Fuels Treatment Longevity Report for the Washington DNR

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**Introduction**

Forest managers and scientists of western dry forests widely support an increase in the pace and scale of fuels and restoration treatments such as thinning and prescribed burning, to mitigate the negative effects of fire suppression. Treatments can serve a variety of purposes, depending on location and details of prescription. These purposes can include:

* Reducing wildfire hazard to communities and economic assets.
* Easing fire suppression operations.
* Increasing forest resiliency to wildfire, drought, insects, and disease.
* Stimulating understory plant diversity.
* Improving habitat for open forest animal species.
* Stimulating tree growth for timber.

The short-term benefits of fuels and restoration treatments in dry forests are well-supported by many studies, but the longer-term fuel and vegetation pattern are less well-known. Even as little as five years after treatment, there is little information to help managers and researchers predict the state of a treated stand. Because of the relative lack of information on treatment longevity, it can be difficult or impossible to:

* Plan optimal treatment rotations.
* Assess tradeoffs between conducting restoration treatments (treating untreated stands) and maintenance treatments (re-treating ‘restored’ stands).
* Assess whether maintenance treatments can provide enough merchantable timber to help offset the cost of treatment, because much of the merchantable material is often removed in the initial restoration treatment.
* Forecast carbon dynamics in treated stands.
* Predict prescribed fire behavior in maintenance treatments.
* Plan efficient and safe fire suppression operations in treated landscapes.
* Model future wildfire behavior in treated landscapes.
* Understand plant and animal habitat quality in treated landscapes.

Given the scope of the modern wildfire problem in fire suppressed forests of the interior west, and the limited resources available to public and private forest landowners, researchers must address the knowledge gap in treatment longevity so that managers can efficiently plan treatment rotations and know what to expect from treated stands. In this report, we touch on some key concepts in treatment longevity from the scientific literature, and then synthesize data from all the published studies of treatment longevity that we could find from western dry forests. These include three in-progress studies led by our team, of forests in eastern Washington State. Our work is meant to highlight both what researchers know about treatment longevity, and the research gaps that remain. Our target audience includes forest managers and policy makers working to find solutions for restoring dry forests of the western US, particularly within Washington State.

**Part 1: Literature Review on Treatment Longevity**

**Quantifying Longevity**

*Definitions*

The first hurdle in determining treatment longevity is defining it. There is likely no magic number of years past which a particular treated stand serves its purpose, even though it will be necessary in many cases to decide on an exact treatment rotation for planning purposes. Instead, changes to forest structure, fuels, and potential fire behavior happen gradually, which also causes a gradual change in the risk of a damaging wildfire. Therefore, the fuels treatment rotation must be based on judgement of acceptable risk within the treated stand and any values in its proximity, in addition to scientific information on likely forest structure, fuels, and fire behavior patterns with time.

One way to judge fuels treatment longevity is by looking at what the fuels themselves do over time, and comparing that to the pretreatment values. Longevity could be thought of as the time it takes for fuels to get back to pretreatment values. This approach is complicated, however, by the wide variety of live and dead vegetation forms that contribute to ‘fuels’. These include litter, duff, downed sticks and logs of different sizes, grasses, forbs, shrubs, tree seedlings, tree saplings, and mature tree canopies. Each of these fuel components can response differently to treatment over time and potentially cause different types of wildfire behavior. Therefore, assessment of fuels treatment longevity based on fuels patterns should be accompanied with an assessment of expected fire behaviors from different relative levels of different fuel components. This ‘fuels-based’ approach allows for assessment of relative benefits of treating different stands. It is not very precise for forecasting expected fire behavior in any given stand, as some differences in amounts of fuel may not result in ecologically or operationally meaningful differences in wildfire behavior. Therefore, it is probably best used in situations where maximizing forest resilience to wildfire across a large landscape is a primary management goal, but where no single stand is crucial to protect.

The issues caused by analyzing multiple fuels components can be somewhat simplified by instead looking at changes over time of modelled fire behavior, such as flame length, rate of spread, torching index, and crowning index. This method may be more meaningful for many managers and researchers because potential wildfire behavior is often a central focus of treatment. It should be used with caution, however, because fire is a notoriously complicated process, and the most commonly-used family of fire models (Rothermel-based) is not good at incorporating fuels variability, linking surface and crown fire behavior, or incorporating spot fires. Results can be sensitive to the ‘fuel-model’ chosen by the user. Furthermore, wildfire behavior is largely contingent on fire weather, so interpretations of fire models will vary with user-inputted weather parameters, which should be chosen based on expected local weather behavior during wildfire season. Fire models are often effective at comparing relative differences in fire behavior even when they are inaccurate at predicting absolute behavior, so they are useful for comparing pretreatment and posttreatment values, or differences between different stands. Use of fire models alone may obscure deeper understanding of long-term fuels patterns, so data on fuels and forest structure patterns should be paired with fire model data when feasible, both as a ‘gut-check’ on model outputs and as a measure of other ecosystem values.

Alternatively, the definition of treatment longevity could be based on meaningful thresholds of expected fire behavior or effects, such as the acceptable crown fire risk or expected tree mortality. This approach is best suited for situations where high value assets need to be protected in a particular location, and is not as good for comparing relative benefits of treating different stands. Fire models should be used with caution for all the reasons highlighted in the previous paragraph. Because they are not always accurate at predicting absolute fire behavior, they are best paired with local knowledge of how modelled wildfire behavior compares with real wildfire behavior, when high-value assets are at stake. Additionally, the weather factor adds another aspect to the risk assessment process, as a manager using the threshold approach must decide what weather conditions to design treatment rotations for. Even good treatments are often not effective at preventing tree mortality or stopping flame spread during very extreme fire weather conditions, at least when untreated area exceeds treated area. These very extreme conditions are becoming more common with climate change, so it is probably infeasible and/or inefficient to plan fuels treatments to control fire behavior in the most extreme possible conditions.

Treatment rotation age can also be based on non-fuels resources while still being effective at managing fuels, provided the rotation is shorter than longevity. The literature on traditional knowledge of fire use has many examples of pre-colonial tribes deciding cultural burning frequency based on non-fuels resources, such as stimulating huckleberry growth or quality of hazelnut shoots, in ways that likely kept the wildfire hazard low. Examples from western paradigms include endangered species management, like red-cockaded woodpecker habitat in longleaf pine (*Pinus palustris*) stands of the southeast and Kirtland’s warbler habitat in jack pine (*Pinus banksiana*) stands of the upper Midwest. And a timber management example? One traditional knowledge critique of western fire management and fire science is that it does not consider broader ecosystem values even when relatively minor changes in fire management, such as seasonality of burning, may have relatively large benefits. Our report focuses on efficient management of fuels, which often needs to be the primary consideration in modern dry forest management because of the legacy of fire suppression. However, we want to emphasize that fuels management is not the only consideration in planning thinning and/or prescribed burning rotations, and that in some cases other ecosystem management goals can be fundamentally compatible with fuel management.

*Statistical significance*

Most studies of fuels treatment longevity fail to find statistically significant differences between different types of treatments or between pretreatment and longterm sample periods for most fuels metrics, but this does not necessarily mean treatment is not giving any benefits. Statistical significance is a tool used to account for the uncertainty caused by having data from only a portion of the area of interest. When only a fraction of a stand is sampled, managers and researchers produce a range of values they think of as the ‘truth’; for example, a manager may conduct a timber cruise and find a basal area of 90 feet squared per hectare, but treat the actual average basal area as lying somewhere between 80 and 100, because they only sampled 1/20th of the area of the stand. The width of this ‘confidence interval’ depends on the variability in basal area from plot to plot, the number of plots, and how ‘confident’ the manager wants to be in having the right answer. This is important to keep in mind for fuels surveys because many fuels metrics have high variability, and fuels surveys are intensive so there often is not money to sample a huge number of plots. Statistical significance is inherently conservative in that it tries to minimize the chance of falsely declaring a difference between two tested entities, such as different types of fuels treatments.

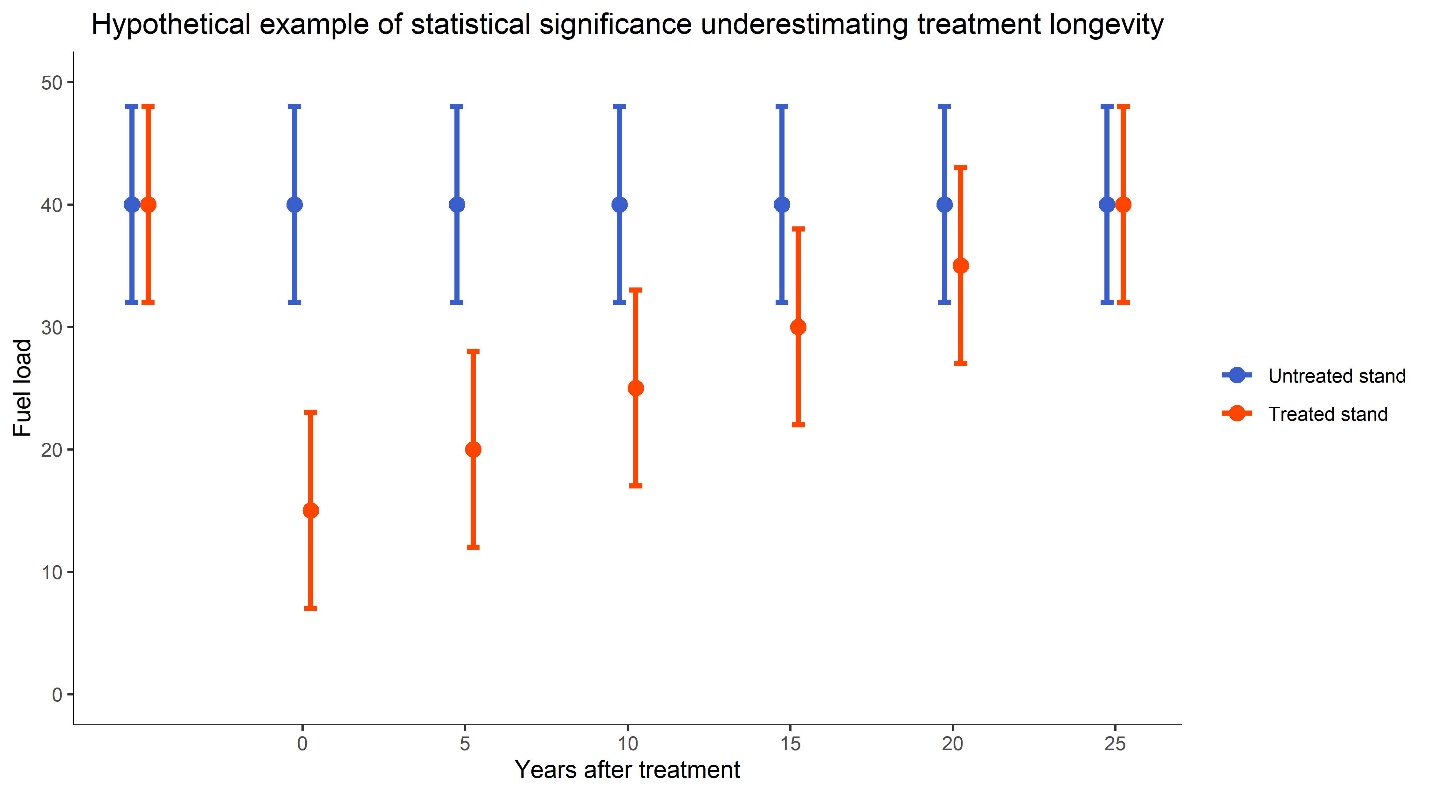
In a fuels treatment longevity context, the conservatism of statistical tests may result in underestimation of longevity, particularly when studies produce wide confidence intervals. For a visual example, see Figure xx. Underestimating treatment longevity could lead to inefficient use of limited resources, such as treating some stands more often than necessary while leaving other stands untreated. Statistical significance is an important tool that helps managers and researchers account for uncertainty in sampling, but in the context of fuels treatment longevity it needs to be used with caution and as one piece in a holistic strategy for thinking about the problem.

Figure xx: A simplified, hypothetical example of how statistical significance could lead to underestimating treatment longevity. Dots represent the true average fuel value of the stands, and the bars around them represent the confidence intervals, which account for uncertainty about the true average, caused by sampling a limited area. In this example, treatment reduced fuel loads relative to untreated stands for 25 years. However, the confidence intervals begin to overlap at 10 years, which would cause researchers to declare no difference between treatments. This kind of underestimation could lead to inefficient use of resources. Confidence interval widths are affected by three factors: variability from plot to plot, sample size, and the desired ‘confidence level’. The latter two factors are related to funding and researcher preferences, and not necessarily linked to biological processes. The upshot is that statistical significance tests are an important tool of research, but they should be used with some caution and not taken as the only measure of a treated stand’s difference from its pretreatment value or from an untreated stand.

**Factors that affect fuels treatment longevity**

*Site productivity*

Fuel treatment longevity is integrally linked to site productivity, which heavily influences vegetation growth and decay rates (Jain et al. 2012), as well as twig and litterfall rates. In general, more productive sites will tend to have faster decay rates of dead woody fuel, but also greater rates of litterfall, greater recruitment of ladder fuels, and faster canopy response to openings. Therefore, longevity is likely to be greater on drier sites, shallower soils, and nutrient-poor soils, as well as drier regions. Managers can take advantage of this knowledge, by preferentially treating stands with relatively low productivity to increase average longevity over a landscape, when overall landscape resiliency to fire is the primary goal. Topography was and is a major driver of local-scale vegetation and fuel variability in precolonial and modern forests, with ridgetops and drier south/west facing mountainsides sustaining lower fuel loads, so topography is good starting point for local/landscape scale planning. In areas where high value assets coincide with productive sites, managers will likely need to treat stands often to maintain low fire hazard.

*Treatment implementation*

Most comparative studies of short-term responses to treatment support thinning followed by burning as the most effective treatment from a fuels-reduction standpoint, but robust studies comparing the longterm response of different treatments are limited, and show little evidence of longterm differences caused by different treatments. It is difficult to talk in generalities about treatment categories because they vary widely in intensity, implementation details, and site context, but some patterns have been established by researchers, particularly for short term responses. Prescribed burning is generally good at reducing surface fuels in the short term, but often doesn’t change the canopy fuel layer much, besides removing some smaller ladder fuels. Managers are often constrained to conducting prescribed burns in mild fire weather conditions, to minimize risk of escape. More intense prescribed burning may produce more desirable changes in canopy fuels but will be infeasible in most cases. Thinning alone is effective at reducing canopy fuels, but can increase short term fire hazard because it moves many twigs and branches to the ground. These excess fuels caused by harvesting are called ‘activity fuels.’ Activity fuels can be addressed by additional measures such as whole tree harvest, mastication, or prescribed burning. Whole tree harvest may be more economically viable than other options in areas with biomass markets. However, it may cause problems for forest nutrient cycling and small animal habitat. Mastication is primarily aimed at increasing decomposition rates of surface fuels, so it could be seen as a strategy for increasing longevity. It is relatively new as a widespread practice, and research thus far suggests that it may create more erratic fire behavior because of relatively unpredictable variation in the sizes and patterns of wood fragments, and decay stages. Burning after thinning is often preferred where feasible, both because it most closely mimics natural processes for restoration purposes and because the fuels it consumes are those that would be most available to a wildfire. Thinning followed by burning has the dual benefit of large reductions in canopy fuels and surface fuels, including activity fuels. Within a given set of fire weather parameters, prescribed fire is often more intense in recently thinned units because of the recent influx of surface fuels, which may result in greater fuel consumption and ladder fuel mortality, but can also cause greater damage to timber value.

Long term responses to different treatment types are less clear, because a very limited number of empirical studies have compared different types of treatments more than five years after implementation. In most cases, burning and thinning plus burning units appear to have sustained their fuels reduction benefits into the longterm period compared to pretreatment values, while thinning alone either shows less benefit or even a detriment to fuels management goals. This has included sustained surface fuel reduction, ladder fuel/sapling density reduction, and modelled fire intensity and severity reductions. The differences are not always statistically significant, but multiple studies based on resampling permanent plots support these relative trends (Stephens et al. 2012, Morici 2017, Hood et al. 2020).

However, thinning should not be written off as a fuels reduction practice without further study; it is possible that thinning alone may produce greater fuels reduction benefits than burning alone in a longer term than most studies have been conducted. Once the activity fuels decompose, units that are thinned at enough intensity likely maintain a lower canopy bulk density. So in the longrun, thinning could cause a lower rate of litterfall and twigfall to the surface accompanying lower crown fire hazard. Downed twig data from (Morici 2017) and downed twig and canopy bulk density data from (Stephens et al. 2012) support this pattern. Furthermore, while Morici (2017) reports higher downed log and twig loads than pretreatment values in thin units 17 years after thinning, the pattern is driven by an increase in rotten logs, with an accompanying decrease in sound logs and twigs. This is consistent with the decomposition explanation. Additionally, when experimental treatments more than a decade old were sampled four years after a beetle outbreak, thinning and thinning plus burning units showed lower surface fuel loads than burning units (Crotteau et al. 2018). These thinned units likely had a lower canopy bulk density at the time of the beetle outbreak, and thus less fuel available to drop from the canopy to the ground. In the longterm, burn-only units may not sustain the same level of benefit as thin-only units. Prescribed burns that leave more canopy fuels intact may leave a higher risk of crown fire in the long run, as well as leaving more litter and twig material to drop to the ground and become surface fuels, in the absence of repeat treatment.

It is important to consider the possibility of thinning alone as a viable longterm strategy for fuels reduction, because it can produce revenue to help offset the costs of treatment, while additional measures such as prescribed burning, mastication, and whole tree harvest are often costly and/or logistically difficult. Additionally, fire scars can cause damage to timber value of leave trees. For all these reasons, burning and other surface fuels reduction methods may be difficult to incorporate on landownerships for which a steady revenue supply is a major goal.

In addition to surface and canopy fuel dynamics, the longterm effects of different treatment types are dependent on the vegetative response to the treatment. This may depend on treatment intensity as much or more than treatment type, and two crucial aspects of treatment implementation to consider are canopy cover and soil exposure. For both surface fuel loads and canopy cover, there may be an inherent tradeoff between intensity of treatment and longevity of treatment, with a possible optimum somewhere along the intensity gradient (Jain et al. 2012). If treatment is not intense enough, it will not change fire behavior. If treatment is too intense, it may stimulate a strong vegetative understory capable of carrying severe fire. Exposed soil is more favorable for recruitment of many tree and shrub species, so heavy surface fuel reductions that expose soil may result in more ladder fuels and live surface fuels in the longterm. Both thinning and burning often expose bare soil. Logging equipment locally displaces and compacts litter and duff with tracks and wheels, and by skidding logs. Prescribed burning can expose large areas of soil by consuming surface fuels, although in many cases it will leave large areas of duff intact, or litter in very mild burning conditions. Fire has the potential additional drawback of stimulating germination for species with heat or smoke activated seeds. These are often shrubs that are adapted to high severity fire and thus produce flammable resin in their leaves, such as several species of *Ceanothus*. Likewise, thinning and/or burning projects that open large areas of canopy can stimulate heavy germination of trees and shrubs that can reduce fuels treatment effectiveness in the longrun, in the absence of subsequent treatment. The consequences of open soil and open canopy are likely greater on more productive sites, where there is enough moisture for a rapid and dense vegetative response. It is easier to maintain lower biomass in open areas on drier sites.

Grass dominance is also easier to maintain on drier sites. This is preferable from a fuels perspective, because grass fires are easier for fire crews to suppress than shrub fires. They also have lower flame lengths, so they are less likely to reach into the canopy. Even on dry sites, several fires in short succession may be required to establish grass dominance. But once grass dominance is established, woody plants have very low regeneration success.

The lesson for fuels rotation planning is that a productive stand should not receive a heavy fuels treatment without plans to re-treat, because initial treatment could increase the fire hazard over no treatment, through dropping large amounts of canopy fuels to the forest floor and/or stimulating heavy tree and shrub regeneration. It is probably infeasible to simultaneously maintain low surface, understory, and canopy fuels without frequent treatments. This is particularly true on more productive sites where heavy vegetative responses to disturbance are likely. Frequent treatment may be feasible in stands surrounding high value areas such as homes, or in limited areas designated for intensive restoration. But unless all stakeholders come together to drastically increase the pace and scale of treatments, it will not be feasible to treat large areas of forest on a frequent rotation.

*Variability*

Thinking about fuels treatments as tools to create forest variability is likely the safest strategy for reducing risk of severe uncontrollable wildfire for the longterm across large landscapes, rather than thinking about reducing fuels uniformly across a treated area. It is difficult to impossible to treat an area so that it will not have high loads of some fuel component within a relatively short time period, because of the intensity/longevity tradeoffs discussed above. However, fuel loads do not necessarily need to be low to make fire behavior more acceptable for forest management goals; they just need to be discontinuous. Remote sensing, simulation, and historical reconstruction studies have shown evidence that fire severity and intensity are reduced when there is more variability, based on metrics like rate of spread and tree mortality. This is true of variability in stand structure within an area as small as an acre, to variability from stand to stand.

In a treatment longevity context, forest managers and researchers could think about creating variability as a strategy for ‘setting the clock’ for different areas to have different levels of fuel loads in different times. As a simplified example of creating variability at the stand level, some stands could be thinned with the expectation that thinning will increase surface fire risk in the short term while decreasing overall fire risk in the long term, and other stands could be more intensively thinned and burned at the same time to decrease fire risk in the short term but possibly increase fire risk in the long term. Whether a wildfire hits the treated landscape in the longer term or the shorter term, it will encounter areas of lower fuel and areas of higher fuel, and the lower fuel areas will likely slow wildfire spread.

Variability at the local level is another important consideration. It is likely that frequent fires in precolonial dry forests created a patchwork of canopy openings, individual trees growing alone in openings, and closed-canopy clumps of trees of different tree and clump sizes. The patchwork probably made these forests resilient to contagious disturbances like wildfires and insect and disease outbreaks, because for any given contagious disturbance, susceptible areas were discontinuous. Traditional forestry in the United States has focused on producing relatively uniform, optimized forest structure within a stand, but alternative paradigms and timber marking metrics such as the ‘ICO’ approach (Churchill et al. 2013) have been developing and put into practice in some areas in recent years. For some high value areas, especially directly adjacent to homes and communities, it may be unacceptable to have any localized areas of high fuel loads. In these cases, stands will probably need to be treated frequently.

In a treatment longevity context, creating forest variability is a critical consideration not only because of the several lines of evidence that variability may reduce wildfire behavior, but also because of uncertainty in both ecological and planning processes:

* From an ecological perspective, our literature review has indicated that there is not enough information about fuels treatment longevity to accurately anticipate the long term effects of any given fuels treatment on potential wildfire risk. Changing ecological conditions such as climate change and species invasions, and the likelihood of future unexpected social or ecological events, further complicate the uncertainty.
* From a planning perspective, there is uncertainty in future budgets, markets, and administrative procedures, both for private landowners and public agencies. Political or economic events could change the feasibility of implementing fuels treatments almost overnight, or change what types of treatments are feasible. Therefore, it would be risky to treat a landscape with the assumption that it can be retreated in a certain way at the appropriate time.

Collecting and synthesizing information to reduce some of these uncertainties was a major component of this project, and our work has provided insights that should help managers, researchers, and policy makers plan to increase forest resiliency in eastern Washington. In this introductory section and the discussion below, we discuss the long term outcomes we believe are most likely based on a range of factors. But we caution that most of our judgements should only be treated as hypotheses, given the evidence available.

Our primary recommendation after reviewing the available literature is to incorporate variability within-stands and variability between-stands into fuels management planning whereever feasible. A broad principle of ecological resilience research states that attempting to optimize any one ecosystem value leaves the entire ecosystem more vulnerable to major, rapid, and irreversible changes, because a more uniform ecosystem has fewer ways of adapting to changes. This becomes catastrophic for communities that grow dependent on one service (Holling and Meffe 1996, Hilderbrand et al. 2005, Franklin et al. 2018). For example, broad areas of even-aged forest managed to maximize profit from timber have proven susceptible to unprecedented beetle outbreaks. An example from our review is that that maximizing fuels treatment benefits in the short term may result in relatively continuous fuelbeds in the longterm, if rate of retreatment is lower than expected.

Variability could be thought in broad terms not directly related to fuels, and still be useful to for wildfire risk mitigation. Metrics could include different stand structures, successional stages, vegetative communities, and/or different stages of recovery from treatment or disturbance. Use of such metrics should be paired with informed expectations about fire behavior implications, which can be informed by research. Which metrics of variability are most useful will depend on local ecological context, and which goals other than fire management are most important to the landowner. Managers will likely need to use broad metrics to understand fuel load and variability in the areas under their jurisdictions while relying on researchers to help inform expectations about the fuels implications, because collecting adequate data on fuels from many stands over a large area would be prohibitively expensive.

**Part 2: Data on Treatment Longevity**

In addition to the treatment longevity review above, our team was funded by the Washington State Legislature to complete three tasks:

1. Contact fire scientists and managers in Washington State to see if they had unpublished datasets that could be used to address research gaps in treatment longevity.
2. Collect field data to increase the sample size of existing datasets where needed.
3. Synthesize fuels data from these datasets in a report and review them in conjunction with other published datasets from dry forests of the western US.

In stage 1, we contacted 54 managers and fire researchers across multiple government agencies, universities, tribes, and nonprofits. For us to use a dataset in this report, the dataset needed to:

* Include numerical data on surface fuels such as twigs, litter, and duff, which are critical elements for predicting surface fire behavior.
* Have data on treatment effects at least ten years after treatment.
* Focus on dry, historically frequent fire forest types.

Out of more than 20 datasets we learned about in this manner, we found three datasets that we could use to address the goals of this report.

* The ‘Colville Chronosequence’, a dataset for which the Colville National Forest sampled different stands at different times since treatments to look for time-since-treatment trends in fuels and vegetation. Most study stands were thin plus burn treatments, so we focused only on this treatment type. This dataset was the best suited for looking at time since treatment, because many points in time were represented. But chronosequence studies need to be used with caution, because it is possible to confuse spatial variation for variation in time.
* The ‘Mission Creek’ site of the Fire and Fire Surrogates study, an experimental comparison of burning, thinning, thinning plus burning, and control units, which was being resampled about 15 years after treatment. This dataset was the best suited for comparing longterm effects of different treatments, but will fail to detect any important thresholds in fuel accumulation with time because the ‘long-term’ period was only represented by one temporal ‘snapshot’.
* The ‘NPS Fire Effects’ dataset, a National Park Service treatment monitoring program at the North Cascades and Lake Roosevelt National Recreation areas, for which we focused on thinning and burning units. Because of frequent retreatments, this dataset was best suited for looking at interactions of different combinations of treatments with high temporal resolution, but only had only a few plots that have been monitored for more than five years following treatment.

In stage 2, we collected field data to augment the Colville Chronosequence and Mission Creek datasets, which best addressed our questions of interest and which would benefit from a larger sample size increasing statistical power.

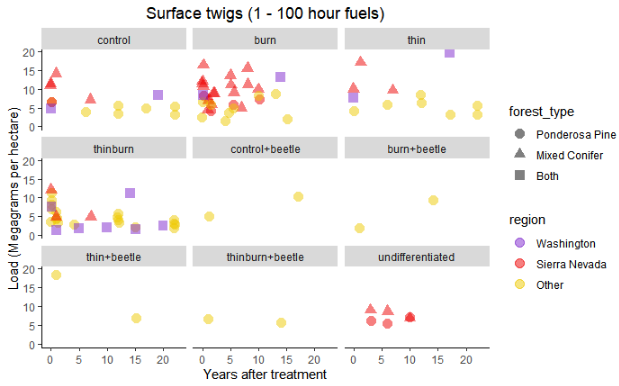
In stage 3, we aggregated data from these Washington datasets along with published data from other dry forest datasets around the western US, into ‘metaanalytical’ scatterplots comparing key fuels variables against time since treatment. For the purposes of this report, we limited the scope of studies to be included in our metanalytical graphs, to fuels-based studies of dry, frequent forest types relevant to eastern Washington (ponderosa pine/yellow pines or dry mixed conifer). Studies had to include information on surface fuels at least five years after a treatment. We did not include analyses of natural disturbances like wildfire or beetle outbreaks, or retrospective studies of treatment performance in real wildfires, because they were beyond the scope of phase one and two. We have plans to incorporate some of these additional opportunities into our future work on treatment longevity.

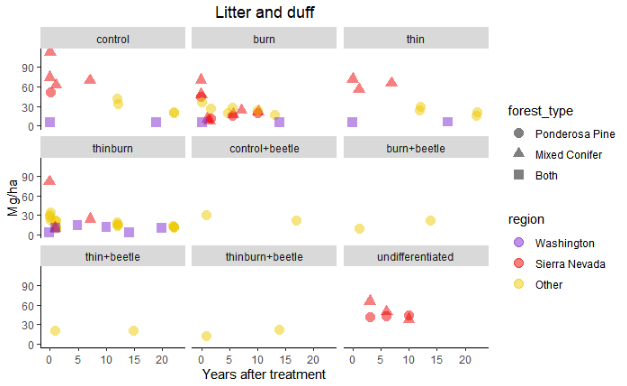
We chose to look at a few key fuels and stand structure variables that are commonly reported in fire ecology studies. Some important variables such as shrub composition, cover, and biomass are often unreported in fuels studies and/or published in separate accounts; therefore we did not include them in the current report. We also did not include modelled fire behavior because of different model parameterization in different studies. We plan to address these components of treatment longevity in more detail in future work. The variables we included are:

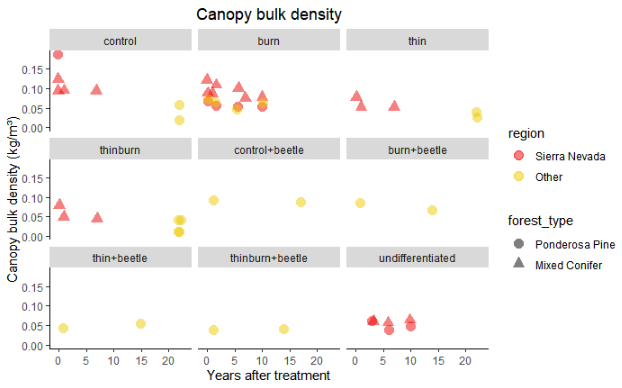
* Surface fuels: twigs and forest floor.
* Canopy fuels: canopy base height and canopy density.
* Stand structure: basal area, density, and quadratic mean diameter.

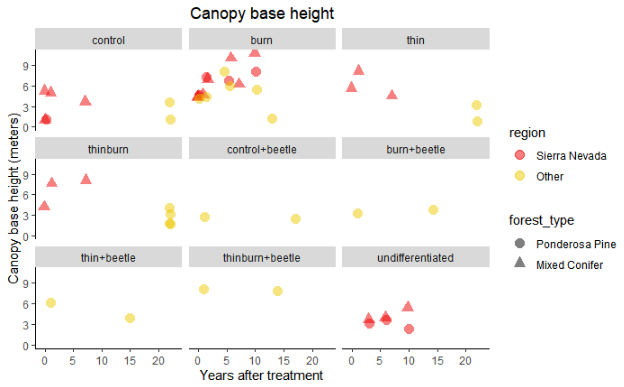
Our metanalytical graphs are best approached as a tool for generating hypotheses and exposing research gaps in treatment longevity, and not as a means for drawing solid conclusions. There are many confounding factors that could lead to erroneous conclusions, including differences in region, forest type, sample size, sample protocol, and details of treatments between studies. We have chosen to present graphs with a complicated scheme of panels, shapes, and colors, to convey the message that this body of this type of knowledge on fuels treatment longevity has complexities that make it difficult to synthesize into clear messages, and to inform the hypotheses we formulate. Because of the many potentially confounding factors, any of these hypotheses we draw from the meta-analytical portion of our work will need to be tested empirically before they are treated as fact.

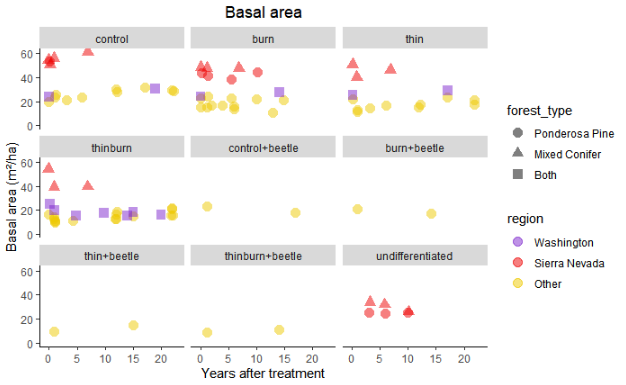
Our graphs are below:

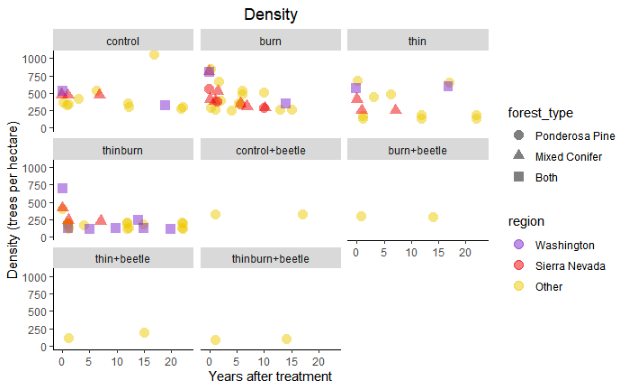


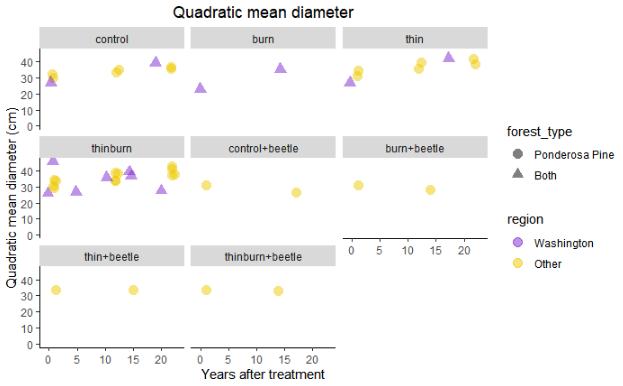












**Add:**

Abline

Thousands

**Remove:**

Beetle/undifferentiated

**Takeaways**

* Productivity time interaction, productivity more important than time?
  + Put some years in there
    - More than twenty: dry sites
    - More productive sites? Dig more
  + Scale
  + Significance, CIs
* Thin and burn
* Intensity tradeoffs? Shrubs, canopy base height
* Variability as a recommendation?
  + More in restoration zones than asset protection

**Results and Discussion**

* Complexity of data: need more research before any solid conclusions can be drawn
  + Our explanations should be treated as hypotheses, not solid conclusions.
* Ponderosa pine forests seem to have lower fuel loads than mixed conifer.
  + There could be issues with applying same allometrics to different forest types, though.
* Sierra Nevada separated because it appears to have more productive forests, and there also is a research bias towards mixed conifer forest there.
* Some variables reported more than others, at least in the types of studies we used.
* Washington datasets we’ve worked with mostly represent thinburn, more research on other treatments is needed.

**Recommendations and future steps**

* May move the variability section down here and expand on it.
  + Employ a range of treatment types at any given time, to ‘set the clock’ differently in different stands.
  + Try to create structure heterogeneity in stands where it is feasible.
  + Local and/or traditional knowledge is essential for good treatment rotation planning, in combination with scientific research which tends to focus more on generalities.
* Our future work:
  + Do more detailed analyses of the Washington datasets.
  + Add more treatments and variables to our synthesis work.
* Scientific needs:
  + The treatment intensity/longevity tradeoff is a likely hypothesis with big management implications, so incorporating treatment intensity into studies would be very useful.
  + More representation of everything: treatments, comparisons of treatments, times (longer), regions, forest types.
  + Monitoring with relatively fine temporal resolution may be critical to uncovering nonlinear fuels dynamics, which the current body of published knowledge is poorly equipped to address.

**Appendix One: Detailed information about Phase 1 – 3 of the DNR Treatment Longevity Project.**

*Phase One*

In the winter and spring of 2020, Don Radcliffe of the University of Washington (UW) compiled a list of fuels treatment studies in Washington State with monumented plots to explore study options for his PhD dissertation. He collaborated with Derek Churchill (Washington Department of Natural Resources [DNR]), Brian Harvey (UW, Don’s PhD adviser), Kate Williams (DNR), Jon Bakker (UW), Ernesto Alvarado (UW), and Dave W. Peterson (USFS), who helped him contact 54 fire ecologists who have worked in Washington, 37 of whom responded. The project, named the Washington Treatment Longevity Project (WTLP), was funded by the Washington State legislature. The intent was to inform the DNR 20 Year Forest Health Strategic Plan. The team’s immediate goal was to find datasets with pretreatment data, that could be resampled in the summer of 2020 to gain information on the long-term effects (10+ years) of fuels treatments. They were interested in several response variables, including fuels, shrubs, merchantable timber, and/or tree regeneration. However, fuels data was a prerequisite to being included in the list. The datasets most relevant to these goals included the Mission Creek Fire and Fire Surrogates Study, the National Park Service Fire Effects Monitoring Project, the Colville National Forest Collaborative Forest Landscape Restoration Project, the DNR Forest Resiliency Burn Pilot, and the Sinlahekin Fuels Monitoring Project.

The Mission Creek Fire and Fire Surrogates Study (FFS) is a long-term interdisciplinary experiment testing the effects of thinning, broadcast burning, and thinning plus burning on a range of response variables. It ia located in the Wenatchee Mountains near Leavenworth. Twelve units were established in the early 2000’s and treated in 2002-2006, three each of control, thinning, burning, and thinning plus burning. Pretreatment sampling took place in 2000, and posttreatment data was collected partially in 2004 and partially in 2006. In 2012, the Poison Creek wildfire burned two of the control units, one burn, and one thin unit. In 2019, Don led a crew that sampled fuels in the 8 units that had not been burned in a wildfire. They only resampled plots for which a plot monument was relocated (137). After preliminary statistical analysis and exploration of datasets that could address long term effects of fuels treatments, the Washington Fuels Treatment Longevity Team decided that the FFS merited sampling of the plots for which a physical monument could not be found, and the plots that burned in the 2012 wildfire. This will give Don needed statistical power to explore dynamics of fuels loadings and heterogeneity in different treatments 15-20 years after treatment, and to compare the effects of treatments to the effects of wildfire. Don, Brian, Derek, Jon, Dave, and Ernesto are collaborating on analyzing the data and producing a publication as a part of Don’s dissertation work. Other short-term data that could be leveraged to explore long term responses include sampling of trees, birds, small mammals, and soil. Understory vegetation was analyzed and published by a team including Jon, and the same team has produced a publication on tree regeneration. Additionally, the Washington LiDAR portal indicates that LiDAR flights have been conducted over the entirety of the study area, a portion in 2015 and a portion in 2017.

The National Park Service Fire Effects Monitoring project (NPSFX) includes monitoring of various combinations of thinning, broadcast burning, and pile burning dating back to 1996, on 155 monumented plots. There are two sites, the Stehekin area of North Cascades National Park, and the Lake Roosevelt National Recreation Area. Karen Kopper, Fire Ecologist with the National Park Service (NPS), was the team’s main contact for this dataset. The NPS employs a seasonal crew that spends a portion of each summer sampling a subset of the plots. They resample plots 0, 1, 2, 5, 10, and 15 years after the most recent treatment. In total, there have been more than 600 plot reads. The project started with a very small number of monitoring plots, and has added new plots in new units nearly every year since inception. Don, Karen, and Brian have agreed to collaborate on analyzing the data and producing a publication, as a part of Don’s dissertation work. No WTLP team fieldwork will be required. The main question of interest will be how the rate of fuels accumulation varies with different treatment and retreatment combinations. There is data to produce publications on other response variables, including dynamics of trees, shrubs, and herbaceous vegetation.

The Colville National Forest Collaborative Forest Landscape Restoration Project (CFLRP) included monitoring of about 150 plots in 2013, including pretreatment reads in two project areas (East Wedge and Walker), and a ‘past treatments’ chronosequence study of commercial thinning, shelterwood cuts, and clearcuts, some of which were burned at various numbers of years after the timber sale. The past treatments portion of the study included units treated up to 20 years prior to sampling. The main contact for information on the monitoring data is Jason Clark, who led the field crews in 2013. He is currently at the University of Alaska – Fairbanks. The two main collaborators currently working on the Colville National Forest are Monique Wynecoop, fire ecologist, and Eric Pfeifer, forester. After reviewing the potential datasources for study of long term fuels treatment effects, the WTLP team decided that building off of the CFLRP past treatments project to develop a chronosequence was the most valuable use of field resources after the FFS study, for isolating the effect of time single combination of treatments. Thinning and burning was the most common type of treatment from the 2013 chronosequence study, and it is considered the most effective treatment type and is widely implemented. The ‘thinning’ treatment type is commercial thinning, and can include shelterwood initiation cuts. Burning includes both broadcast burning and jackpot burning units. Don conducted a GIS analysis of the western portion of the Colville National Forest to identify potential study sites. He used the Forest Service FACTS database to identify units that were thinned and burned from 2000-2013, in units located in potential vegetation types of dry ponderosa pine or dry mixed conifer, excluding units burned in wildfires since 1984 and excluding units that have been retreated since 2013. Potential sample units were so narrowly defined in order to isolate the effect of time to the extent possible.

The Forest Resiliency Burn Pilot (FRBP) was a study of prescribed burning effects conducted by the Washington DNR in 2016 and 2017. It includes pre and post treatment data from 140 monumented plots in 7 prescribed fires conducted in various locations of central and eastern Washington. Response variables included fuel loads, fuel consumption, tagged trees, and vegetation response. Jim Cronan at the Pacific Wildland Fire Sciences lab is the main contact. The WFTL team decided not to resample FRBP plots because the time between sample periods would not be large enough to address questions of fuels treatment longevity. However, the dataset is exceptionally well organized and resampling the plots in the future should hold scientific value.

The Sinlahekin Fuels Monitoring Project (SFMP) included data on surface fuels only, collected on at least 145 plots in 2011, prior to thinning and burning treatments in 2011 and 2012. Dale Swedberg, former manager of the Sinlahekin Natural Area (SNA), led the funding and sampling efforts. Additionally, Justin Haug, a more recent manager of the SNA, was a major source of information on more recent management activities. About 12 plots burned in the 2015 Okanagan Complex, and about 124 have been retreated in prescribed burns in 2017-2019. Because of these recent disturbances and management interventions, and because of the lack of short term post-treatment data, the WFTL team decided not to resample the plots at the SFMP. However, resampling these plots would help address questions about areas that have been treated twice. Additional data collection efforts involving fuels treatment effects include 2011 monitoring of small mammals, led by Dale Swedberg, and 2008 and 2018 monitoring of stand structure conducted by Dylan Fisher of Evergreen State College.

*Phase Two*

In summer of 2020, Don led the field crew that sampled additional plots for the Mission Creek and Colville Chronosequence projects. At Mission Creek the 2020 team sampled 112 plots including 25 thinburn plots, 24 thin plots, 21 burn plots, 5 control plots, and 35 low severity wildfire plots, which were added to the 137 plots sampled in 2019. At the Colville National Forest Don’s crew in conjunction with a DNR crew led by Sam Tharpgeorge (currently at Resilient Forestry LLC) collected 54 plots from thinburn units in dry forest types, using the same FIREMON protocol as the 2013 crews.

*Phase Three*

Data from the summer 2020 field season and Mission Creek data from 2019 were entered and quality controlled by crewmembers under the supervision of Don. Data from past field seasons on the Colville Chronosequence and NPS Fire Effects projects were provided by the main contacts at each location, sometimes in raw and sometimes in summarized form. Don processed, merged, summarized, and graphed the three Washington datasets using the statistical program R. These datasets were included in the meta-analytical graphs within this report, and the WTLP team has plans to conduct more detailed analyses of all three datasets in the future, to leverage the unique strengths of each.

In addition to the data from the Washington datasets, Don gathered data from published reports of fuels treatment longevity from across the interior west to help form the metanalytical graphs. The data were either taken directly from published tables, or by using webplotdigitizer to extract numerical values from published graphs. Data were either provided as treatment-level averages in comparative studies, usually summarizing the results from multiple plots within multiple replicate unit into one average value, or as averages within a given time-band, in which case Don used the center of the time band as the time point to assign as the x-axis value on the meta-analytical graphs.

**Appendix Two: further research products to come from the Washington Treatment Longevity Project datasets.**

The Washington State legislative grant that funded the WTLP gave Don a plethora of opportunities for work on treatment longevity in his dissertation, including datasets found in stage one, additional data gathered in stage two, and time to synthesize both literature and data in stage three, for this report. Because of the complexity and scale of the question of treatment longevity, this report is an initial stage in the process of synthesizing literature on treatment longevity and analyzing the Washington datasets to tease out more nuance in fuels dynamics. Don has plans to lead four peer reviewed manuscripts based on work started for this report, including:

* A conceptual literature review paper, synthesizing existing knowledge and research gaps in treatment longevity, and proposing conceptual frameworks for future research.
* A Mission Creek paper, comparing control, burn, thin, thinburn, and low severity wildfire performance in the long-term.
* An NPS Fire Effects paper, assessing the relative benefits of retreatment vs. new treatments for fuel accumulation rates.
* A Colville Chronosequence paper, assessing the effects of time, treatment intensity, and site productivity on fuel accumulation rate in thin+burn treatments.

The first three papers will also be included as dissertation chapters. Don has a proven ability to publish his graduate school work in peer-reviewed journals (Radcliffe et al. 2020, 2021), experience working with fuels and restoration treatments in management, policy, and academic contexts, and the WTLP has helped him built collaborative relationships with a number of respected fire and restoration ecologists in Washington.

The literature review paper is the first planned for publication, and will draw heavily on work completed for this report. Planned directions for expansion include incorporating studies not focused directly on fuels, such as stand structure, regeneration, shrub, and/or grass focused studies, adding natural disturbances like wildfires to the categories of ‘fuels treatments’, adding fire modelling outputs, and incorporating more traditional knowledge perspective throughout. Don has been collaborating with Derek, Brian, Monique Wynecoop (USFS), and Ernesto Alvarado (UW) in this work.

The Mission Creek paper is the first empirical publication planned, and is the most progressed thus far of any of Don’s dissertation chapters. It is best suited for comparing effects of different treatment categories. Don has carried out preliminary analyses of fuels based on generalized linear mixed models that help account for clustering plots in units and differences in productivity between units, and presented the results in multiple conferences and symposia. He also plans to add multivariate ordinations to give more context on differences between units, and to add wildfire behavior and severity modelling outputs from the Forest Vegetation Simulator Fire and Fuels Extension (FVS-FFE) and the First Order Fire Effects Model (FOFEM). Don has been collaborating with Brian, Derek, Jon Bakker (UW), Madison Laughlin (UW), Ernesto Alvarado, and Dave W. Peterson (USFS) in this work.

The NPS Fire Effects paper is planned as a dissertation chapter, and may be suited for comparing relative benefits of retreatment vs. new treatments. Time series analysis, linear programming, and/or fire models are likely tools. Don has been collaborating with Brian and with Karen Kopper (NPS) in this work.

The Colville Chronosequence is planned as a manuscript analyzing the effects of time, site productivity, and treatment intensity on longevity of thinburn treatments. This will likely be achieved using generalized linear models. Time has been quantified using the Forest Service FACTS database, site productivity will likely be represented by DNR raster layers of actual evapotranspiration and/or soil water deficit, and pretreatment canopy cover might be parameterized with historical aerial photos. Shrubs will likely be an important response variable in this work, as dry forests within Colville National Forest are fairly productive compared with other dry forests of Washington State. Don has been collaborating with Brian, Derek, and Monique Wynecoop in this work.