire forest biomass were not an important predictor of fire severity. Similarly, Cansler and Mckenzie (2014) reported that weather conditions (wind speeds, relative humidity, dryness, and air temperature) at the time of fire ignition and throughout the period of wildfire burning were the primary controllers of the rate and direction of fire spread in the northern Cascade Range.

From a divergent perspective on the negative environmental aspects of intensive logging in western forests over the past several decades, Hanson (2010, 2021) and Levine et al. (2022) have attempted to refute the narrative that forest management limits the severity of wildfire burning over timberlands and helps reduce the amount of carbon released into the atmosphere in the event of a major wildfire. This viewpoint asserts that numerous large trees often survive high severity burning in western wildfires, and that tree growth in these stands tends to increase substantially after the fire, which converts decomposing woody material on the forest floor into highly usable nutrients for tree growth. Hansen (2010) further claimed that vigorous natural regeneration of conifer seedlings occurs after high-severity fire and that patches of high-severity burning (where most or all trees are killed) support the highest levels of native biodiversity of any forest type in western U.S. conifer forests, including many rare and imperiled species that live only in high severity burned patches.

Additionally, Hanson (2021) contends that thinned forests often burn more intensely in wildland fires, mainly because thinning reduces the windbreak effect of denser (unmanaged) forests, allowing winds to sweep through more rapidly, while also having previously reduced the shade of the forest canopy and creating hotter and drier conditions on the ground. Any actual empirical evidence for this assertion of a reduced windbreak effect in managed forest stands has not yet been offered by Hanson (2021).

It should be noted that our study results have been supported by a well-conceived scientific design and by a robust statistical methodology to account for the spatial configuration of forest management treatments (within the context of topography), patterns of pre-fire biomass fire fuels from satellite remote sensing, and the influence of daily weather conditions (wind speeds, relative humidity, dryness, and air temperature) at the time of fire ignition and throughout the period of spread. Furthermore, the intent of this study was to go far beyond the notion of land ownership as a simple proxy for forest management. Our results include numerous case studies of recent large wildfires on a mosaic of privately owned and managed timberlands and largely unmanaged adjacent forest lands wherein satellite images have been analyzed to provide detailed visual insights into actual management activities that have occurred prior to severe wildfires in the study area. Although understory fuel treatments and prescribed burning are not easily detectable from satellite image analysis, clear-cutting and mechanical stand thinning can be visualized and mapped on managed forest lands from the methods described in this study.

Given the conflicting viewpoints about the effects on forest management (public or private) on fire burn severity, the following specific and well-defined research questions were addressed in this study for the largest wildfires in the Pacific states over the past decade:

- Does the thinning and selective harvest of trees in privately owned and managed timberlands reduce biomass fuel loads (aboveground and forest floor)?
- Does the thinning and selective harvest of trees in privately owned and managed timberlands significantly increase the severity (from relatively low to high) of wildfire burning?

2. Materials and Methods

Polygons of large wildfire boundaries that burned in the Pacific states from 2012 to 2022 were obtained from the Monitoring Trends in Burn Severity project (mtbs.gov), along with burn severity class maps (also from mtbs.gov), all of which are based primarily on Landsat multi-spectral imagery. We selected the largest fires in the recent MTBS record to assure that a high number of 30 m Landsat pixels would be available to out analysis formulations to support robust statistical tests of differences. Consequently, a large data set was selected, but without any other sampling bias in the fires analyzed.

The Normalized Difference Moisture Index (NDMI), a closely related index to the one used by the MTBS from the Landsat satellite (the Normalized Burn Ratio—NBR; Miller & Thode, 2007), was used to further quantify changes in vegetation density and soil cover at a 30 m pixels resolution in the years before and after a wildfire incident. Landsat NDMI is computed from the equation:

$$\text{NDMI} = (\text{NIR} - \text{SWIR})/(\text{NIR} + \text{SWIR})$$

where NIR is the near-infrared band and SWIR is the short-wave infrared band. Healthy, dense vegetation biomass has a high reflection of NIR energy and strongly absorbs SWIR energy, resulting in high NDMI values. Increasing removal of vegetation cover by mechanical forest thinning or fire and the exposure of the bare soil surface results in relatively low NDMI values near zero (Miller & Thode, 2007; Campbell et al., 2021).

By using pre-fire NDMI as a fire fuel surrogate, our methodology effectively accounts for differences in slope, aspect, vegetation type, microclimate, elevation, and past disturbance history that determine biomass fuel loads in both privately-owned timberlands and forested buffer zones surrounding them. Using machine learning prediction methods, Castillo et al. (2024), much like Povak et al. (2025), showed that Landsat NDMI was strongly correlated ($R^2 = 0.67$) with forest biomass in stands that had not burned over the past 50 years in California, Oregon, and Washington. The measured forest biomass map used to train this Random Forest regression model by Castillo et al. (2024) was developed by the United States Forest Service (USFS) at 30 m resolution from forest inventory data compilations (Blackard et al., 2008; Menlove & Healey, 2020). Specifically, the SciKit-Learn Python package was used by Castillo et al. (2024) to run a series of hyperparameter tuning sequences on it using the Randomized Search Cross Validation class which tested multiple combinations of parameters (including pre-fire Landsat NDMI, forest stand age, and long-term precipitation normals) while fitting the regressor model to the mapped datasets.

For the wildfire impact maps we have used, the MTBS program carries out burn severity classifications based in part on analyst interpretation. The analyst evaluates the dNBR data range and determines where significant thresholds exist in the data to discriminate between burn severity classes, aided by the pre-fire and post-fire imagery, and analyst experience with fire behavior and effects in a given ecological setting. Where available, high-resolution imagery is visually inspected to provide confidence in selecting the burn severity thresholds. The resulting MTBS burn severity class layers for each year are thematic raster images depicting four burn classes as 1 = unburned, 2 = low, 3 = moderate, and 4 = high severity (Whittier & Gray, 2016).

Figure 1. Locations of the largest wildfires since the year 2013 that have burned into tracts of privately owned timberlands in the Pacific states (Fire boundaries were derived from the MTBS database).

Each of the MTBS wildfire polygons from 2013 to 2022 was overlaid in the software package QGIS on maps of private forest land (**Figure 1**) that were derived from ForestOwn_v1 (Nelson et al. 2010), a 250 m resolution raster dataset of forest ownership in the conterminous United States (CONUS). This dataset was prepared by the Forest Inventory and Analysis (FIA) program of the United States Department of Agriculture (USDA), and differentiates forest from non-forest land and water, public and private ownership, and the percent of private forest land in corporate ownership. Public and private land ownership class is derived from the Protected Areas Database of the United States (USGS, 2024). Corporate ownership of private forest land is derived from the USFS Resource Planning Act (RPA) dataset. To create non-privately owned forest land cover areas as "control" buffer zones, we generated bounding polygons in the software package QGIS of 2 km distance around each managed forest polygon that had burned in a wildfire between 2013 and 2022.

All privately owned managed forest units that fell with a (potentially overlapping) control buffer zone area were excluded from burn severity summary statistics for that non-privately owned control area. We used these control buffer zone areas to statistically compare the mean Landsat NDMI and MTBS burn severity class estimates to the same estimates from the treated forest areas within the managed forest unit polygons. However, the actual forest treatment (s) that have been carried out before wildfire in any of these privately owned managed forest units have never been disclosed to the public nor to researchers, and remains proprietary information owned by the private forest companies. Nonetheless, it can safely be assumed from the pre-fire Landsat images in the figures published in this paper of several large burned areas that small clear-cut treatments were scattered across the managed forest units, along with thinned forest stands with relatively low NDMI readily apparent across much of the privately owned forest lands.

Although weather conditions (wind speeds, relative humidity, dryness, and air temperature) at the time of fire ignition and throughout the period of burning must be acknowledged as important controllers of the rate and direction of fire spread (Cansler & Mckenzie, 2014; Parks et al., 2018; MacDonald et al., 2023, Povak et al., 2025), our methodology of pairing each private forest landholding polygon with its adjacent non-privately owned buffer zones to 2 km distance around each managed forest polygon effectively controlled for daily fire weather conditions in our analysis. Because of the close spatial proximity of each managed-to-control polygon pair, any differences in daily weather conditions could be assumed to be negligible.

Zonal statistics in QGIS were used to summarize the statistical attributes (mean, median, variance, range) of a raster layer (such as burn severity classes or NDMI values) within the zones of another dataset (polygon layer), such as the managed forest area. To determine the level of significant difference (if any) in burn severity class distribution between individual managed forest areas and control (unmanaged) buffer zones that burned in wildfires since 2012, t-tests were performed using the mean and standard deviation computed as zonal statistics from QGIS. A two-sample t-test (Rice, 2006) was carried out to evaluate the null hypothesis that the means of two populations were equal in the paired burned areas (managed forest areas versus their control buffer zones).

3. Results

The U. S. Forest Service (USFS) and the National Park Service own and help manage 60% of the forested lands in California (CRS, 2020). The remaining 40% is privately owned; two-thirds of which are held by families, individuals, and tribes, and the remaining one-third is owned by industrial timber companies. The Oregon Department of Forestry (ODF) and the USFS help manage approximately 64% of all forestlands in Oregon (CRS, 2020). Private landowners in Oregon manage 34% of the state's forests and the remaining 2% of forest land is managed under tribal ownership. In the state of Washington, 63% of the forested land is under public ownership and management (44% by the USFS), whereas 37% of forest land is privately owned (Palmer et al., 2019). The extent of the largest wildfires since the year 2012 that have burned into tracts of privately owned timberlands are shown in **Figure 1** for these three states.

Totaled on a regional basis over all three Pacific states, managed forest areas were found to have a lower percentage of class 3 and 4 severely burned areas (to total burned area) than the unmanaged buffer zone areas surrounding them (**Figure 2**). To more closely examine change over time, this comparison was divided into burn severity results from wildfires that occurred between 2013 to 2018 and those that burned between 2019 to 2022 (**Figure 3**). The unmanaged buffer zone areas showed 46% low severity (class 2) and 10% high severity burn (class 4) in wildfires from 2013 to 2018, compared to 44% low severity and 5% high severity burn area in the managed forest areas. For wildfires from 2019 to 2022, the differences were greater, as unmanaged buffer zone areas showed 40% low severity (class 2) and 15% high severity burn (class 4), compared to 51% low severity and 3% high severity burn area in the managed forest areas.

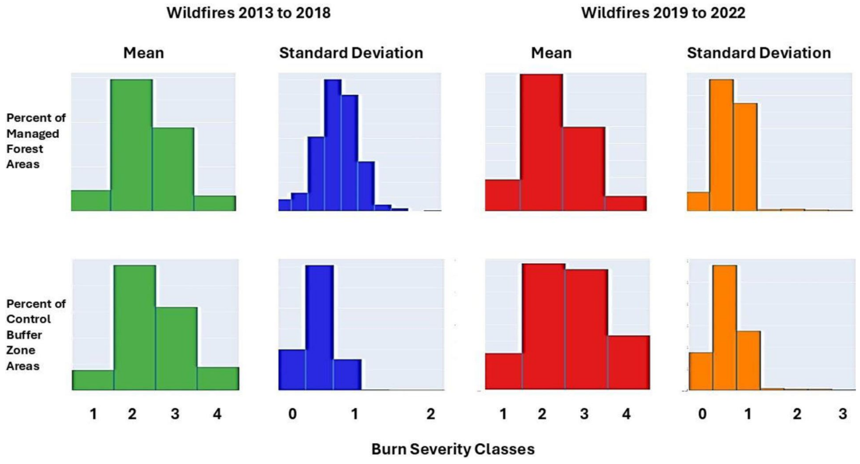


Figure 2. Histograms for the percentage of area in MTBS burn severity classes from wildfires since 2013 for managed forest areas and their unmanaged buffer zone areas surrounding them in the Pacific states.

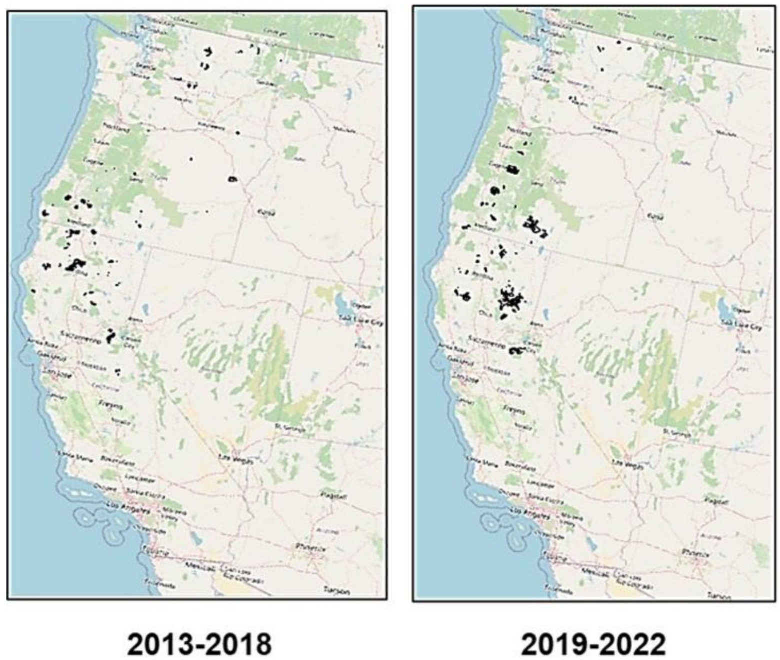


Figure 3. Boundaries of wildfires that occurred between 2013 to 2018 and those that burned between 2019 to 2022 into privately owned forest stands in the Pacific states (Wildfire boundaries were generated by the MTBS program.).

Variability in burn severity classes was higher in managed forest areas compared to unmanaged buffer zone areas (**Figure 2**). During both time periods (2013 to 2018 and 2019 to 2022), the standard deviation within managed forest areas was more frequently estimated at greater than one burn severity class, compared to unmanaged buffer zone areas with a notably lower distribution of standard deviation values in burn severity.

Comparison of burned severity classes in and around 100 individual managed forest areas (**Figure 1**) across the Pacific states (with a total of 800 privately owned management units) showed that 43% of these timberland units burned at significantly lower severity ($p < 0.05$; two-sample t-test) than their surrounding (unmanaged) buffer zones in large wildfires between 2013 and 2022. In addition, 23% of managed forest lands were not significantly different in mean burn severity from their unmanaged buffer zones. Less than 35% of the managed areas burned at significantly higher mean severity ($p < 0.05$) than their surrounding buffer zones.

Closer examination of several major wildfires that recently burned across extensive tracts of privately owned forest management units was carried out next to illustrate the spatial patterns of burn severity outcomes and the contrast of timber management practices within privately owned lands and their adjacent control buffer zones. While understory fuel treatments and prescribed burning are not readily visible from satellite image analysis, clear-cutting and mechanical stand thinning can be visualized and mapped on forest lands from pre-fire NDMI maps and their corresponding MTBS burn severity class maps.

Starting with the 167,335 ha (413,496 acres) Bootleg Fire in southern Oregon that began on July 6, 2021, our comparison of privately owned and managed forest lands with post-fire burn severity mapping (**Figure 4(a)**) showed that most high burn severity areas were located in the control buffer zones surrounding privately owned and managed forest lands. On the whole, most privately owned forest units burned at significantly ($p < 0.001$; two-sample t-test) lower severity than their surrounding control buffer zones in the Bootleg Fire, nearly all of which were heavily forest stands of the Fremont-Winema National Forest. None of these areas in the surrounding control buffer zones showed signs of forest thinning or clearcutting in pre-fire Landsat NDMI images, but nearly all of these dense forest stands in the National Forest control areas were lost to high severity burning according to the MTBS mapping.

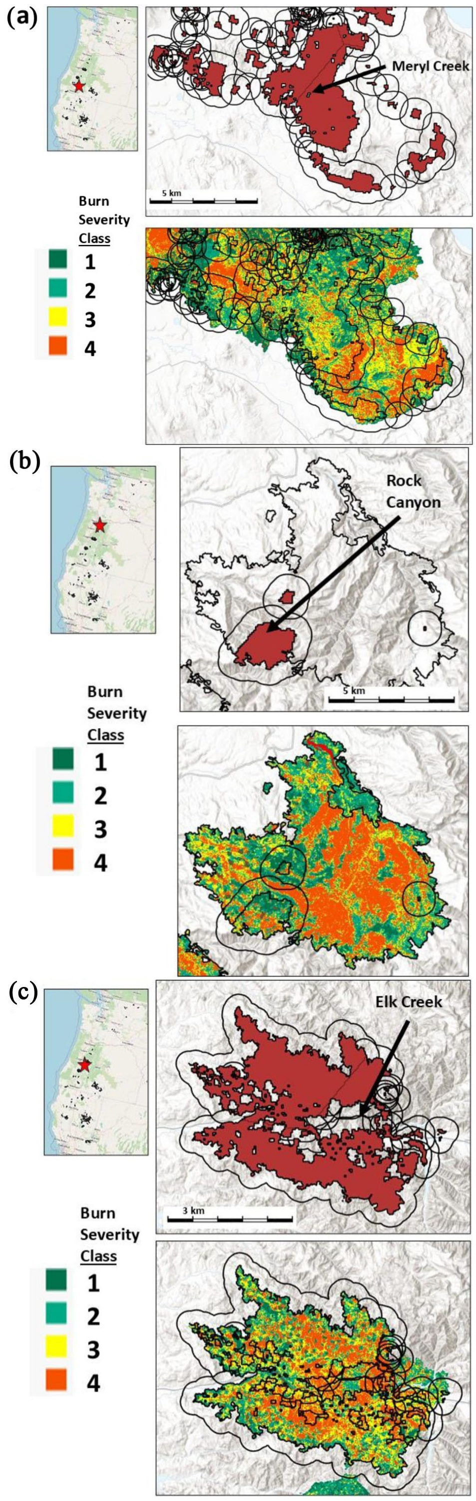
The 55,924 ha (138,190 acres) Riverside Fire in northern Oregon burned over privately owned industrial timberland (30% of the total burned area) and on the Clackamas River watershed in the Mt. Hood National Forest (70% of the total burned area) in 2020 (**Figure 4(b)**). A small fire was reported near Riverside Campground in the early morning hours of September 8, 2020, and was spread rapidly by high winds, growing to over 45,324 ha (112,000 acres) within 30 hours. Pre-fire biomass fuel loads in control buffer zone forest areas, nearly all contained within the Mt. Hood National Forest boundary, were typically between 120 and 130 Mg ha^{-1} (USFS, 2018) and showed no signs of recent thinning or logging in pre-fire NDMI images, whereas fuel loads were generally lower than 60 Mg ha^{-1} in the industrial timberland that were burned over in 2020 (USFS, 2018). Within the privately owned forest lands, thinning and logging patches, each smaller than 75 ha in area cover, were easily identified in pre-fire NDMI images and were shown to have burned in 2020 as low burn severity patches in MTBS maps. Fire burn severity mapping (**Figure 4(b)**) showed that most high burn severity areas were located in the control buffer zones of the Mt. Hood National Forest surrounding privately owned and managed forest lands in the Rock Canyon and Cougar Creek drainages. Numerous privately owned forest units burned at significantly ($p < 0.001$; two-sample t-test) lower severity than their surrounding control buffer zones of the Riverside Fire.

The 70,170 ha (173,393 acres) Holiday Farm Fire in central Oregon burned mainly over industrially managed timberlands in the McKenzie River valley in September of 2020 (**Figure 4(c)**). Pre-fire biomass fuel loads in unmanaged buffer zone forest areas in the Willamette National Forest along Elk Creek were typically between 130 and 150 Mg ha^{-1}, whereas pre-fire fuel loads were generally lower than 50 Mg ha^{-1} in the industrial timberlands that burned in 2020 (USFS, 2018). Fire burn severity mapping (**Figure 4(c)**) showed that most high burn severity areas were located in the unmanaged buffer zones surrounding managed forest lands in the Elk and Martin Creek drainages. Privately owned forest units burned at significantly ($p < 0.001$; two-sample t-test) lower severity than their adjacent control buffer zones in the Holiday Farm Fire. A patchwork of small clearcuts, each typically no more than 30 ha in area coverage on privately owned forest lands, were burned over on the western sections of the Holiday Farm Fire perimeter and practically all of these patches showed a low burn severity classification in the MTBS map. In contrast, nearly all of the control buffer zones adjacent to these privately owned timberlands, which are part of the Willamette National Forest, showed no signs of thinning or clear-cutting from pre-fire NDMI images, but were destroyed almost completely at high burn severity in the Holiday Farm Fire.

The Caldor Fire burned 89,773 ha (221,835 acres) in the Sierra Nevada counties of El Dorado, Amador, and Alpine, starting on August 14, 2021 near the community of Grizzly Flats (**Figure 4(d)**). Extremely high wind gusts (>35 mph) and heavy biomass fuel loads (between 80 and 120 Mg ha^{-1}; USFS, 2018) in the largely un-thinned or logged El Dorado National Forest stands south of Pollack Pines resulted in high burn severity and complete loss of most trees across 28,500 ha of timberlands during the first days of the Caldor fire storm. Embers were being cast up to 1.6 km out from the fire front and creating new ignition points in dense forest stands that had not burned since 1940.

El Dorado National Forest land across the western portion of the fire that burned at high severity in August 2021 was managed primarily by the USFS (Baker & Hanson, 2022) and showed signs of selected logging in approximated 30 small forest stands of between 200 - 300 ha that we could identify in pre-fire NMDI images. All of these selective logging stands on the public National Forest lands burned at the Low Severity MTBS class level (**Figure 4(d)**), compared to the unthinned and unlogged control buffer zones of heavily timbered, steep mountain slopes on El Dorado National Forest, which all burned at Moderate to High Severity MTBS class levels in 2021. For the following days of the Caldor Fire (after August 16, 2021) our burn severity analysis of the progression of the Caldor Fire to the east, into drainages of the north fork of the Cosumnes River and over Alder Ridge to the south fork of the American River, showed that it passed through numerous large, privately owned forest units which also burned at significantly ($p < 0.01$; two-sample t-test) lower severity than their surrounding control buffer zones of heavily timbered national forest lands (**Figure 4(d)**).

The 2021 Dixie Fire in northern California began in the Feather River Canyon near Cresta Dam in Butte County on July 13, 2021 when a weakened tree fell onto power lines. The fire burned 89,837 ha (963,309 acres) on the Lassen and Plumas National Forest timberlands before it was declared 100% contained on October 25, 2021 (**Figure 4(e)**). Collins Pine Co. has stated that the Dixie Fire burned across 55,000 acres of Sierra Nevada timberland that were being managed like natural forests with protected habitat and trees of all ages, killing an estimated 65,000 old-growth trees. Logged areas seen in the Landsat NDMI imagery for these approximately 50 timber company stands were typically between 200 - 300 ha in size. Our burn severity analysis of the Dixie Fire showed that it passed through numerous privately owned forest units north of Lake Amador which were burned at significantly ($p < 0.01$; two-sample t-test) lower severity than their surrounding control buffer zones on National Forest lands (**Figure 4(e)**). These adjacent control buffer areas within the Lassen National Forest (that we paired with and compared to burn severity patterns on privately owned forest units) showed a mix of relatively low standing biomass, ridgetop tree stands and heavier forested valleys, a minority of which showed patterns of tree harvest or thinning and most of which that burned at Moderate to High Severity MTBS class levels in 2021.



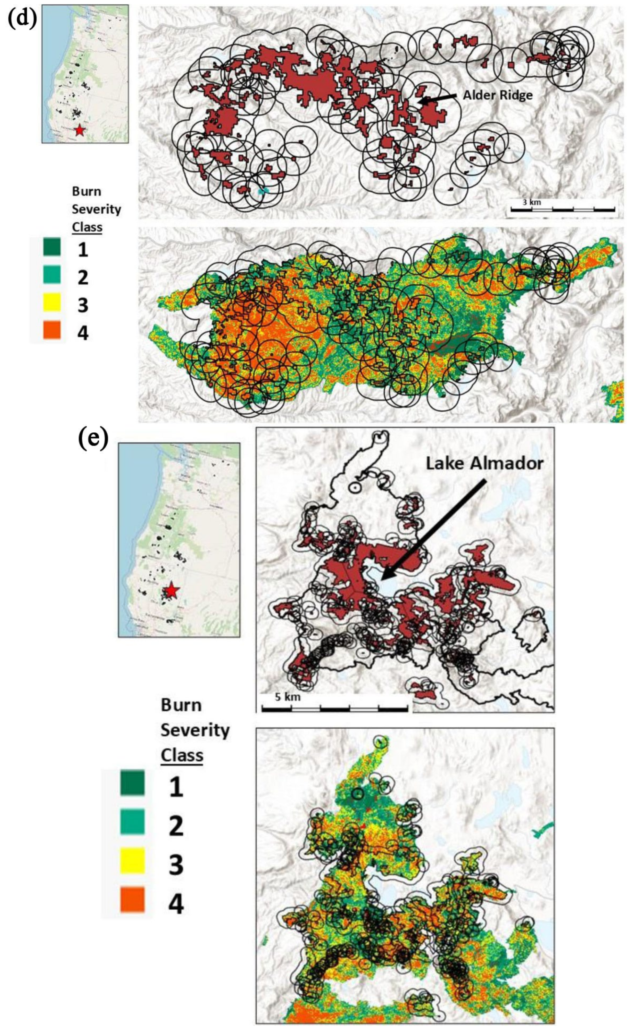


Figure 4. Maps of major wildfires that recently burned across extensive tracts of privately owned forest management units to illustrate the spatial patterns of burn severity outcomes (a) Bootleg Fire (b) Riverside Fire (c) Holiday Farm Fire (d) Caldor Fire (e) Dixie Fire. All maps are oriented with north at the top (Wildfire boundaries were provided by the MTBS database; Privately-owned lands were shaded in red in each of the top panels for each fire incident).

At the opposite end of the burn severity spectrum from the examples presented for managed forest areas which burned at significantly lower severity than their surrounding unmanaged forest buffer zones, we next examined those privately owned forest units that were within wildfire perimeters (2013 to 2022) and had the highest burn severity ranking, all (on average) greater than class 3 (moderate). Comparisons of these severely burned managed areas were made to characterize the pre-fire forest landscape in terms of standing biomass levels and the mosaic of fuel loads within and surrounding each managed forest unit. To do so, we examined the pre-fire Landsat NDMI images for the largest (>250 ha) privately owned and managed areas that had the highest post-fire mean burn severity classification (>3.5) from wildfires over the period 2013 to 2022. Results showed that each of these high burn severity managed areas had extensive coverage of heavily wooded stands, apparently unthinned for decades, with extremely high pre-fire NDMI values (>3000) representing dense forest growth and standing fuels (Campbell et al., 2021), adjacent to or surrounding equally large thinned or logged forest patches with pre-fire NDMI values < 1000 (**Figure 5**). In the case of the Archie Creek Fire (2020), the Caldor Fire (2021) and the Haypress Fire (2021) examples, these severely burned managed forest units were dominated by high pre-fire NDMI values (>3000). In the case of the North Complex Fire (2020) and the Dixie Fire (2021) examples, these severely burned managed forest units were covered by a mosaic of high pre-fire NDMI values (>3000) and low pre-fire NDMI values (<1000).

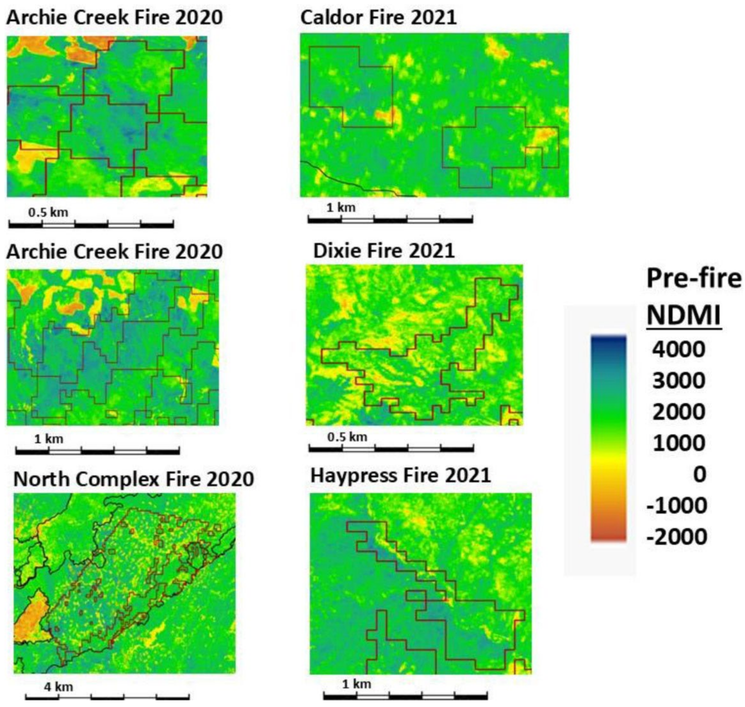


Figure 5. Pre-fire Landsat NDMI images for the largest (>250 ha) privately owned and managed areas with the highest MTBS mean burn severity classification (>3.5) from wildfires over the period 2013 to 2022.

4. Discussion

The main finding from this comparison of the burned severity patterns in and around 100 individual managed forest areas across the Pacific states (hosting a total of 800 privately owned management units) showed that nearly 45% of these timberland units burned at significantly lower severity than their surrounding unmanaged forest areas in large wildfires between 2013 and 2022, whereas 23% of managed forest lands were not significantly different in mean burn severity from their surrounding, largely unmanaged, forest areas. This means that fewer than 35% of the privately owned and managed forest areas burned at significantly higher mean severity than their surrounding unmanaged forest zones. Mostly unharvested control forest areas overall had 10% high severity burn (class 4, as a percentage all burn severity classes) area in wildfires from 2013 to 2018 compared to 5% high severity burn area in the managed forest areas, and for wildfires from 2019 to 2022, the difference was even greater, as surrounding USFS National Forest stands overall showed 15% high severity burn (class 4), compared to only 3% high severity burn area in privately owned and managed forest areas. These findings were statistically significant despite the fact that industrial forest management activities are often carried out to optimize economic returns and maximize merchantable timber.

It is noteworthy that our general findings were strongly supported by those of Povak et al. (2025), who reported that the Landsat NMDI was the most reliable indicator of live fuel loading and moisture levels, and was a leading predictor of fire severity for both first-entry fires and reburns in an analysis of 17 large wildfires that burned in central Washington during 2014 and 2015. NDMI values < 0 (i.e., low biomass) were associated with reduced fire severity, while values > 0.25 (i.e., high biomass) were associated with increased severity. In general, these authors further reported that forest management was effective in controlling burn severity levels across a variety of conditions, especially under low to moderate wind speeds (<17 m s^{-1}), and where canopy base heights were ≥ 1.3 m.

Nevertheless, it must be recognized that fire weather conditions (wind speeds, relative humidity, dryness, and air temperature) throughout the period of wildfire burning are critical controllers of the rate and direction of fire spread (Cansler & Mckenzie, 2014; Parks et al., 2018; MacDonald et al., 2023). However, our methodology of pairing each private forest unit polygon with its adjacent non-privately owned forest buffer zones to 2 km distance fundamentally controlled for daily fire weather conditions in our analysis. There was such a close spatial proximity of each managed-to-control polygon pair that any local geographic differences in daily weather conditions could be assumed to be unimportant in the statistical test results we have reported.

Nonetheless, the main findings from our study results must be seen as contradictory to the assertions of Hanson (2010, 2021) that forest harvest and thinning in the western U. S. fails to limit the severity of wildfire burning over timberlands and thereby augments the amount of carbon released into the atmosphere in the event of a major wildfire. On the contrary, our analysis supports that supposition that thinned forests generally have lower biomass fuel loads and burn less intensely in wildland fires than unthinned stands, regardless of any effect that dense, largely unmanaged forest may have on slowing wind speeds or shading by the closed forest canopy to mitigate hotter and drier conditions at the soil surface.

Numerous case studies presented in our results illustrated these findings and the validity of our "private managed timber units versus control buffer zone" analysis methodology for the largest and most destructive recent wildfires in the study area. For instance, the Bootleg Fire burned through areas where the USFS and Klamath Tribes had thinned the forest and set controlled fires. The USFS manages most of the Fremont-Winema National Forest, where many of the wooded stands had not been thinned or logged recently, before 2021 wildfires started, as we confirmed by pre-fire Landsat NDMI map inspections. However, the Black Hills region that burned in the Bootleg Fire had received small-scale thinning and prescribed fire treatments and showed higher tree survival rates (Friedman, 2021).

Another area that received thinning treatments before the Bootleg Fire occurred was the Sycan Marsh Preserve in the upper Klamath Basin. Its 4,713 forested acres are owned and managed by The Nature Conservancy (TNC). Before the wildfire, TNC managed different blocks of trees using different management techniques. The Bootleg Fire burned through all of these stands, but the outcome was drastically different in each one. Nearly all the vegetation was completely burned in the untreated areas. Areas that had been only thinned or treated with controlled fire survived relatively well. An area that received both thinning and prescribed fire showed the highest post-fire tree survival rate. As a consequence, ecological forest restoration (Kelsey, 2019) is presently advocated by the TNC as forest thinning combined with controlled burns to significantly reduce the risk of wildfires in conifer forests of the Pacific states. Additionally, the TNC states that these management practices help combat the effects of drought and climate change, with significant benefits for air quality, water quality, carbon storage and wildlife habitat. Our analysis of burn severity classes from the Bootleg Fire showed that large, privately owned forest units burned at significantly lower severity than their surrounding control (unmanaged) buffer zones in the Meryl Creek, Cain Creek, and Long Creek drainages shown in **Figure 4(a)**. The same pattern of significantly lower burn severity from the Bootleg Fire in privately owned forest units was observed around the Gearhart Mountain Wilderness.

In a separate study of the 2021 Caldor Fire, Baker and Hanson (2022) used a categorized basal area mortality dataset (the source of which was not cited) and reported that significantly higher cumulative burn severity occurred in commercial thinning areas compared to unthinned forest areas on the El Dorado National Forest. However, their burn severity mapping also showed many locations where unthinned or largely unmanaged forest stands had burned at the highest severity level, mainly on USFS El Dorado National Forest lands in the Grizzly Flats area and also to the east, over Alder Ridge into drainages of the south fork of the American River. Our results (shown in **Figure 4(d)**) further identified numerous privately owned forest units that burned at significantly lower severity than their surrounding control (mostly unmanaged) buffer zones in these same drainages of the Caldor Fire. Hence, this unprecedented wildfire that reached high elevations (i.e., to the crest of the Sierra-Nevada range near Lake Tahoe) in California, in extremely steep and rugged terrain, and driven by high winds across a wide mix of standing biomass fuel sources, defied the efforts of firefighters to contain it for over a month and, for the most part, did not discriminate between unmanaged and managed forest areas in leaving behind large tracts of completely destroyed timber stands on extremely steep mountain slopes.

To present a balanced and unbiased understanding of why some privately owned forest areas have burned at high severity levels in recent wildfires, the pre-fire forest landscapes of these managed forest units were closely examined in terms of standing biomass levels from USFS inventory mapping (Blackard et al., 2008; Menlove & Healey, 2020) and the mosaic of fuel loads within and surrounding each of these industrially managed forest units. Our findings consistently showed that each of these high burn severity managed areas had extensive heavily wooded stands, likely unthinned or unlogged for many years, with extremely high pre-fire Landsat NDMI values representing dense forest growth adjacent to or surrounding equally large thinned or logged forest patches with much lower pre-fire NDMI values. We conclude that this type of mixed-age forest mosaic may create potentially volatile fuel-loading conditions across a partially managed forested landscape, whereby wildfire flames and embers can be readily carried by high winds from dense fuel areas (not recently thinned or managed) for kilometers, into other patches of dense forest cover and also into low biomass stands that have been recently thinned and logged.

It is worth documenting that, in an open letter posted by the GEOS Institute (2018) with more than 200 scientist signatories, the unequivocal declaration was made that "Thinning large trees, including overstory trees in a stand, can increase the rate of fire spread by opening up the forest to increased wind velocity…", with citations for this statement to Moritz et al. (2014) and Schoennagel et al. (2017). However, review of these two cited publications revealed no mention whatsoever of increasing rates of fire spread, much less as a consequence of a thinned forest opening up a large area to increased wind speeds. Therefore, this letter posted by the GEOS Institute in 2018 evidently fabricated this adverse impact of forest thinning effects with no empirical evidence to support it from the published literature.

On the contrary, previous research studies have shown that forest thinning practices have minimal impacts on wind gusts, humidity, and air temperatures that could influence fire spread and intensity. For instance, Bigelow and North (2012) measured fuels-reduction thinning and group selection effects on microclimate in mixed-conifer forests. These authors reported that wind gusts were slightly faster in thinned stands, but air temperature and humidity did not vary notably among treatments, nor among most fuel moisture classes. Likewise, in a simulation modeling study, Banerjee et al. (2020) reported that a reduction of midstory and understory vegetation did not strongly drive fire behavior in isolation. Hence, to evaluate the efficacy of fuel treatments, these authors concluded that fuel structure alone is insufficient to understand how treatments will alter future wildfire spread and suppression success.

The fact is that only a large-scale (covering hundreds of hectares), precisely measured "wind-tunnel" meteorology experiment, conducted during a real wildfire, could substantiate the significantly reduced windbreak effect speculated upon in the GEOS Institute (2018) letter and by Hanson (2021). Such meteorology measurements would need to simultaneously compare wind speeds within a burning managed (thinned or logged) forest stand versus a burning unmanaged forest nearby. To our knowledge, such a meteorological experiment has never been conducted.

Nonetheless, while burn area and severity outcomes can be highly specific to forest type, treatment type, and treatment execution (i.e., whether there is abundant slash remaining), results from Brodie et al. (2024) provided clear evidence that the suppressing effect of crown fuel reduction far outweighed any enhancing effect of increased drying or higher windspeeds on fire behavior. These conclusions were based a 1,200 ha randomized and replicated experiment on the Klamath National Forest in northeastern California that burned almost entirely in a subsequent wildfire under a wide range of weather conditions. The authors compared the impacts of four fuel treatments on fire severity, including two thin-only, a thin-burn, a burn-only, and an untreated control. The main findings were that reducing canopy bulk density via mechanical thinning treatments can help to limit crown fire behavior for 20 years or more. Further, while fuel treatment effectiveness may decline under the most severe fire weather conditions for burn severity levels associated with tree mortality, it is maximized under severe fire weather conditions for metrics associated with crown fire behavior (bole charring and torching).

The GEOS Institute (2018) letter went on to prominently cite a study by Bradley et al. (2016), who found that fires burned more severely between 1984 and 2014 in previously logged forest areas in 11 western U. S. states, while in wilderness areas, parks, and roadless areas, fires tended to burn in more "natural fire mosaic patterns" of low, moderate and high severity. These authors used the Gap Analysis Program (GAP) protection classes (Crist et al., 2009) to determine whether areas with the most protection (i.e., GAP1 and GAP2) had a tendency to burn more severely than areas where intensive management was allowed (i.e., GAP3 and GAP4) and compared Landsat satellite-derived burn severity data for 1,500 fires affecting 9.5 million hectares. The modeling results reported by Bradley et al. (2016) totaled to less than one page of published text and showed a low overall prediction accuracy of around 30% - 35% for burn severity outcomes in the four GAPS classes. Moreover, forest management practices included in this study such as large-scale clear-cutting that date back to the 1980s are rarely (if ever) being used in today's western forests that are managed on either on public or private lands, making these findings outdated in many respects.

5. Conclusion

Comparison of MTBS burned severity classes by individual managed forest area showed these timberlands burned at significantly lower severity ($p < 0.05$) than their surrounding (unmanaged) buffer zones in large wildfires between 2013 and 2022. These key finding were backed-up with valid statistical and quantitative data analysis. The principal results from this present study of forest management practices versus burn severity from recent wildfires in timberlands of the Pacific states can be added to the body of peer-reviewed scientific evidence summarized by

Prichard et al. (2021) which overwhelmingly confirms that fuel reduction treatments can mitigate wildfire behavior and that, by expanding managed forest areas including the use of forest thinning, prescribed burning, and cultural burning, greater landscape resilience to future wildfires can be conferred in forests of the western U. S. Landsat NDMI clearly shows recent clear-cuts, fire scars, and thinning management in every case we examined, eliminating the possibility of underestimating or overlooking timber management activities in control buffer zones. While there are admittedly some trade-offs in our study methodology, for instance the fact that one cannot detect within forest stand wind speed increases if concurrently crown fire is avoided by management treatments, it is reasonable to conclude that mixed-age management may create a potentially explosive fuel-loading status in a forest, whereby wildfire can be readily carried by high winds from dense fuel areas in lower fuel treatments.

Data Availability Statement

All data sets generated in this study will be made available upon request to the corresponding author. Major results data will be placed and identified in the following repository: https://doi.org/10.5281/zenodo.10525125.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Ansley, J. S., & Battles, J. J. (1998). Forest Composition, Structure, and Change in an Old-Growth Mixed Conifer Forest in the Northern Sierra Nevada. *Journal of the Torrey Botanical Society, 125,* Article No. 297. https://doi.org/10.2307/2997243

Baker, B. C., & Hanson, C. T. (2022). Cumulative Tree Mortality from Commercial Thinning and a Large Wildfire in the Sierra Nevada, California. *Land, 11,* Article No. 995. https://doi.org/10.3390/land11070995

Balch, J. K., Iglesias, V., Mahood, A. L., Cook, M. C., Amaral, C., DeCastro, A. et al. (2024). The Fastest-Growing and Most Destructive Fires in the US (2001 to 2020). *Science, 386,* 425-431. https://doi.org/10.1126/science.adk5737

Banerjee, T., Heilman, W., Goodrick, S., Hiers, J. K., & Linn, R. (2020). Effects of Canopy Midstory Management and Fuel Moisture on Wildfire Behavior. *Scientific Reports, 10,* Article No. 17312. https://doi.org/10.1038/s41598-020-74338-9

Bigelow, S. W., & North, M. P. (2012). Microclimate Effects of Fuels-Reduction and Group-Selection Silviculture: Implications for Fire Behavior in Sierran Mixed-Conifer Forests. *Forest Ecology and Management, 264,* 51-59. https://doi.org/10.1016/j.foreco.2011.09.031

Blackard, J., Finco, M., Helmer, E., Holden, G., Hoppus, M., Jacobs, D. et al. (2008). Mapping U.S. Forest Biomass Using Nationwide Forest Inventory Data and Moderate Resolution Information. *Remote Sensing of Environment, 112,* 1658-1677. https://doi.org/10.1016/j.rse.2007.08.021

Bradley, C. M., Hanson, C. T., & DellaSala, D. A. (2016). Does Increased Forest Protection Correspond to Higher Fire Severity in Frequent-Fire Forests of the Western United

States? *Ecosphere, 7,* 1-13. https://doi.org/10.1002/ecs2.1492

Brodie, E. G., Knapp, E. E., Brooks, W. R., Drury, S. A., & Ritchie, M. W. (2024). Forest Thinning and Prescribed Burning Treatments Reduce Wildfire Severity and Buffer the Impacts of Severe Fire Weather. *Fire Ecology, 20,* Article No. 17. https://doi.org/10.1186/s42408-023-00241-z

Campbell, M. J., Dennison, P. E., Kerr, K. L., Brewer, S. C., & Anderegg, W. R. L. (2021). Scaled Biomass Estimation in Woodland Ecosystems: Testing the Individual and Combined Capacities of Satellite Multispectral and Lidar Data. *Remote Sensing of Environment, 262,* Article ID: 112511. https://doi.org/10.1016/j.rse.2021.112511

Cansler, C. A., & McKenzie, D. (2014). Climate, Fire Size, and Biophysical Setting Control Fire Severity and Spatial Pattern in the Northern Cascade Range, USA. *Ecological Applications, 24,* 1037-1056. https://doi.org/10.1890/13-1077.1

Castillo, A., Potter, C., & To, W. (2024). Forest Fire Fuel Prediction for Managed Forest Areas in the Pacific States. In *Annual Meeting of the American Geophysical Union*. https://agu.confex.com/agu/agu24/meetingapp.cgi/Paper/1560149

Congressional Research Service (CRS) (2020). *Federal Land Ownership: Overview and Data*. https://crsreports.congress.gov

Crist, P. J., Prior-Magee, J. S., & Edwards, T. C., Jr. (2009). Land Stewardship Mapping Methods [Gap Analysis Program]. U.S. Geological Survey.

Davis, K. T. et al (2023). Reduced Fire Severity Offers Near-Term Buffer to Climate-Driven Declines in Conifer Resilience across the Western United States. *Proceedings of the National Academy of Sciences, 120,* e2208120120.

Fettig, C. J. (2012). Forest Health and Bark Beetles. In *Managing Sierra Nevada Forests. General Technical Report PSW-GTR-237* (pp. 13-22). USDA Forest Service, Pacific Southwest Research Station.

Friedman, S. (2021). *Good Wildfire News? Evidence from the Bootleg Fire Supports Thinning Forests*. https://forestpolicypub.com/2021/07/30

GEOS Institute (2018). *Open Letter to Decision Makers Concerning Wildfires in the West*. https://www.biologicaldiversity.org/programs/public_lands/forests/pdfs/scientist-letter-wildfire-signers-2018-08-27.pdf

Hanson, C. T. (2021). *Smokescreen: Debunking Wildfire Myths to Save Our Forests and Our Climate* (280 p.). The University Press of Kentucky. https://doi.org/10.2307/j.ctv1m592c5

Hanson, C. T. (2010). *The Myth of "Catastrophic" Wildfire: A New Ecological Paradigm of Forest Health. John Muir Project Technical Report 1*. John Muir Project of Earth Island Institute.

Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S. et al. (2017). Estimating Economic Damage from Climate Change in the United States. *Science, 356,* 1362-1369. https://doi.org/10.1126/science.aal4369

Kalies, E. L., & Yocom Kent, L. L. (2016). Tamm Review: Are Fuel Treatments Effective at Achieving Ecological and Social Objectives? A Systematic Review. *Forest Ecology and Management, 375,* 84-95. https://doi.org/10.1016/j.foreco.2016.05.021

Kelsey, R. (2019). *Wildfires and Forest Resilience: The Case for Ecological Forestry in the Sierra Nevada.* The Nature Conservancy. https://www.scienceforconservation.org/assets/downloads/WildfireForestResilience_2019_Kelsey_2.pdf

Levine, J. I., Collins, B. M., Steel, Z. L., de Valpine, P., & Stephens, S. L. (2022). Higher

Incidence of High-Severity Fire in and near Industrially Managed Forests. *Frontiers in Ecology and the Environment, 20,* 397-404. https://doi.org/10.1002/fee.2499

MacDonald, G., Wall, T., Enquist, C. A. F., LeRoy, S. R., Bradford, J. B., Breshears, D. D. et al. (2023). Drivers of California's Changing Wildfires: A State-of-the-Knowledge Synthesis. *International Journal of Wildland Fire, 32,* 1039-1058. https://doi.org/10.1071/wf22155

McKelvey, K. S., & Johnston, J. D. (1992). Historical Perspectives on Forests of the Sierra Nevada and the Transverse Ranges of Southern California: Forest Conditions at the Turn of the Century. In *The California Spotted Owl: A Technical Assessment of Its Current Status* (pp. 225-246). US Department of Agriculture Forest Service.

Menlove, J., & Healey, S. P. (2020). A Comprehensive Forest Biomass Dataset for the USA Allows Customized Validation of Remotely Sensed Biomass Estimates. *Remote Sensing, 12,* Article No. 4141. https://doi.org/10.3390/rs12244141

Miller, J. D., & Thode, A. E. (2007). Quantifying Burn Severity in a Heterogeneous Landscape with a Relative Version of the Delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment, 109,* 66-80. https://doi.org/10.1016/j.rse.2006.12.006

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F. et al. (2014). Learning to Coexist with Wildfire. *Nature, 515,* 58-66. https://doi.org/10.1038/nature13946

Nelson, M. D., Liknes, G., & Butler, B. (2010). *Forest Ownership in the Conterminous United States: ForestOwn_v1 Geospatial Dataset.* U.S. Department of Agriculture, Forest Service, Northern Research Station.

National Oceanic and Atmospheric Administration (NOAA) (2023) U.*S. Billion-Dollar Weather and Climate Disasters.* National Centers for Environmental Information. https://www.ncei.noaa.gov/access/billions/

Palmer, M., Kuegler, O., & Christensen, G. (2019). *Washington's Forest Resources, 2007-2016: 10-Year Forest Inventory and Analysis Report* (79 p.). Gen. Tech. Rep. PNW-GTR-976, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Parks, S. A., Holsinger, L. M., Panunto, M. H., Jolly, W. M., Dobrowski, S. Z., & Dillon, G. K. (2018). High-Severity Fire: Evaluating Its Key Drivers and Mapping Its Probability across Western US Forests. *Environmental Research Letters, 13,* Article ID: 044037. https://doi.org/10.1088/1748-9326/aab791

Potter, C., Pass, S., & Ulrich, R. (2024). Net Primary Production of Ecoregions across North America in Response to Drought and Wildfires from 2015 to 2022. *Journal of Geophysical Research: Biogeosciences, 129,* e2023JG007750. https://doi.org/10.1029/2023jg007750

Povak, N. A., Prichard, S. J., Hessburg, P. F., Griffey, V., Salter, R. B., Furniss, T. J. et al. (2025). Evidence for Strong Bottom-Up Controls on Fire Severity during Extreme Events. *Fire Ecology, 21,* Article No. 27. https://doi.org/10.1186/s42408-025-00368-1

Prichard, S. J., Hessburg, P. F., Hagmann, R. K., Povak, N. A., Dobrowski, S. Z., Hurteau, M. D. et al. (2021). Adapting Western North American Forests to Climate Change and Wildfires: 10 Common Questions. *Ecological Applications, 31,* e02433. https://doi.org/10.1002/eap.2433

Rice, J. A. (2006). *Mathematical Statistics and Data Analysis* (3rd ed.). Duxbury Advanced.

Schoennagel, T., Balch, J. K., Brenkert-Smith, H., Dennison, P. E., Harvey, B. J., Krawchuk, M. A. et al. (2017). Adapt to More Wildfire in Western North American Forests as Climate Changes. *Proceedings of the National Academy of Sciences, 114,* 4582-4590. https://doi.org/10.1073/pnas.1617464114

Singleton, M. P., Thode, A. E., Sánchez Meador, A. J., & Iniguez, J. M. (2019). Increasing Trends in High-Severity Fire in the Southwestern USA from 1984 to 2015. *Forest Ecology and Management, 433,* 709-719. https://doi.org/10.1016/j.foreco.2018.11.039

Stone, C., Hudak, A., & Morgan, P. (2003). *Forest Harvest Can Increase Subsequent Forest Fire Severity*. In *Proceedings of the 2nd International Symposium on Fire Economics, Planning, and Policy: A Global View* (pp. 525-534). Córdoba.

U.S. Forest Service (USFS) (2018). *The Forest Inventory & Analysis Geospatial Showcase*. https://fia-usfs.hub.arcgis.com/

U.S. Geological Survey (USGS) (2024). *Protected Areas Database of the United States (PAD-US)*. U.S. Geological Survey Data Release.

Westerling, A. L. (2016). Increasing Western US Forest Wildfire Activity: Sensitivity to Changes in the Timing of Spring. *Philosophical Transactions of the Royal Society B: Biological Sciences, 371,* Article ID: 20150178. https://doi.org/10.1098/rstb.2015.0178

Whittier, T. R., & Gray, A. N. (2016). Tree Mortality Based Fire Severity Classification for Forest Inventories: A Pacific Northwest National Forests Example. *Forest Ecology and Management, 359,* 199-209. https://doi.org/10.1016/j.foreco.2015.10.015

Zald, H. S. J., & Dunn, C. J. (2018). Severe Fire Weather and Intensive Forest Management Increase Fire Severity in a Multi-ownership Landscape. *Ecological Applications, 28,* 1068-1080. https://doi.org/10.1002/eap.1710

Zhang, J., Finley, K. A., Johnson, N. G., & Ritchie, M. W. (2019a). Lowering Stand Density Enhances Resiliency of Ponderosa Pine Forests to Disturbances and Climate Change. *Forest Science, 65,* 496-507. https://doi.org/10.1093/forsci/fxz006

Zhang, Y., Fan, J., Logan, T., Li, Z., & Homeyer, C. R. (2019b). Wildfire Impact on Environmental Thermodynamics and Severe Convective Storms. *Geophysical Research Letters, 46,* 10082-10093. https://doi.org/10.1029/2019gl084534