Cumulative severity of thinned and unthinned forests in a large California wildfire

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Abstract: Studies pertaining to fire severity in commercially thinned versus unthinned forests are based on a comparison of tree mortality between the two categories. Commercial thinning is widely conducted on public and private forestlands as a fire management approach designed to reduce fire severity and associated tree mortality. However, tree mortality from thinning itself, prior to the occurrence of the wildfire, is generally not taken into account, which leaves a potentially important source of tree loss, and associated forest carbon loss and carbon emissions, unreported. I investigated "cumulative severity" of commercially thinned and unthinned forests in a large 2021 wildfire, the Antelope fire, occurring within mixed-conifer forests on public lands in northern California, USA. Using published data regarding the percent basal area mortality for each commercial thinning unit that burned in the Antelope fire, combined with percent basal area mortality due to the fire itself from post-fire satellite imagery, I found that commercial thinning was associated with significantly higher overall tree mortality levels, or cumulative severity. More research is needed, in other large forest fires, to determine whether my finding, that commercial thinning is killing more trees than it is preventing from being killed, is common elsewhere.

Keywords: fire severity; wildfire; mixed conifer; forests; commercial thinning

Introduction

Research regarding commercial thinning and fire severity in conifer forests of the western U.S. is highly variable, with some studies reporting somewhat lower overall severity in commercially thinned forests (Lydersen et al. 2017, Johnson and Kennedy 2019), and others reporting mostly higher fire severity with commercial thinning (Cruz et al. 2014, Hanson 2021). If forest basal area removed by thinning, prior to fire, was nominal, such research could simply be compared and debated based on the methods and results. However, unlike noncommercial thinning that generally removes only seedlings up to trees slightly larger than saplings, commercial thinning often removes substantial portions of live-tree basal area prior to occurrence of wildfires, including many mature and old conifers (USDA 1994), and this tree mortality from thinning is rarely accounted for in current research.

As fire severity, in forests, is fundamentally a metric pertaining to the level of tree mortality (Miller and Thode 2007, Miller et al. 2009), there is reason to understand cumulative tree mortality, and "cumulative severity", from thinning and wildfire, in order to determine whether the result of thinning is more, or fewer, live trees on the landscape. This is particularly true in light of plans to substantially scale-up commercial thinning of western U.S. forests as a fire management and forest resilience strategy. Recently, the U.S. Agriculture Department announced a $50 billion plan to commercially thin tens of millions of acres of forest over the next two decades, mostly on public lands, as a wildfire strategy predicated upon the notion that this will reduce tree mortality in forests and increase resilience in the face of climate change (USDA 2022).

Yet commercial thinning and other logging practices play a large role in removing live trees and thus reducing forest carbon storage, which influences climate change (Law et al. 2018, Hudiberg et al. 2019). Moreover, there are many native wildlife species that depend upon dense, mature and old conifer forests, both before and after mixed-severity wildfires. Commercial thinning can adversely affect such species by degrading dense, older forests that many imperiled species need for nesting or denning, while also reducing the quality of "complex early seral forest" habitat (DellaSala et al. 2014) by removing so many trees from forests that they may be deficient for many snag-dependent species when such areas later experience high-severity fire (DellaSala and Hanson 2015, DellaSala et al. 2017).

Therefore, there is an important need to understand the degree to which commercial thinning itself affects overall tree mortality in forests. However, in many cases it may be difficult to determine tree mortality from thinning, for example in cases where recorded estimates may not exist. Therefore, addressing this question depends upon wildfire occurring in a previously-thinned area for which specific data regarding tree mortality from thinning are publicly available.

In this study, I investigated whether cumulative fire severity, based on percent basal area mortality from commercial thinning and subsequent wildfire, would be different in thinned versus unthinned forests, using fire severity data from the 2021 Antelope fire in northern

California in combination with pre-fire published data on tree mortality from commercial thinning in the same area.

Methods

I analyzed 15 commercial thinning units, and adjacent unthinned forests, in a portion of the Goosenest Adaptive Management Area on the Klamath National Forest in northern California. The study area is comprised of mixed-conifer forest, dominated by white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), and incense cedar (*Calocedrus decurrens*), with smaller amounts of red fir (*Abies magnifica*) and lodepole pine (*Pinus contorta*) in some areas (Ritchie 2005, 2020). Elevation in the study area ranges from 1460 m to 1515 m.

The study area was heavily logged (mostly selective logging focusing on pine removal) in the 1920s and 1930s. Commercial thinning in the 15 units occurred 1998-2000, with prescribed fire occurring in 5 of the 15 units in 2001 (no post-thin burning occurred in the other 10 units). Each thinning unit was 40.49 ha in size. At the time of thinning, 5 control (no thinning) units of the same size were also established (See Figure 1). Forests outside of the 20 units had a mix of thinning and other logging activities in some areas, and no contemporary-era thinning or other logging (i.e., no logging since the 1920s and 1930s) in other areas. Locations and shapes of each unit are from Ritchie (2005, 2020).

In August of 2021, the 58,935-ha Antelope lightning fire burned through the Goosenest Adaptive Management Area, including the 20 units in the study area. For each of the 15 commercial thinning units, I analyzed "cumulative severity" at pairs of locations 150 m inside, and 150 m outside, of the thinning units at the midpoint of each side of the units (Fig. 1). I defined cumulative severity as percent basal area mortality from thinning (if any) for a particular location, plus percent basal area mortality of the remaining (after thinning) live tree basal area due to the Antelope fire. Percent basal area removal (mortality) from commercial thinning at any location was determined based on values for each unit reported in Ritchie (2005), which ranged from 7% to 52% (mean = 32%), depending on the unit. For the Antelope fire, I used the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) satellite imagery data (https://fsapps.nwcg.gov/ravg/), which provides continuous data for percent basal area mortality from fire at a 30 m resolution.

If any locations 150 m outside of thinning units burned on different days from the corresponding paired location 150 m inside the thinning unit, I excluded these pairs. I also excluded pairs if the "outside" location had any evidence of pre-fire logging in the contemporary era. For this determination, I used satellite imagery from the National Agricultural Imagery Program (https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/). The imagery was of sufficient quality to clearly see canopy cover reduction from tree removal due to logging, along with skid trails, logging roads, and landings.

I used a Chi-square test for differences in proportion (Zar 2010) to evaluate whether it would be warranted to analyze plots with commercial thinning and no prescribed fire ("thin/no-burn") separately from plots with commercial thinning and prescribed fire ("thin/burn"). There was no significant difference between these two categories in terms of the proportion of plots with cumulative severity that was lower than unthinned forests ($\chi^2 = 0.094$, $df = 1$, $p = 0.759$). Therefore, I combined the two thinning categories. I assessed whether there is a difference in cumulative severity between commercial thinning and no thinning using a Chi-square goodness of fit test (Rosner 2000).

Results

Commercial thinning locations had cumulative severity levels that were higher than adjacent unthinned locations significantly more often than the opposite effect ($\chi^2 = 6.26$, $df = 1$, $p = 0.012$). Overall, commercial thinning had higher cumulative tree mortality than corresponding unthinned areas in 20 out of 27 pairs of locations (Table 1). Mean cumulative percent basal area mortality in commercial thinning locations was 56.1%, compared to 38.6% in corresponding unthinned forests (Table 1).

Discussion

Commercial thinning resulted in overall higher levels of tree mortality, as compared to unthinned forests, when tree mortality from both thinning and the Antelope fire were combined. Accounting for the tree mortality from commercial thinning, prior to the occurrence of the 2021 Antelope fire, provided a more contextualized and complete assessment of the cumulative effects of this type of forest management on tree mortality. If percent basal area mortality from thinning had not been considered, and only tree mortality from the Antelope fire had been used, it could have created misleading results, given that fire-only mean basal area mortality was 34.7% in commercial thinning locations and 38.6% in unthinned locations. Without accounting for tree mortality from thinning, one might erroneously conclude from the fire-only data that thinning was modestly effective in maintaining live-tree cover and basal area in the Goosenest Adaptive Management Area.

There are substantial impacts to imperiled and endangered wildlife species that depend in part on dense, mature/old forests, such as the California spotted owl (*Strix occidentalis occidentalis*), Pacific marten (*Martes caurina*), and Pacific fisher (*Pekania pennanti*), that can result from commercial thinning (Garner 2013, Stephens et al. 2014, Moriarty et al. 2016). If commercial thinning, conducted as a fire management strategy, often kills more trees than it prevents from being killed by wildfires, such impacts would be hard to justify.

Similarly, if thinning kills more trees than it prevents from being killed in wildfires, there would be substantial climate change implications. Even when the assumption is made that commercial thinning will effectively reduce fire severity, research indicates that it results in three times the greenhouse gas emissions per hectare than wildfire alone (Campbell et al. 2012).

More research is needed, in additional large fire areas, to determine how broadly my findings in the Antelope fire may apply to other areas in terms of cumulative severity.

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Tables

Table 1. Paired thinned/unthinned locations and whether cumulative severity was lower or higher in commercially thinned forests in the Goosenest study area within the Antelope fire of 2021.

Location Identifier	Thin/No-Burn (TNB), Thin/Burn (TB), or No Thin (NT)	% Basal Area (BA) Mortality from Thinning	Cumulative % BA Mortality	Thinned Location Lower Cumulative % BA Mortality?
1-4-in	TNB	21	22	Y
1-4-out	NT	0	100	
2-1-in	TNB	51	62	Y
2-1-out	NT	0	100	

2-2-in	TNB	51	53	Y
2-2-out	NT	0	100	
3-3-in	TB	39	94	N
3-3-out	NT	0	89	
5-4-in	TNB	28	96	N
5-4-out	NT	0	73	
6-1-in	TB	7	9	Y
6-1-out	NT	0	74	
7-1-in	TNB	9	39	N
7-1-out	NT	0	3	
7-2-in	TNB	9	86	N
7-2-out	NT	0	35	
8-1-in	TNB	52	74	Y
8-1-out	NT	0	100	
9-2-in	TNB	38	44	N
9-2-out	NT	0	0	
9-3-in	TNB	38	96	N
9-3-out	NT	0	0	
11-1-in	TNB	29	45	N
11-1-out	NT	0	0	
11-2-in	TNB	29	55	N
11-2-out	NT	0	49	
12-1-in	TNB	22	100	N

12-1-out	NT	0	17	
12-2-in	TNB	22	74	N
12-2-out	NT	0	52	
12-3-in	TNB	22	31	Y
12-3-out	NT	0	100	
13-1-in	TB	44	44	Y
13-1-out	NT	0	100	
13-2-in	TB	44	44	N
13-2-out	NT	0	0	
13-3-in	TB	44	44	N
13-3-out	NT	0	0	
13-4-in	TB	44	44	N
13-4-out	NT	0	0	
14-1-in	TNB	23	24	N
14-1-out	NT	0	8	
14-3-in	TNB	23	36	N
14-3-out	NT	0	0	
15-2-in	TB	17	17	N
15-2-out	NT	0	0	
17-1-in	TB	41	41	N
17-1-out	NT	0	0	
17-3-in	TB	41	41	N
17-3-out	NT	0	0	

19-1-in	TNB	43	100	N
19-1-out	NT	0	30	
19-3-in	TNB	0	100	N
19-3-out	NT	0	11	

Figures Captions

Figure 1. The Goosenest study area within the Antelope fire of 2021, with plots and paired locations shown.